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Workshop-based Tailoring of Interdisciplinary Product Development Processes by Means of Structural Analysis

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FOREWORD OF THE EDITOR

Problem statement

Organizational reference process models are an established best practice to support a range of activities, such as managing procedural knowledge in engineering design, planning, organizing, and carrying out product development projects. However, due to their generality, such reference process models always require a certain amount of adaptation to the specific characteristics of each project within an organizations' project portfolio in order to become useful. This adaptation is part of project planning and generally termed "tailoring."

As product development processes generally exhibit a dense network structure, tailoring represents an adaptation of a highly complex system. The complexity of this network structure is caused by a multitude of dependencies between its numerous constituent elements, which is driven by, among others, an increasing number of involved disciplines and stakeholders, a multitude of development goals, and technological advances such as digitalization. This structural complexity hinders the assessment of the effects of tailoring operations and thus represents one focal challenge for process tailoring. Furthermore, like project planning in general, process tailoring requires input from different project stakeholders as well as close collaboration and thus represents a socio-technical problem, which requires intensive communication, an aspect which is currently insufficiently explored and supported by existing approaches.

Objectives

The overall objective of this thesis is to develop a prescriptive approach to support practitioners in collaboratively tailoring structurally complex, interdisciplinary product development processes. This approach should enable practitioners to carry out tasks such as externalizing and documenting tailoring knowledge as well as identifying relevant tailoring stakeholders for particular projects and supporting communication and collaborative tailoring decision-making between them. The development of the prescriptive support draws from existing work in the area of process tailoring, e.g. within software engineering, as well as structural analysis of complex systems and transfers these onto tailoring of interdisciplinary product development processes.

Results

This thesis presents a methodology to enable and support collaborative process tailoring of organizational reference process models in the context of interdisciplinary product development. The developed tailoring methodology constitutes a five-phase procedure, covering the following steps: Preparation, acquisition of organization-specific tailoring knowledge (project characteristics, process variety, and dependencies between both), documentation of this acquired knowledge in a graph-based model, subsequent analysis of graph patterns and visualization as reports, and eventual application of the analysis results in collaborative tailoring workshops. The methodology integrates a catalog of methods for information acquisition and a metamodel for graph-based documentation of tailoring knowledge. A framework structures the analyses carried out upon the graph model using structural network metrics to quantify structural characteristics and a set of reports is used to visualize and supply the generated analysis information to stakeholders for workshop set-up and tailoring decision-making. Lastly, a procedure and checklist describe how to set up and carry out tailoring workshops.

Implications for Industrial Application

The empirical studies undertaken in this work corroborate the importance of considering process tailoring as a distinct activity during project planning, which merits an explicit and systematic approach. For practitioners, the methodology represents a scalable approach with a comparatively low threshold of implementation. This is owed to the fact that the methodology can be realized using mature software which is commercially available. Furthermore, while the individual elements of the methodology build upon each other, they are technically independent, therefore tailoring workshops can be implemented and carried out separately from the proposed analysis framework, thereby realizing partial benefits.

Contribution to Academia

This work contributes to filling a void within process research for interdisciplinary product development, due to the lack of previous research in this area. In particular, it highlights the collaborative, socio-technical nature of process tailoring, emphasizing the importance of project stakeholders during the act of process tailoring, and providing a prescriptive approach for collaborative tailoring. This thesis contributes to the body of knowledge by bridging the areas of process tailoring and structural analysis, uncovering a new area of applications for methods of structural analysis, such as design structure matrices, which should be investigated further. As explicit process tailoring has the potential to make development processes more flexible, this work also contributes to the rising research area of project agility.

In addition to the current knowledge gain, the identified problem areas provide fertile ground for future research. The developed methodology can be used as a framework, as it is extendible through future research. For example, further structural analyses and metrics can be tested for their ability to satisfy information needs during workshops. Tailoring workshops should be investigated as a form of organizational knowledge creation from sociological and psychological perspectives.

Garching, October 2019

Prof. Dr.-Ing. Udo Lindemann
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Hollauer, C.; Frisch, B.; Wilberg, J.; Omer, M. & Lindemann, U. (2018). Design of flexible product development processes - An automotive case study. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.), *Proceedings of the 21st International Conference on Engineering Design (ICED18)*. Volume 2. Hook, NY: Curran Associates Inc, pp. 289–298.

Hollauer, C.; Wilberg, J.; Omer, M. & Lindemann, U. (2018). Context-specific process design: An integrated process lifecycle model and situations for context factor use. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.), *Proceedings of the 21st International Conference on Engineering Design (ICED18)*. Volume 2. Red Hook, NY: Curran Associates Inc, pp. 81–90.

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[1] This technical report does not represent a peer-reviewed publication. It is not publicly available, but only to members of the bayme vbm association. It has been included for the sake of completeness, as it contains significant contributions by the author and served as a vehicle to transfer aspects of the developed tailoring support to industry.

Contents

Abbreviations and Symbols

Abbreviation	**Description**
A	Alignment
AM	Alignment matrix
AVISPA	Analysis and Visualization in Software Process Assessment
B2B/ B2C	Business to Business/ Business to Customer
CASPER	Context Adaptable Software Process Engineering
$C_{B;}$ *CB*	Betweenness Centrality
CC	ContextConstraint
CF	Context factor
Cr	Criticality
CS	Case Study
CSV	Comma-separated values
CVal	Context value
CVar	Context variable
$D_{(Cl)}$	Distance
DMM	Domain Mapping Matrix
DRM	Design Research Methodology
DS I	Descriptive Study I
DS II	Descriptive Study II
DSM	Design Structure Matrix
DTC	DecisionTreeConstraint
E	Edges
GCR	GlobalConstraintRule
GI	GeneralImpact
iPD	Interdisciplinary Product Development
hasCRSw	hasContextRelationshipWith
hasRSw	hasRelationshipWith
hasPRSw	hasProcessRelationshipWith
hasSHRSw	hasStakeholderRelationshipWith

LCC	LocalContextConstraint
MDM	Multiple Domain Matrix
OD	Organizational distance
OEM	Original Equipment Manufacturer
OU	Organizational unit
PA	Problem area
PAF	Process architecture framework
PCR	ProcessConstraintRule
PD	Product development
PDF	Portable Document Format
PDP	Product development process
PMI	Project Management Institute®
PMO	Process management office
PrL	Process Line
PROVOP	PROcess Variants by OPtions
PS	Prescriptive Study
PSS	Product-Service System
PTR	ProcessTailoringRule
RACI	Responsible, Accountable, Consulted, Informed
RAM	Responsibility Assignment Matrix
RC	Research Clarification
RPM	Reference process model
RQ	Research question
SBF	Snowball Factor
SE	Systems Engineering
SiME	Situational Method Engineering
SME	Small to Medium-sized Enterprise
SPEM	Software & Systems Process Engineering Metamodel
TSM	TailoringSystemModel
UML	Unified Modeling Language
UoA	Unit of Analysis
V	Vertices

1 Introduction

The act of process tailoring is pivotal in project planning as it bridges the gap between generic organizational reference processes and concrete project-specific project plans. In this capacity, it lays the basis for subsequent planning activities, such as scheduling and budgeting, consequently affecting the daily work of numerous stakeholders participating in product development projects. Simultaneously, a multitude of influencing factors and information have to be considered during process tailoring, as it represents an invasive procedure carried out in light of structurally and dynamically complex processes, which define intricate dependencies between development activities and stakeholders.

1.1 Motivation: Initial situation and problem description

The initial situation illustrates the relevance of process tailoring research in academia and industry, in light of rising complexity in interdisciplinary product development (iPD) as well as the concurrent need for adaptivity and agility in project planning. Based on this initial situation, four focal problem areas are presented, which constitute the primary motivation and focus of this work.

1.1.1 Initial situation

Product development (PD) has increased in complexity as well as importance for a companies' economic success, necessitating sophisticated **processes** and methods to orchestrate and support the multitude of development-related tasks and their dependencies (Markham & Lee, 2013, p. 408; Marle & Vidal, 2016, p. 53). This increasing complexity can be attributed to a multitude of technical, organizational, and environmental drivers (cf. Bosch-Rekveldt et al., 2011 for an overview of 40 drivers).

Current trends in product development: Complexity drivers

Increasing market pressure leads to shorter development cycles with a high degree of division of labor and parallelization (Ehrlenspiel & Meerkamm, 2013, p. 149). As exemplified by the rise of Product-service systems (PSS), an **increasing number of disciplines** and corresponding **stakeholders** (technical as well as non-technical) need to be integrated into and coordinated within PD projects (Schenkl et al., 2013, p. 918). This is further intensified in light of **technological advances**, such as the advent of digitalization, evidenced by the rising prevalence of machine learning and increased product connectivity, which require an adaptation of existing processes to accommodate the integration of data scientists (Wilberg et al., 2017, p. 2; Davenport et al., 2012, p. 23). Simultaneously, current PD needs to address additional development goals besides the classic trifecta of cost, quality, and time, such as social, economic, and ecologic sustainability (Held et al., 2018), leading to additional activities, experts, and corresponding dependencies. The coordination of these, often distributed, activities and stakeholders requires a high degree of interdisciplinary communication and synchronization (Heimberger, 2017; Moser et al., 2015; Stetter & Pulm, 2009; Eckert et al., 2005).

In addition to this baseline process complexity, many PD companies manage project portfolios, with multiple projects running in parallel (Browning & Yassine, 2016). Since different business units or even individual projects have different characteristics (e.g. due to different development goals or different required disciplines), they require different processes for their fulfillment, causing **process diversity** or **variance** (Hammer & Stanton, 1999; Shenhar, 2001). An exemplary factor contributing to this process variance is the rising complexity of product portfolios, due to increasing product variance (e.g. via customer individualization) (Schuh, 2014)) and the close relationship between product and process architecture (Brosch & Krause, 2010).

Managing complex product development processes with process models

These complexity drivers intensify the need for a systematic approach to manage and coordinate complex PD processes (PDP) in order to raise efficiency and ensure project goals are met (PMI, 2013; Kreimeyer, 2010; Smith, 1996). Effective management requires a thorough understanding of process behavior and potential performance influences (Le, 2012, p. 2). However, due to the involved complexity, their navigation and management pose a challenge compared to many other processes (Wynn & Clarkson, 2017, p. 1). Particularly in this context, process models are used to support a number of essential activities, such as project **visualization**, project **planning** (e.g., making commitments, choosing activities, and structuring the process), project **execution and control**, and project **development** (e.g. organizational learning and knowledge management) (Browning et al., 2006, p. 111). Among other objectives, good process models support process agility, adaptation, and empower employees, for example regarding communication and decision-making (Browning et al., 2006, p. 117). In PD, process and project management are closely related, as individual projects (deployed processes) within an organization represent instances of the reference (standard) development process (Browning et al., 2006, p. 118; Lindemann, 2009, p. 16; Vajna, 2005).

Surveys show that the definition of **standardized process structures** is regarded as a beneficial factor for PD and innovation performance and used by best-in-class companies (Markham & Lee, 2013, pp. 417–418; Ringel et al., 2015, p. 9). An appropriate amount of process structure even for early, conceptual design yields efficiency by focusing on value-adding activities and enabling coordination, while a purely mechanistic design of innovative organizations is not possible (Browning et al., 2006, p. 119; Tatikonda & Rosenthal, 2000; Spear & Bowen, 1999; Dougherty, 2001; Austin et al., 2001). Especially maturing organizations tend to define their processes in order to make them more predictable and traceable (Hurtado & Bastarrica, 2009), although this is often driven by external certification requirements (Browning, 2014c; Ittner, 2006, p. 2). This standardization is possible, as even in PD, recurring patterns can be identified (Browning et al., 2006). The resulting knowledge regarding “what work to do and how to do it in order to get the intended results” represents crucial knowledge in organizations (Browning, 2018, p. 1). Decomposing and modeling complex projects also can help to identify latent „knowable unknown unknowns” (Ramasesh & Browning, 2014; Browning et al., 2006, pp. 115–116). Many projects fail not only due to technical but also “managerial reasons,” for example due to the lack of identification and coordination of essential interactions (Browning et al., 2006, p. 109).

Recent data also shows an increase in required flexibility and agility, such as conditional decisions, overlapping gates, and the possibility to skip stages within the development process (Markham & Lee, 2013, p. 419; Cooper, 2014). Appropriate PDP modeling and standardization can **increase agility**, as the fast reaction to changes in complex projects requires managers to be aware of the process (Ittner, 2006, p. 2) by having access to “rich, organized, accurate, and integrated information” regarding a programs or projects architecture (Browning, 2014c).

Delimitation from agile development approaches

In light of this requirement for process adaptability and agility, the structured approach is often contrasted with the plethora of **agile development** approaches, which originated[2] mainly from software engineering as a response to bureaucratic processes and extensive process modeling (Kalus, 2013, p. 2; Highsmith, 2006; Boehm, 2002). They are increasingly drawing interest from hardware-related industries (cf. Schmidt et al., 2018), as they promise the desired increase in flexibility (Schmidt et al., 2018; Becerril et al., 2018). Yet purely agile approaches also face **criticism**: They cover only the “microcosmos” of a project, thereby ignoring the organizational environment (e.g. interfaces to other units), often suggest the concept of “process” to be an optional aspect of development weighable against other aspects such as individuals and interaction, and as a general rule require small teams to be applicable (Kalus, 2013, p. 1; Stephens & Rosenberg, 2003; Ittner, 2006; Glazer, 2001). Therefore, hybrids of conventional (e.g. Stage-Gate) and agile approaches are eventually seen as preferable (Cooper & Sommer, 2016; Cooper, 2014; Kalus, 2013, p. 2; Kruchten, 2011).

Process tailoring – Definition and importance

In order to bridge the perceived gap between extensive, generic reference process models on the one hand, and appropriate, lean, and agile project-specific processes on the other hand, a systematic adaptation of rich reference process models to project-specific situations is necessary (Kalus, 2013, p. 3; Ittner, 2006, p. 2). This step is generally referred to as **process tailoring**[3], carried out by selecting which activities are necessary and which artifacts need to be produced (cf. Ginsberg & Quinn, 1995; Kalus, 2013; Ittner, 2006; Graviss et al., 2016). Process tailoring as a **sub-activity of project planning** produces input for and thus directly **influences further planning activities**, such as budgeting and scheduling, and can eventually impact product quality (Graviss et al., 2016, p. 276). Hence, like project planning, tailoring represents an iterative and ongoing activity (progressive elaboration) (cf. PMI, 2016, p. 55). Process tailoring is feasible in the same way PDP modeling is, as most design activities remain consistent and reusable between project instances, with adaptations if necessary (cf. activity

[2] However, it can be argued that the basic concept of “Scrum” teams has its origin in the development of physical products as described in “The New New Product Development Game” (Takeuchi & Nonaka, 1986)

[3] The term process tailoring is further defined and explained in section 2.5.

modes), even as projects are never exactly the same (Browning, 2014c; Lévárdy & Browning, 2009; Browning, 2018; Austin et al., 2000; Louis-Sidney et al., 2016; Davies et al., 2009).

The **necessity** and **importance** of adapting reference processes to project instances for them to be helpful in contrast to "one size fits all" approaches are well-established in a number of sources, particularly so in software engineering (cf. Kalus, 2013; Browning et al., 2006; Shenhar, 2001), with some authors going to such lengths as to state that project success may be endangered if no tailored process is used (Payne & Turner, 1999, p. 56; Costache et al., 2011, p. 464). Further examples are the increasing prevalence of the subject in standard literature: For example, recent editions of the *Guide to the project management body of knowledge* (Whitaker, 2012, p. 4) or the *INCOSE Systems Engineering Handbook*, where tailoring is portrayed as a necessity to strike a "balance between the risk of missing project […] objectives on the one hand and process paralysis on the other hand" (Walden et al., 2015, p. ix). Instead, the specific organizational and project context needs to be taken into account during process design and adaptation (Rosemann & Recker, 2006, pp. 1–2; Roelofsen, 2011, p. 36), which requires sound understanding of this context (Bender & Gericke, 2016, pp. 415–416; Gericke et al., 2013). Adaptive and flexible processes are becoming more attractive in practice, especially in environments of high uncertainty, requiring a balance between overbearing process design and no process at all (Browning et al., 2006, p. 119; Ittner, 2006, p. 2)., Finally, some (software) process standards, such as CMM, explicitly mandate tailoring in order to ensure standard compliance and traceability (Pedreira et al., 2007, p. 4).

Benefits of tailoring are related to managing project risks and challenges (Fontoura & Price, 2008; Xu & Ramesh, 2008b). It can lead to leaner projects by removing non-value adding elements, to cost and time savings, and to increased transparency in budgeting and scheduling (He et al., 2008; Pedreira et al., 2007, p. 1). Further effects are increased process control and consistency of deliverables (Xu, 2005, p. 1), reuse of gained knowledge (Xu, 2005, p. 1; Bustard & Keenan, 2005), and increased employee satisfaction (Pedreira et al., 2007, p. 1). Systematic process tailoring can furthermore contribute to alleviating several barriers[4] towards establishing process documentation (Browning et al., 2006), as it allows the concretization of processes for individual projects, which better fit the description of the work to be done.

Both, planning each project from scratch or not using a process model at all **do not represent viable alternatives**, due to the increased effort for modeling each project instance, "reinventing the wheel", and the missed opportunity of organizational learning (Cesare et al., 2008; Hurtado & Bastarrica, 2009; Browning et al., 2006, p. 114; Browning, 2014c, p. 18). Instead, process tailoring increases the reusability of process models and thus contributes to more economical process modeling (Browning et al., 2006).

Based on these arguments, an appropriate amount of process standardization in combination with tailoring can increase process model value, enable adaptability and agility, and improve innovation (Browning, 2018, p. 15, 2014c; Mir et al., 2016; Browning, 2014c).

[4] A discussion on the value and challenges of process modeling can be found in section 2.4.2.

1.1.2 Problem areas associated with process tailoring

The primary **motivation** for the work performed in this thesis is distilled into **four problem areas** (PA) related to process tailoring within the previously described initial situation (Figure 1-1). These problem areas originate from the reviewed literature in conjunction with the empirical studies conducted within this thesis. While further problem areas, challenges, and neighboring research topics exist, these are outside the scope of this thesis (cf. section 1.2.2).

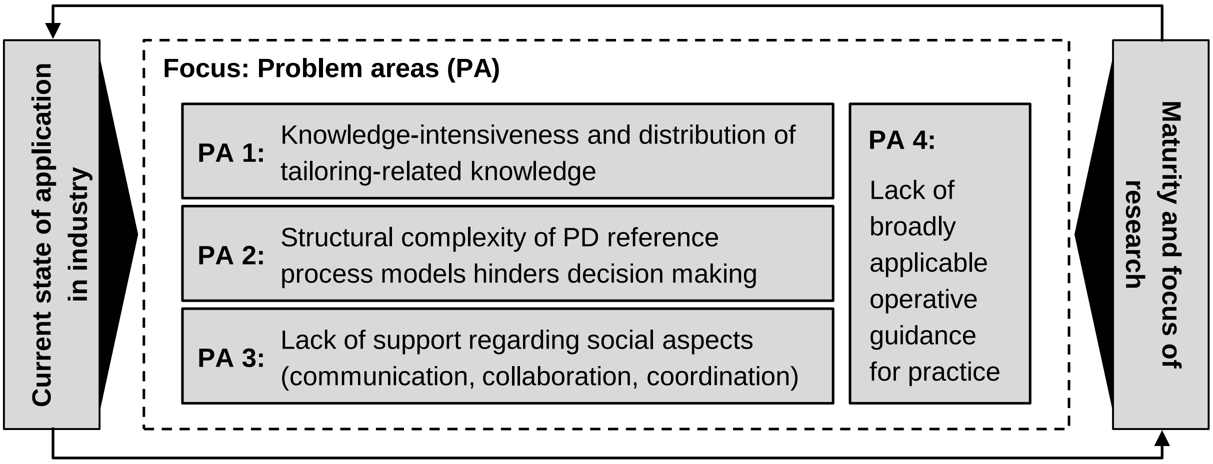

Figure 1-1: Four identified problem areas as the primary motivation for this thesis

On the one hand, the insights and approaches provided by research, which so far mainly concentrated on solving technical issues related to process tailoring automation, influence the **current state of application of process tailoring**. On the other hand, **the maturity and focus of research** are hindered by the limited degree to which tailoring is currently practiced. At this intersection, this work aims to **address** four identified problem areas outlined in the following subsections: The intensiveness and distribution of tailoring-relevant knowledge within an organization, the structural complexity of the process to be tailored, the social nature of tailoring in terms of stakeholder communication, and the overall lack of broadly applicable operative guidance. These problem areas are also interdependent. For example, structural process complexity hinders the generation of necessary knowledge regarding tailoring decisions and influences communication during tailoring.

The current state of application regarding process tailoring in industry

Tailoring is in practice currently most often **performed informally or implicitly**, in an ad hoc fashion from memory, depending on undocumented expert knowledge (Pedreira et al., 2007, p. 1; Xu & Ramesh, 2008a, p. 282; Graviss et al., 2016). This causes several negative consequences: Responsibilities and impacts cannot be attributed explicitly to decisions made during tailoring, while experiences and rationale for tailoring are not captured, limiting the possibilities for learning through sharing and reuse, which results in reactive instead of proactive tailoring (Cesare et al., 2008, p. 158). By using an informal, ad-hoc approach, the tailored process is further highly dependent on the skills and preferences of the responsible individuals (Pedreira et al., 2007, p. 4).

Maturity and focus of current research

Research on process tailoring gains importance as standard processes become more commonly used for project planning and to support organizational learning (Browning et al., 2006, p. 119). Simultaneously, process tailoring is often characterized as a **relatively young field of research** with advancements mainly driven from the area of software engineering (Martinez-Ruiz et al., 2012; Park et al., 2006), with some authors calling it "an emerging practice" (Akbar et al., 2011, p. 577). As Pedreira et al. (2007) state, existing work has focused mainly on supporting large companies. Within interdisciplinary development, for example, systems engineering, mechatronics, or PSS development, tailoring research and guidance, is even less prevalent in general (Graviss et al., 2016, p. 277; Browning et al., 2006, p. 119). The investigation of PDPs and the relationship with their application context has so far not been widespread in this area (Gericke et al., 2013).

As the conducted literature reviews have indicated (section 4.2.3), the predominant approaches in the literature focus on solving technical issues related to modeling and storing context and process variance information, thus automating the tailoring activity, for example through model transformation based on model-driven engineering approaches (e.g. Hurtado Alegria, 2012). Existing tailoring support therefore often requires specific skills and expertise regarding software techniques such as transformation programming languages, which may not be available, for example in smaller companies and thus raise the implementation threshold (Silvestre, 2015; Hurtado Alegria, 2012, p. 144). By some authors, such automated, mechanistic process tailoring is seen as outright unfeasible (Bender & Gericke, 2016, p. 416).

Besides the provision of support, descriptive studies regarding process tailoring applications are also limited, with studies often focusing on the resulting process rather than the applied guidelines and methods (Zakaria et al., 2015b, p. 133; Pedreira et al., 2007). Other authors go as far as to state that there is a lack of empirical evidence regarding the feasibility of tailoring-related approaches, such as method engineering, in total (Kuhrmann et al., 2014).

PA.1: Knowledge-intensiveness and distribution of tailoring-related knowledge

Process tailoring is a "**knowledge-intensive activity**" (Xu & Ramesh, 2008a, p. 1) as it requires "extensive knowledge regarding the appropriateness of different processes in different contexts" (Xu & Ramesh, 2007). This (externalized) knowledge can be differentiated into **generalized** knowledge (how to perform process tailoring and general tailoring rules with low contextual specificity) as well as **contextualized** knowledge (episodic knowledge regarding previous experiences and tailoring decisions with high contextual specificity). The latter contains the tailoring problem, information describing the context of the tailoring problem, strategic knowledge about tailoring strategies, and causal knowledge (reasons and justifications for selecting particular tailoring strategies) (Xu & Ramesh, 2008a, pp. 282–286). Both types affect the quality of the decision making processes involved in process tailoring (Xu & Ramesh, 2008a, p. 301). Contextualized knowledge has a more significant potential to increase tailoring performance as it may lead to greater learning effects, in particular for complex tailoring tasks, but is more expensive to acquire (Xu & Ramesh, 2008a, p. 299). The reuse of contextual knowledge is particularly important to support inexperienced practitioners tasked with tailoring (Pedreira et al., 2007).

Process- and tailoring knowledge is **distributed** within organizations, for example on **different levels** within the organization (Pedreira et al., 2007, p. 5) as well as **across individuals** managing and carrying out the projects (Browning, 2018, p. 2). For example, roles such as process owners and project managers generally have a broader overview of the process and dependencies between activities, while individual functional roles, such as engineers and designers carry in-depth insight into the individual activities carried out and different ways to perform them. Besides appropriate knowledge **codification**, process tailoring relies on the **exchange** of knowledge through interactions between project team members as well as knowledge integration (Xu & Ramesh, 2008a, p. 302), both of which need to be adequately supported but are often inadequately addressed in existing support.

PA.2: Structural process complexity hinders decision-making

As outlined previously, solving complex tailoring tasks requires a considerable amount of and interaction between knowledge elements and information. However, problems and issues to be considered can become obstructed by these large amounts of data required (Xu & Ramesh, 2008a, p. 287; Nickerson & Zenger, 2004). Tailoring is hindered by the **complexity** of the standard process to be tailored (Ittner, 2006, p. 3). Structurally complex process models become difficult for humans to assess and handle without further means, such as modeling and systematic analysis (Kreimeyer, 2010, p. 19). According to empirical studies conducted within this thesis (cf. section 3.2), the **consideration of dependencies between process elements,** such as activities and stakeholders, is of particular importance for the proper assessment of impacts and consequences of tailoring decisions. The ability to identify and assess potential “ripple effects” in process models induced by such process changes (cf. Browning, 2009, p. 322) is therefore vital when making tailoring decisions yet difficult. Due to the inherent network characteristic of PDPs, tailoring decisions themselves can also be closely related and potentially conflicting.

In combination with the previously described knowledge-intensiveness, this issue impedes tailoring decision-making, due to the lack of transparency regarding the individual impacts and cumulative effect of the multitude of tailoring decisions that need to be made. Therefore, tailoring support needs to be complexity-oriented in order to facilitate the handling of complex process models during tailoring by increasing the transparency of the process network and comprehension of tailoring decision effects. This can be achieved by applying general strategies for complexity handling, such as creating transparency through system views, avoiding or reducing complexity, or managing it, for example through analytical approaches (Maurer, 2017, pp. 117–129). Existing tailoring approaches do not explicitly address the consideration of structural complexity in order to increase process comprehension (cf. sections 4.2.3 and 4.3.3).

PA.3: Lack of support regarding social aspects

Communication, **collaboration**, and **coordination** between stakeholders play an essential role in PD project management (Heimberger, 2017; Maier, 2008, p. 28). Engineering failures can often be traced back to communication issues, such as in the case of the *Challenger* disaster (Maier, 2008, p. 2; PMI, 2016, p. 23). Effective project management hinges on the organizational communication style and capabilities, with the project team depending on input and feedback from all involved stakeholders (PMI, 2013, 21) and project managers spending large amounts of time communicating with team members and other stakeholders (PMI, 2013, p. 55). Effective communication bridges stakeholders with different perspectives and views, which eventually impact a projects' execution and success (PMI, 2013, p. 287). Similarly, determining which processes and activities are necessary and applicable for a particular project (i.e. tailoring) requires close collaboration and communication between project managers and their project team (PMI, 2013, p. 48). These **social aspects** are regarded as highly critical for tailoring in practice, as evidenced by the conducted empirical studies (cf. chapter 3) and described in the literature (Karlsson & Hedström, 2009, p. 492) (cf. Section 2.5.6). Social aspects are particularly important for large projects in large companies involving a multitude of disciplines and stakeholders. However, tailoring is currently rarely understood and investigated as a social activity, although it often takes the form of **negotiation**, with stakeholders holding different and often conflicting values and interests (Karlsson, 2008; Karlsson & Hedström, 2009, p. 492). This statement is corroborated by the conducted literature studies within this work, which show that existing tailoring support only insufficiently addresses social aspects (cf. sections 4.2.3 and 4.4.3).

To summarize, within the context of this thesis, **social aspects** of tailoring support constitute the **targeted integration of relevant stakeholders** (i.e. project participants) into the tailoring activity, as well as the identification of **communication** and **coordination** needs between these stakeholders in order to realize a **collaborative** tailoring effort.

PA.4: Lack of broadly applicable operative guidance for practice

Tailoring can be considered a critical part of the reference process itself (Costache et al., 2011, p. 1) and is often required as part of process standards. While these standards define which activities are necessary in this regard (e.g. "identify project environment", "solicit inputs", "select processes", etc. for ISO/IEC 12207), they do not elaborate how they are to be carried out and often focus on first-level tailoring (tailoring for a particular organization, cf. section 2.5.1) (Xu & Ramesh, 2008a, p. 278). Similarly, while stressing its importance, Systems Engineering literature provides little operational guidance on how to implement and perform tailoring (Graviss et al., 2016). Furthermore, guidelines provided by frameworks such as the *Rational Unified Process* (RUP) are often abstract and limited to generic project types, e.g. "small" vs. "large" (Xu & Ramesh, 2008a, p. 278). However, in order to design tailorable processes, the stimuli for required processes and adaptations need to be understood first (Kumar & Narasipuram, 2006). Currently, it often remains unclear, what factors lead to tailoring of the standard process (Khan et al., 2014, p. 3).

As the examples illustrate, the **guidance** provided by standard process models and existing frameworks is **insufficient** to support process tailoring in practice broadly (Xu & Ramesh, 2007; Browning et al., 2006, p. 119). Therefore, an integrated and systematic approach to process tailoring is required, which provides operative guidance for practitioners and addresses the previous problem areas.

1.2 Research objectives and thematic scope

Based on the established motivation, this section first presents the central research objective and questions, followed by the delineation of the thematic scope regarding research areas of contribution and relevance.

1.2.1 Research objectives and research questions

Based on the presented initial situation and problem description, an overall research objective and five research questions delineate the research program underlying this thesis.

Research into complex systems should focus on enabling decision support regarding the design, operation, and use of such systems (cf. Rouse, 2007). This thesis aims to contribute to this superordinate objective by providing a corresponding complexity-oriented form of process tailoring support. However, due to the complex nature of process tailoring itself and the plethora of possible considerations, addressing this objective in its entirety is a task far too extensive to be covered within the scope of a single thesis.

Based on the problem areas outlined in section 1.1.2, the overall objective (OO) of this thesis is summarized as follows:

OO*:* The overall objective of this thesis is to develop a prescriptive approach to support practitioners tasked with project-level tailoring of interdisciplinary reference product development processes during project planning, with a specific focus on facilitating the handling of structurally complex reference process models and supporting communication during collaborative process tailoring.

In order to fulfill the stated overall objective, the following research questions (RQ) have been defined to structure the research activities:

RQ 1: Which activities are required to introduce and operationalize the envisioned process tailoring support within iPD, and how can they be logically structured?

RQ 2: How can tailoring-relevant knowledge within a particular organization be documented for its subsequent use, application, and analysis?

RQ 3: Which supporting methods are required to provide further operative support within the defined activities?

RQ 4: How can collaboration and communication during the tailoring activity be supported by utilizing the documented knowledge?

RQ 5: How can the documented tailoring-relevant knowledge be analyzed and prepared in order to support the preparation and execution of collaborative tailoring regarding structurally complex PDPs?

How the presented research objectives are to be fulfilled, and research questions answered, is laid out in section 1.3.1 via the description of the research methodology. The overall objective and research questions are further detailed and translated into *requirements* for the development of the tailoring support in section 3.3. The eventual *fulfillment* of the research objective and research questions is summarized in section 9.1.

1.2.2 Scope and thematic classification

The **main areas of relevance and contribution** for this thesis are visualized in Figure 1-2, grouped around the objective of this thesis. **Areas of contribution** signify areas where this thesis makes a direct contribution. The respective areas are addressed in related work (chapter 4). **Areas of relevance** describe further research areas of high significance, particularly for the development of the envisioned tailoring support in order to realize the intended contributions (cf. chapter 2).

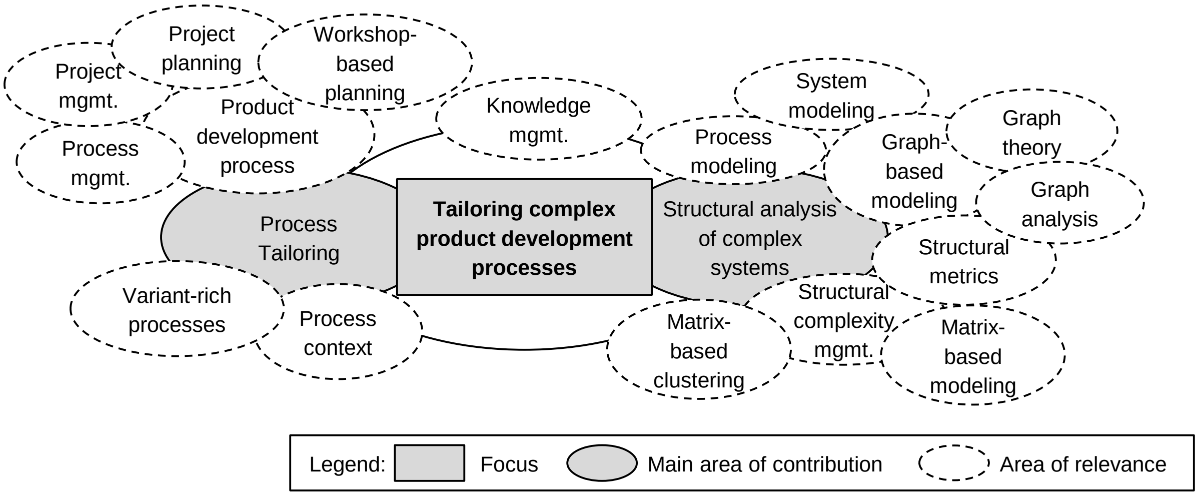

Figure 1-2: Areas of relevance and contribution forming the basis of this thesis (based on Blessing & Chakrabarti 2009, p. 66)

The objective of this thesis mandates the investigation of two significant areas of research: **Process tailoring** as well as **modeling and structural analysis of complex systems**, in the particular form of **process models**. This thesis aims to contribute to linking these two fields and transferring knowledge between a) the different research areas and b) from areas where process tailoring is already more firmly established (e.g. software engineering) to iPD. **Knowledge management** forms the conceptual foundation for both fields, as both process tailoring as well as modeling of complex systems require knowledge.

The selected focus furthermore addresses the **intersection of process and project management** within the area of iPD, which contains activities related to project planning, of which tailoring is a sub-activity. Thus, relevant areas are related to the fields of process management, project management, and approaches explicitly for planning and tailoring processes. Regarding tailoring, supporting approaches such as the modeling of variant-rich process models as well as process contexts are of further relevance.

As a methodical foundation to realize the intended support, this thesis relies on **structural modeling and analysis**, due to the multi-layered network characteristic of process models (Kreimeyer, 2010, pp. 105–106). These can be modeled and analyzed via graph- or matrix-based approaches, using e.g. **graph analysis**/**rewriting** (Helms, 2013), **metrics** to quantify structural characteristics (Kreimeyer, 2010), or matrix-based **clustering** (Browning, 2001). As the field of structural modeling is well-established, it provides a rich foundation for the selection and adaptation of existing approaches.

The intended tailoring support specifically addresses companies with an **iPD** background, such as mechatronic or PSS development. The targeted primary users of the developed support are companies managing and tailoring large, mature, and structurally complex reference process models, such as automotive OEMs. However, the approach is intended to be applicable within a broad spectrum of boundary conditions and thus targets no products or industry branches specifically.

Since there is a multitude of aspects that can be further considered within the domain of process management, the subsequent section further **delineates the scope** of this dissertation in order to avoid possible misconceptions. Therefore, the following aspects are related to the topic but **explicitly out of scope** for this thesis:

- The adaptation of generic literature-based to organizational reference processes.
- Process tailoring automation as addressed in related work, for example via model transformation (cf. e.g. Hurtado Alegria, 2012).
- The development of a generic, universally applicable catalog of context factors. As seen throughout this work, the completeness and reliability of any such catalog are debatable, although they may provide suitable starting points for further concretization.
- Replacing established methods and paradigms of process design and project planning. Instead, the developed tailoring support is intended to complement them by increasing context orientation.
- Explicit investigation of agile approaches. The developed tailoring support is not explicitly associated with agile development. However, the developed tailoring support can contribute to the hybridization of conventional and agile approaches.
- Aspects related to organizational change management that support the continued implementation of the tailoring support are not within the scope of this research.
- Cross-project influences (e.g. shared resources between projects) are not regarded.

1.3 Research approach

This section presents the research approach pursued in this dissertation. First, an overview of the overall methodology is given, highlighting the aspects characterizing the specific instantiation within this dissertation. Subsequently, the author's experience and data basis are described.

1.3.1 Research methodology and methods

In order to fulfill the stated objective, the thesis at hand followed the **Design Research Methodology** as defined by Blessing & Chakrabarti (2009) and outlined in Figure 1-3. The methodology consists of four consecutive stages but allows for flexible instantiation by performing iterations and recursions as necessary. Each stage provides guidelines and research methods for solving specific tasks, e.g. regarding literature reviews or the acquisition and analysis of empirical data.

In order to be applicable, the individual stages need to be adapted to the investigated research subject by choosing corresponding methods (cf. Figure 1-3). This thesis is classified as the development of design support[5] based on a **comprehensive DS I** concluded by an **initial DS II** (Type 5) (Blessing & Chakrabarti, 2009, p. 62).

In light of the low prevalence of the research topic in industry and the novelty of the approach within iPD, a primarily qualitative, **case study** based overall approach was chosen, augmented with additional focus interview studies. The case studies enable in-depth analysis of boundary conditions as well as the application of the tailoring support in natural environments (companies), grounding the development of the tailoring support in practice (cf. Yin, 2014). The case studies served as primary data sources for the concretization of the research objective **(RC)**, identification and analysis of the current situation and concretization of requirements (**DS I**), and the intermediate and final assessment of the support (**DS II**). The explorative nature of this work resulted in several iterations within the DRM, primarily between DS-II and DS I/PS (cf. Figure 1-3), as first an initial form of tailoring support has been developed, tested, and subsequently elaborated in its constituent elements due to the insights gained. This iterative approach is reflected and discussed in detail in section 8.5.2.

Phase		Methods	Main results
Research Clarification *(RC)*		• Interviews • Explorative Literature Study	• Research objective: Tailoring of complex PDP in iPD
Descriptive Study I *(DS I)*	**L**	• Literature review	• Implications from practice • Characteristics/gaps of existing support
	E	• Case studies • Interviews	
Prescriptive Study *(PS)*		• Synthesis • Decomposition and elaboration of constituent elements	• Developed tailoring support: Methodology, metamodel, and further constituent elements
Descriptive Study II *(DS II)*		• Application case studies • Test Case & Interview study	• Evaluated support • Benefit, contribution, and limitations

Figure 1-3: DRM phases and instantiation in this thesis - chronological sequence and iterations, main methods, and results (based on Blessing and Chakrabarti 2009, p. 15)

The **Research Clarification** is based on both a literature review as well as observations and interviews (open and semi-structured) primarily made during the research project “A^2TEMP” (cf. section 1.3.2). It provides an overview of the general research context and initial situation,

[5] As the support developed using the DRM within this work does not directly support design work, it shall henceforth be referred to as “tailoring support”.

and the general problem areas regarding the adaptation of PDP models in practice. Results are the overall objective, research questions, and delineation of the thematic scope which guided the subsequent detailed analyses.

The **Descriptive Study I** serves to build a comprehensive knowledge base regarding the overall objective. On the one hand, **literature reviews** illuminate the current state of the art regarding fundamentals and related work (chapters 2 and 4). On the other hand, the current state of process tailoring in industry is investigated in **empirical studies** (observations, interviews, and initial case studies) (chapter 3), applying the principle of triangulation to concretize research gaps (cf. Hollauer et al., 2016; Collis & Hussey, 2014, p. 71). In summary, the DS I results in empirical implications and requirements for the envisioned tailoring support, as well as an analysis and evaluation of existing approaches in light of these requirements.

The **Prescriptive Study** is carried out based on the results generated during the RC and DS I. Elements are taken from related work, adapted as necessary and extended by newly developed approaches. The PS has been carried out by defining and applying (cf. DS II) a tentative form of tailoring support, which was progressively elaborated in its constituent elements. This approach resulted in the methodology for supporting the preparation and operationalization of workshop-based process tailoring in iPD, with constituent elements to support the individual activities and address the identified problem areas (cf. chapters 5 to 7).

During the initial **Descriptive Study II**, the developed tailoring support is evaluated regarding applicability and success, deriving lessons learned for support improvement. For this purpose, a primarily case study-based application evaluation has been chosen (cf. section 8.1). This iteration between PS and DSII closely resembles action research but differs in that the developed support is not iteratively tested and optimized for the same but different organizations[6]. Thus, the objective of the evaluation is increasing generalization instead of individualization, focusing on the reliability of the tailoring support to produce the intended results (replicability) (cf. Blessing & Chakrabarti, 2009, p. 193). Elements of the tailoring support have been implemented as (software) demonstrators to aid the evaluation. The DS II is classified as initial since no assessment of long-term effects could be conducted.

[6] However, it can be argued, that within the individual case studies, action research is performed, because the support is applied and adapted until a satisfactory solution is generated within the specific environment. Generalization is then achieved through repeated application in different environments.

1.3.2 Research environment: Data and experience background

In order to establish full traceability of the work presented in this dissertation, the experience background of the author is disclosed in this section[7]. The primary data sources are the execution of research projects as well as the close supervision of student theses, particularly in cooperation with industry partners between March 2014 and December 2018.

KME - A2TEMP[8] *(Anforderungs- und Änderungsmanagement in der Top-Down Entwicklung Mechatronischer Produkte)* represents the central research project, targeting a process-oriented and architecture-driven development of mechatronic products. The project laid the basis for the RC and DS I. The respective PDP reference models of ten cooperating small- to medium-sized enterprises were analyzed, resulting in the identification of the initial problem of process tailoring in iPD. The closeness to industry allowed for a deep immersion in the subject, providing valuable insights and partners for subsequent interviews.

Within the subproject **A10** *(Supporting innovation of PSS through model-based assessment of PSS use phase information)* of the **collaborative research center 768[9]** (*Managing cycles in innovation processes – Integrated development of Product-Service Systems based on technical products*), the previously gained knowledge was further extended in regard to its importance in the rapidly changing landscape of iPD. This change is characterized by the integration of new disciplines in the context of Product-service system development and the integration of additional development goals such as increased sustainability and digitalization of products. The changing landscape affects the complexity of PD processes through an increased number of and variability in development activities within organizations.

Participation in the research project **KMEagil[10]** (*Einführung agiler Methoden in klein und mittelständischen Unternehmen zur Verbesserung des Entwicklungsprozesses*) further highlighted the need for flexible instantiation of PD reference process models in light of decreasing development time and the demand for increased agility.

The presented work was furthermore supported by several **student theses**, which were closely supervised by the author (cf. section 11.3) and the majority conducted together with industry partners (DS II). This student support allowed for a high number of partially parallel case studies, which otherwise would not have been possible due to organizational and resource constraints. It allowed to generate a broad insight into different boundary conditions, while at the same time increasing the depth of each case study by embedding the respective student into the organization. Furthermore, it allowed to alleviate concerns regarding the confidentiality of company data. Some of these student theses resulted in peer-reviewed publications, cited correspondingly in this thesis. The remaining theses are cited using the prefix “PE-“ (e.g. PE-Langner, 2017).

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[7] As far as permitted through confidentiality agreements.

[8] Funded by Kompetenzzentrum Mittelstand GmbH (KME), joint venture of TUM and bayme vbm

[9] Funded by Deutsche Forschungsgemeinschaft (DFG)

[10] Funded by Kompetenzzentrum Mittelstand GmbH (KME) , joint venture of TUM and bayme vbm

1.4 Structure of the dissertation

The structure of this thesis, as illustrated in Figure 1-4, is aligned with the DRM according to Blessing & Chakrabarti (2009). The individual chapters are subsequently briefly summarized.

Chapter 1 describes the initial situation for this thesis as well as current problems related to process tailoring. From this, research objectives and the thematic scope regarding areas of relevance and contribution are derived. Based on the research objectives, the research methodology and applied research methods are presented. The author's research environment concludes this chapter to increase the traceability of the research results.

Within the body of **Chapter 2**, the relevant research fields are elaborated, clarifying their relevance for this thesis. Therefore, relevant terminology is defined and put into context before the theoretical as well as methodical fundamentals are presented. Initial conclusions for the tailoring support complete the chapter.

Chapter 3 summarizes insights from empirical studies conducted in order to concretize the objective for the intended tailoring support and its translation into requirements. Requirements are used to assess related work and guide the development of the envisioned process tailoring support.

Chapter 4 presents an overview of related work regarding existing tailoring approaches with relevancy for the objective at hand. The existing approaches are categorized in order to identify gaps in the current state of research and create a foundation for the tailoring support to be developed.

Chapter 5 serves to bridge the gap between the analysis of the theoretical and methodical fundamentals and identified related work on the one hand, and the subsequent presentation of the developed tailoring support on the other. This is achieved by describing the derivation of the constituent elements of the tailoring support based on the defined requirements.

Chapter 6 presents the developed metamodel for graph-based storage of tailoring-relevant knowledge and elaborates the individual modeling elements provided.

Chapter 7 presents the developed methodology for implementing workshop-based process tailoring, which integrates the description of further constituent elements.

Chapter 8 addresses the evaluation of the tailoring support using application case studies and evaluation interviews. The developed tailoring support, as well as the research approach, are reflected and discussed in conclusion.

Chapter 9 concludes the thesis by summarizing the research results and the industrial as well as academic contributions. The thesis ends with a discussion of limitations and the resulting outlook on future work, which outlines possible advancements of the developed tailoring support as well as avenues for further research in the area of process tailoring.

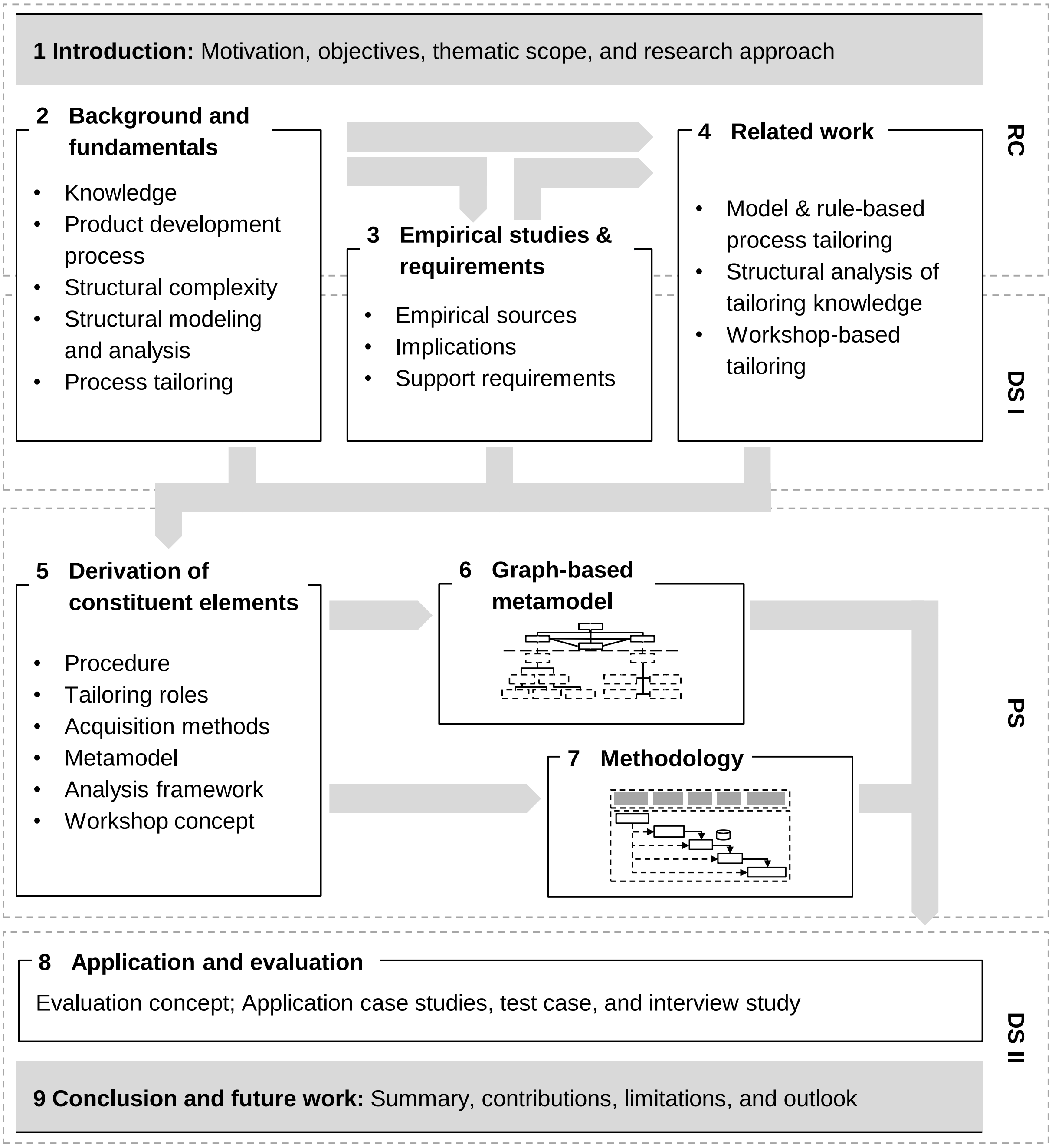

Figure 1-4: Overview of the structure of this thesis

2 Background and Fundamentals

The body of chapter 2 provides an overview of the necessary background and fundamental concepts as laid out in the thematic scope. In this function, chapter 2 contributes to the RC and DS I of the applied research methodology. First of all, section 2.1 gives an overview of basic terminology. Section 2.2 briefly outlines the importance and characteristics of knowledge as the fundamental resource required for process modeling and tailoring. Section 2.3 delves deeper into PD processes, highlighting their characteristics primarily from a complexity perspective and outlining, fundamentals of process and project management. Section 2.4 illuminates the background on modeling and analysis of structurally complex PD processes. Section 2.5 represents a central part of this chapter, as it presents the concept process tailoring.

The chapter closes with a summary and implications for the subsequent chapters of this work. The statements in this section ultimately inform the definition of requirements in chapter 3and selection of relevant research fields and approaches for the analysis of the related state of the art in chapter 4.

2.1 Basic concepts and their interpretation

In this section, the basic terminology relevant within the scope of this thesis is briefly presented and put into context, as shown in Figure 2-1. The central terms and definitions within this work are derived from the areas of product development (PD) as well as project- and process management research.

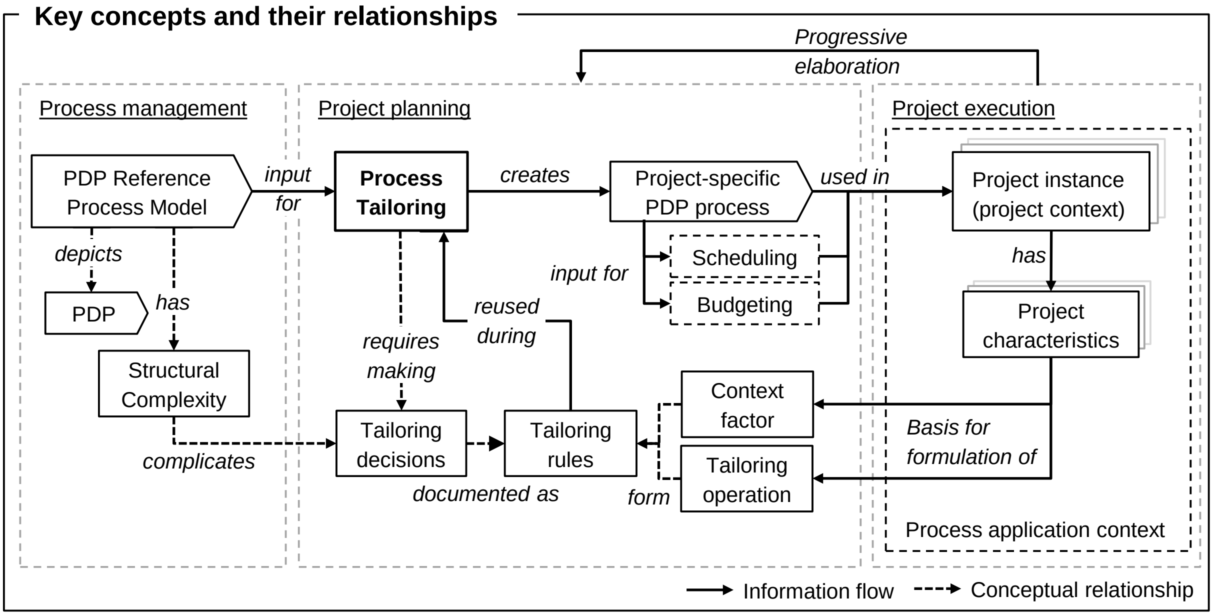

Figure 2-1: Basic concepts and their relationships

A **process** is defined as "an organized group of related activities that work together to create a result of value" (Hammer, 2001). Within a process, "*interdependent tasks [...] exchange information via artifacts. The process is enabled and supported by the purposeful allocation of resources and time-oriented constraints. All of these entities are interrelated, on the one hand, via the input-output relationships among tasks along the principal process flow, and, on the other hand, via other relationship types that generate the overall process network*" (Kreimeyer, 2010, p. 63). Particularly in **product development processes (PDP)**, knowledge about the development object, whose nature is at least partially unknown, is generated during the process, causing uncertainty and a much less deterministic process, as compared to business processes (Kreimeyer, 2010, p. 64).

Concerning PDPs, two different types of processes and corresponding models can be differentiated: Organizational **reference processes** (also known as standard or canonical processes) represent templates and document standard activities, deliverables, and best practices. Through adaptation (tailoring), **project-specific processes** (also known as deployed processes) are derived, which are subsequently used as a basis for project planning such as budgeting and scheduling, as well as controlling. (Browning et al., 2006, p. 118)

Process and project management are dependent on the creation and use of **process models,** which are purpose-built, reduced representations of an actual process used by model users, such as project managers, for the different model purposes (cf. Stachowiak, 1973). While any work (and thus, company) has a process, it may not be modeled or documented (Browning et al., 2006, p. 106). This thesis focuses on external, codified process models (Lindemann, 2009, p. 11), which depict a process' network structure in the form of **graphs** or **matrices** and exhibit particular structural characteristics (cf. Lindemann et al., 2009). These structural characteristics can be quantified and visualized by calculating structural metrics (Kreimeyer, 2010). Numerous modeling languages and formalisms exist to create such process models, for example, event-driven process chains (EPC) (cf. e.g., Amigo et al., 2013; Browning & Ramasesh, 2007).

Within the scope of this thesis, these process models are investigated in the context of **interdisciplinary product development[11] (iPD)** of (partially) physical products, exemplified by, e.g. mechatronic (cf. Isermann, 2005) or Product-service system development, which includes physical products (cf. Tukker, 2004).

Processes and their corresponding models exhibit **structural complexity**, which is an attribute of the investigated system, and defined by a large number of components, with numerous and intricate dependencies, and variants within the systems' structure (Lindemann et al., 2009). Structural complexity contributes to a systems' behavior (Sharman & Yassine, 2004), resulting in behavioral complexity, with the systems' behavior being "difficult to predict, analyze, describe, or manage" (de Weck et al., 2011, p. 185). Knowledge regarding the structure of a system thus improves comprehension and prediction of its behavior (Maurer, 2007).

In order to derive deployed processes, **process tailoring** becomes necessary. Process tailoring is generally defined as "*the act of adjusting the definitions and/or particularizing the terms of*

[11] Product development and **engineering design** are often used synonymously (cf. e.g. Maier & Störrle, 2011). In the context of this thesis, the term is also used synonymously with **Systems Engineering** (cf. Walden et al., 2015)

a general description to derive a description applicable to an alternate (less general) environment" (Ginsberg & Quinn, 1995, p. 3). Synonyms are "adaptation," "adaption," or "customization." While applicable on different levels, this thesis focuses on the adaptation of organizational standard processes to deployed, project-specific processes which is carried out within project planning in a manner of progressive elaboration over a projects' execution. Tailoring involves making a multitude of decisions regarding individual adaptation operations, which are termed **tailoring decisions**. A tailoring decision encapsulates the contextual condition for a tailoring operation and the change operation on the standard process model, e.g. the deletion of an activity or the selection of an activity mode. Conditions are termed **context factors** and described as a **context variable** that can assume multiple **values** (cf. Park et al., 2006). Context factors represent process variant drivers, leading to different deployed processes for different projects. Recurring tailoring decisions can be generalized, formalized, and subsequently reused in future tailoring applications in the form of **tailoring rules.** Tailoring rules describe the conditional and impact aspect of a tailoring decision using a corresponding formalism. The process application **context**[12] is defined as the "the interrelated conditions in which something exists or occurs," hence the sum of context factors (project characteristics) for a particular project portfolio (cf. Gericke et al., 2013; Merriam-Webster, 2016).

2.2 Knowledge as fundamental resource

There is no universally accepted definition of the term knowledge (Barnes, 2002). In particular, the differentiation between the closely interrelated terms data, information, and knowledge varies between authors (Davenport & Prusak, 2000). Most generally, **data** denotes discrete and uninterpreted facts (e.g. sequences of numbers and letters), **information** represents structured data with a degree of human interpretation, giving context and meaning to data (Wiig, 1995; Davenport & Prusak, 2000; North, 2011; Tuomi, 1999). Finally, **Knowledge** is defined by Davenport & Prusak (2000, p. 5) as "*a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organizations, it often becomes embedded not only in documents or repositories, but also in organizational routines, processes, practices, and norms*." Concerning systems, information describes its current or past state, while knowledge allows making "predictions, causal associations, or predictive decisions" (Bohn, 1994, p. 62)

This definition highlights several aspects relevant to the concept of knowledge within the scope of this thesis: The **complexity** of the concept, the **importance of humans** as generators and carriers of knowledge (Hicks et al., 2002, p. 267; Davenport & Marchand, 1999), as well as the relationship of knowledge with organizational **processes** and process modeling, among other categories (cf. procedural knowledge, Ahmed, 2005; Alavi & Leidner, 2001). Furthermore, it provides two critical distinctions: **individual vs. organizational** and **tacit** vs. **explicit** knowledge (Nonaka, 1994; Polanyi, 1966) Tacit knowledge can be expressed and codified up to a certain degree (explicit knowledge), which represents an important organizational asset (van den Berg, 2013; Choo, 1996; Spender, 1996), prompting Nickols (2012) to further

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[12] A similar concept is the "domain" as defined in domain engineering (cf. Czarnecki & Eisenecker, 2005)

distinguish implicit knowledge, which can be codified, in contrast to tacit knowledge, which cannot[13]. Knowledge representations can be categorized into three main classes: rule-, model-, and case-based (Helms, 2013, pp. 26–39).

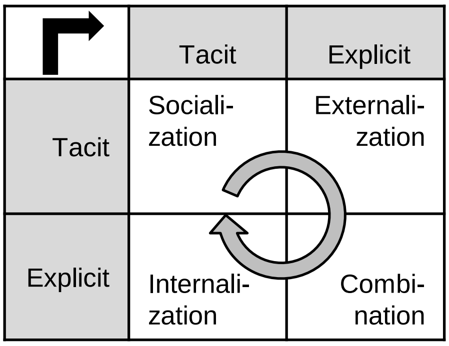
The generation, distribution, and use of (organizational) knowledge is a decisive success factor for technology-oriented organizations (Teece, 2003; Nonaka & Takeuchi, 1995), with reuse, generation, and identification as key dimensions (Lettice et al., 2006, p. 222). Knowledge enhances the ability to make decisions (Jashapara, 2004, p. 16). In particular, **procedural** knowledge regarding how work is done in complex PD environments represents a valuable asset, due to knowledge drain resulting from experienced employees leaving or retiring, and as a lever for **improving project performance** (Browning, 2018, p. 1). However, such procedural knowledge is incomplete when a process is first implemented and needs to be developed gradually through different forms of **organizational learning** (see below) (Bohn, 1994, p. 61). In this context, the **knowledge-intensiveness of process tailoring** and has been presented in section 1.1.2. Xu & Ramesh (2008a) experimentally established the benefit of knowledge support for tailoring, in particular of contextualized knowledge for complex tailoring tasks.

The **management of knowledge** is challenging due to the required adaptation to its continual change and development and because objectification of knowledge should be avoided in light of the role humans play (Wenger et al., 2010). However, a multitude of knowledge management approaches has been developed due to the importance of knowledge. Effective knowledge management depends on a successful infrastructure determined by four categories of key factors: human-oriented factors, organizational aspects, information technology, and management processes (Heisig, 2009). The concept of **organizational learning** is closely related to knowledge management, with the difference of the focus respectively lying on the goal and process vs. content and flow (Easterby-Smith & Lyles, 2011; Lehner & Maier, 2000). The **SECI model** ("knowledge spiral") by is one model (Nonaka, 1994; Nonaka & Takeuchi, 1995) to describe the process of organizational knowledge creation. The model does this through a series of dynamically interacting knowledge creation modes, which are iteratively cycled through in order to increase organizational knowledge, transforming tacit and explicit knowledge in a "knowledge spiral" as depicted in Figure 2-2. According to Nonaka (1991, p. 99), externalization and internalization are particularly critical for extending organizational knowledge as they require personal commitment. Schulze & Hoegl (2016, p. 225) further emphasize the importance of socialization during early PD.

In order to **assess the state of knowledge** regarding a particular process and its influences, Bohn (1994) presents a **framework** of 8 stages, ranging from "complete ignorance" to "complete knowledge." While the framework is generally targeted at production and manufacturing processes, it is generally valid also for more intangible processes. Each stage describes the state of knowledge regarding the process as well as its influencing variables, as a process "can do no better than the knowledge about its most important drivers" (Bohn, 1994, p. 65). An increase in knowledge is gained via systematic learning mechanisms regarding these individual variables (e.g. experiments), with the objective to improve understanding regarding the variable and its effect on the process outcome. Different states of knowledge can exist in

[13] Therefore, the term "implicit" is henceforth used to refer to codifiable but as of yet undocumented knowledge

parallel, depending on the particular variable, which can result in the necessity for hybrid process management styles. Due to their nature, PD processes range rather low on this scale (Bohn, 1994, p. 68).



Socialization	Sharing of experiences and mental models between colleagues
Externalization	Codification of knowledge (e.g. through modeling)
Combination	Combination of explicit knowledge artifacts through social processes
Internalization	Creation of new tacit knowledge through application of explicit knowledge

Stage	Name	Description
1	**Complete ignorance**	Unawareness of variables; influences appear as random disturbances
2	**Awareness**	Variables are apparent but unusable; possibility to investigate variables (e.g. by bringing in outside knowledge)
3	**Measure**	Variables can be measured but not controlled; process can be altered in response to mitigate or exploit effects
4	**Control of the mean**	Variables can be controlled, albeit with some variance; facilitates further learning through experiments on variables
5	**Process capability**	Variables can be controlled with precision across a range of values; Further investigation of influences on input variables
6	**Process characterization**	Knowledge on how variables affect results; process fine-tuning, e.g., to reduce costs.
7	**Know why**	Scientific model of the process; automation possible; experiments over multiple variables to find interactions
8	**Complete knowledge**	Never reached in practice due to complexity of variable interactions, can only be approached asymptotically

Figure 2-2: Top: SECI-Model with knowledge creation modes based on Nonaka (1994). Bottom: Stages of process knowledge based on Bohn (1994)

2.3 Fundamentals of product development processes and their management

The following section outlines the fundamental concepts required for understanding PDPs, starting with their definition, delineation from business processes, and the disambiguation of reference and deployed processes. The definition of PDPs concludes by presenting a system perspective. Based on this, two complexity-related aspects are introduced: Structural complexity as well as variety. Section 2.3.3 concludes with an overview of process and project management as functions to manage PDPs.

2.3.1 Definition and delimitation

Processes, in general, are systems of activities and their interactions, which comprise a project or business function. A process' architecture is a process's structure, as determined by its constituent activities and their interactions, and the principles guiding its design and evolution (Browning, 2016, p. 34; Eppinger & Browning, 2012). This definition correlates with the definition by Kreimeyer (2010, p. 63, cf. section 2.1), which defines processes as networks of interrelated tasks, which can reach considerable density (Browning et al., 2006, p. 109; Negele, 1998; Negele et al., 1997). Tasks or activities are logical work units carried out by a particular resource, e.g. persons, machines, or groups thereof, over a certain period of time (Kreimeyer, 2010, p. 64). Within the individual activities, inputs (e.g. information) are processed to generate output (Lindemann, 2009, p. 16).

Delimitation from business processes

PDPs are characterized by the creation of knowledge about the development object (i.e. product), which generates uncertainty and causes PDPs to be less deterministic than general business processes (Kreimeyer, 2010, p. 64). Due to these particular characteristics, PDPs are challenging to manage and navigate (Wynn & Clarkson, 2017, p. 1). **PDPs** can generally be differentiated from general **business processes** such as order processing, retail processes, or the credit assignment of a bank. Differences between both are listed in Table 2-1. They emphasize the need for process navigation for PDPs, leaving control and decision competence with the process user, whereas, in more controlling approaches, process participants become mostly “production means” (Vajna, 2005, p. 371).

In addition to the listed aspects, PD is a **multidisciplinary** endeavor, creating a multitude of **interdependencies** between activities which are often carried out in **parallel** instead of sequentially. Furthermore, the arising interdependencies are often less evident than in business processes, since many interactions are undocumented and ambiguity in required interactions and actions is higher. This requires increased flexibility and agility, with an appropriate amount of process structure. This structure should on the one hand not constraint participants and on the other hand, prevent participants from “reinventing the wheel” and wasting effort on non-value-adding activities. (Browning et al., 2006, p. 114)

Table 2-1: Differences between business processes and product development processes (based on Vajna, 2005, p. 371; Browning et al., 2006, p. 114)

Characteristic	**Business process (process control)**	**Product development process (process navigation)**
Execution frequency	Repetitive	Unique (in terms of project outcome)
Support focus	Repetition and optimization	Novelty and innovation
Structure	Fixed, rigid, reproducible, checkable; Sequential execution	Dynamic, creative, chaotic; iterations and jumps; Highly parallelized
Process deliverables	Predictable	Not always predictable
Information dependencies	Hard information	Also estimates and assumptions
Deliverable verification	Immediately possible	Possible often only much later
Nature of process assets	Physical (e.g. material, technologies, tools) and/or completely described	Often virtual and not always precise (concepts, ideas, designs, etc.)
Possibility of disruptions	Low (options and environment precisely described)	High (imperfect definitions and change requests)
Dynamic reaction	Capabilities not required	Capabilities definitely required
Interdependencies	Clearly defined	Ambiguous and often undocumented

Based on the previously described multidisciplinary and knowledge-generating nature of PDPs, design can be strongly considered a **social process,** and due to its interaction with technical systems as a **socio-technical process** (Parraguez, 2015, pp. 19–24). Understanding this social dimension and the associated communication is critical for PD process improvement (Eckert et al., 2005; Maier et al., 2005).

However, while differences between both types of processes are apparent, PDPs can be seen **as semi-structured or hybrid processes**. They contain structured as well as non-structured sub-processes, with varying portions of knowledge-intensive and creative work (Ferreira et al., 2016, pp. 539–540). In particular large-scale PDPs involve novelty but also **routine activities**, **repeatable structures**, and **patterns** – which can be modeled (Wynn & Clarkson, 2017, p. 2; Browning et al., 2006, p. 106).

Process types: Standard vs. deployed processes vs. design strategies

The term design process generally carries two different interpretations: The generic, high-level PD approach within an organization acting as a guideline for each project carried out, and the concrete, project-specific set of activities, which describes the actual work done within a project (Browning et al., 2006, p. 118; O'Donovan et al., 2005, p. 61). Synonyms for the former are **reference**, **standard**, **canonical** processes, or „industrial procedures” (Andreasen et al., 2015, p. 106), while the latter are often termed **project-specific** or **deployed** processes. Both types must be developed iteratively and progressively during cycles of organizational learning, distilling modeled project-specific processes into reference processes. (Browning et al., 2006, p. 118)

Reference processes are usually high-level, standardized sets of activities and deliverables. As they are often detached from the work actually done and too generic due to differences between projects, they require tailoring in order to be helpful for planning and controlling individual project instances. They are often designed purposely ambiguous, providing umbrella terms under which different activities can fall, in order to satisfy compliance auditors and attain certifications (e.g. ISO or CMM) (Browning, 2014c, p. 22; Browning & Ramasesh, 2007, p. 234). (Browning et al., 2006, p. 118)

The differentiation further highlights the nature of PDPs, which are most commonly carried out in the form of projects, whereby the individual projects are based on the adapted **deployed processes** (i.e. instantiations of the reference PDP). This duality requires the management of both reference processes as well as project instances, with an appropriate interface between both functions (cf. section 2.3.3). (Roelofsen, 2011, pp. 104–105)

Projects are defined as “temporary endeavor[s] undertaken to create a unique product, service, or result.” The temporary nature implies a definite beginning and end, although it does not necessitate projects to be short. Projects may be terminated when objectives are met, cannot be met, the need for a project does not longer exist, or the client requests so. (PMI, 2013, p. 3)

In addition to these two common interpretations, an additional meaning can be found: PD processes as generic **design strategies** or **methodologies** described in literature, which serve as input for the design of organization-specific standard processes or for training design novices (Andreasen et al., 2015, pp. 104–105; Gericke et al., 2013). Examples of such design strategies are described in VDI 2206 (2004) or by Pahl et al. (2007) (cf. Gericke & Blessing, 2012 or Wynn & Clarkson, 2017 for further overviews and classification). However, this additional differentiation will not be of further relevance for the remainder of this thesis.

System perspective on product development processes

Due to their characteristics, PDPs can be approached as a particular class of systems (Browning et al., 2006, p. 107). A **system** is generally defined as “an integrated set of elements, subsystems, or assemblies that accomplish a defined objective.” Systems are delineated by a system border, and exchange inputs and outputs with their environment. Changes to system parts cause dynamic effects, resulting in particular system behavior. (Maurer, 2007, p. 31)

According to Browning et al. (2006, pp. 108–109), individual projects as systems can be decomposed into five interrelated **project subsystems** (Figure 2-3), which can be further decomposed into individual elements and relationships between them: The **process system** represents the work done and deliverables produced. The **organization system** contains the people assigned to do the work to create the **product** system, which represents the desired result. The **tool system** describes technologies and support used by people within the process system. The **goal system** sets the requirements and context for the project. Within the scope of this thesis, the focus lies on the process and organization system.

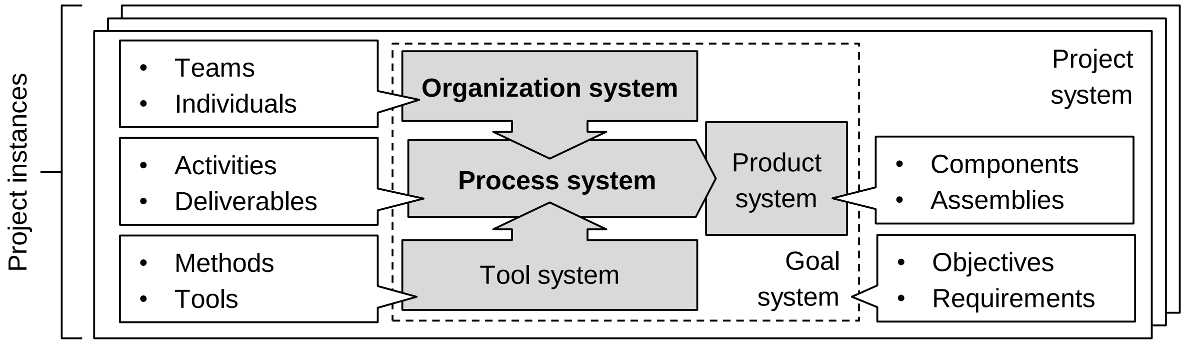


Figure 2-3: Partial systems of projects (based on Browning et al., 2006)

2.3.2 Complexity of product development processes

Based on the preceding definition, characterization, and classification of PDPs, this section discusses complexity as a significant characteristic of PDPs (cf. Maier & Störrle, 2011; Sheard & Mostashari, 2010, p. 938). The two facets of complexity highlighted in this section are the **structural complexity** of process models and **variety** between project instances.

Structural Complexity

A multitude of definitions exists for the term "complexity" without consensus, as they cater to different perspectives and address different facets (Kasperek, 2016, p. 18; Lindemann et al., 2009, p. 25). In general, complexity is a property of systems as defined earlier in section 2.3.1 and can be defined by a system consisting of *multiple parts*, having a number of *connections between these parts*, exhibiting *dynamic interactions* between these parts, and the resulting *behavior being unexplainable as the simple sum of the parts* (Oehmen et al., 2015, p. 5). While the former two aspects address structural, the latter two address dynamic (i.e. behavioral) complexity. Both perspectives are closely related, with structurally complex systems usually[14] exhibiting complex behavior, i.e. behavior which is "difficult to predict, analyze, describe, or manage" (de Weck et al., 2011, p. 185). In the context of processes, complexity is similarly defined as "*the degree to which a process is difficult to analyze, understand or explain. It may be characterized by the number and intricacy of activity interfaces, transitions, conditional and parallel branches, the existence of loops, roles, activity categories, the types of data structures, and other process characteristics*" (Kreimeyer, 2010; Cardoso, 2005; IEEE, 1990)

Comprehending a systems' structure is a crucial aspect for predicting its behavior (Oehmen et al., 2015; Maurer, 2007). In light of this thesis' objective, the focus lies on **structural complexity**, which with respect to the general definition by Oehmen et al. (2015) above is determined by the size of the network formed by system elements and dependencies as well as their respective variety (Lindemann et al., 2009, p. 29; Bosch-Rekveldt et al.,

[14] The source also states that the opposite is not true: structural complexity is not a prerequisite for behavioral complexity

2011, p. 730). Regarding PDPs, this relates to the partial project systems, e.g. the number and density of the activity network in the process system or the number of stakeholders in the organization system (cf. Bosch-Rekveldt et al., 2011).

In the context of complexity, Ramasesh & Browning (2014, pp. 191–197) provide a conceptual framework to support the identification and handling of "knowable unknown unknowns" in development projects to reduce project failures: Knowable unknown unknowns are foreseeable **uncertainties** which for some reasons are not identified by project managers a priori. This framework further differentiates between **element** and **relationship complexity,** applicable to all five project subsystems (cf. Table 2-2). The general assumption is that an increased amount of complexity increases the likelihood of encountering unknown unknowns in projects. The framework further differentiates complexity from **complicatedness**, which is more observer-dependent and subjective. Both may correlate, but without a generalizable causal relationship. For example, the complicatedness of a PDP depends on the ability to understand the process, e.g. the ease with which cause and effect relationships between elements can be identified. There is no distinct threshold of numbers of elements and dependencies to designate a system or process as complex, but it depends on the impact complexity has on people in terms of system understanding (Maurer, 2017, p. 24). Even systems consisting of ten elements can be difficult to model and manage manually (Browning, 2001, p. 302).

Table 2-2: Sub-factors of complexity (Ramasesh & Browning, 2014, p. 193)

Element complexity	**Relationship complexity**
• Number of project elements • Variety of project elements • Internal complexity of project elements • Lack of robustness of project elements	• Number of relationships among project elements • Variety of relationships among project elements • Criticality of relationships among project elements • Internal complexity of relationships among project elements • Externality of relationships

As thus implied, structural complexity impedes (structural) process **transparency**, which is the foundation for process understanding and process management (Vom Brocke & Sonnenberg, 2011, p. 56). Maintaining an overview of complex design processes is a challenge (Clarkson & Eckert, 2005, p. 3). Transparency is impacted, for example, due to ambiguity being introduced when managers are unaware of elements within the projects, and propagating consequences of actions are difficult to predict (Marle & Vidal, 2016, pp. 58–59).

In light of these properties, system complexity severely affects decision processes related to the complex system under investigation, either through making **wrong decisions** or being **unable to make decisions** at all. Further negative aspects of high complexity in projects are **long duration** as well as **frequent crises** and **product changes**. On the other hand, effective management of complexity can provide competitive advantages. (Maurer, 2017, p. 26)

Management of structural complexity requires a systematic approach (Maurer, 2017, p. 113). Therefore, Maurer (2017, pp. 113–142) presents a **generic approach** for implementing complexity management in general and structural complexity management in particular. The approach integrates several generic **strategies and methods** (cf. Lindemann et al., 2009, pp. 29–36), such as **acquisition** and **evaluation** of complexity of the system under investigation using modeling approaches (e.g. Design Structure Matrices), creating comprehensible **system views** to increase transparency (either through isolation of specific system parts or aggregation), **avoiding** and **reducing** complexity, and **managing** and **controlling** complexity (by applying e.g. structural analysis methods). Along similar lines, Oehmen et al. (2015, p. 7) suggest the following strategies for handling complex projects:

- Applying systems-oriented analysis
- Experimentation
- Interpretation
- Involving subject matter experts to analyze, manage, and explore different opportunities
- Active investigation of projects and their environment
- Creation of a beneficial environment for experimentation by managers

Graph-and matrix-based approaches to support modeling, analysis, and management of structural complexity in processes and projects are more thoroughly reviewed in section 2.4.

Variety as an aspect of complexity

In addition to structural complexity, **variety** is another aspect of complexity relevant within the context of this thesis. Variety generally is defined as the number of distinguishable states a system[15] can assume (Ashby, 1956, p. 126), emerging from the interaction of a variety of elements in a system (Malik, 2008). In the context of this thesis, a reference process model intended to serve as a template for the instantiation of different types of projects needs to be adaptable to the variety of possible project instances and consequently be able to assume these different states.

In order for a controller (here: reference process model) to be effective, its variety has to match the variety of the system to be controlled, as "only variety can destroy variety" ("Law of Requisite Variety", cf. Ashby, 1956, p. 207). From a management cybernetics perspective (Elezi, 2015, p. 27; Beer, 1959), two general controller design strategies are conceivable to address this variety (Elezi, 2015, p. 29):

1. Design the controller to have the same variety (complexity) as the system to be controlled in order for it to be stable (e.g. by modeling each project separately), with the controller being subject to the Law of Requisite Variety.
2. Design the controller to utilize the concepts of variety *amplification* (enhance controller to necessary variety) and *attenuation* (decrease possible variety of system to be controlled), through structural (e.g. modularization or constraints such as standardization and rules), conversational (e.g. team-problem solving), or cognitive (e.g. perceptual filtering or modeling to gain system comprehension) mechanisms (Schwaninger, 2006, pp. 15–16; Herrmann et al., 2008, p. 310) (cf. "Conant-Ashby theorem", Conant & Ashby, 1970)

[15] In the context of the previously elaborated structural complexity, this also refers to the different types of elements constituting a particular system, e.g. a project.

In real-life organizations, and also in the context of process and project management, the latter strategy represents a more feasible solution, due to the amount of complexity involved and the impossibility to precisely quantify it (cf. Elezi, 2015, p. 29; Beer, 1995, p. 24). As presented previously, projects are definition undertakings with unique circumstances and therefore represent an enormous amount of variety. As a consequence, on the one hand, modeling reference processes for each conceivable project variation represents tremendous effort, one the other hand, projects cannot be standardized or aggregated arbitrarily.

Therefore, as stated by the Conant-Ashby theorem (Conant & Ashby, 1970), a good controller must be a model of the system to be controlled, monitoring only the essential states and variables required for good control, and not the entire possible variety (Ashby, 1956, p. 197). However, the amplification and attenuation mechanisms **need to be designed properly**. Otherwise, they will "happen" in an uncontrolled manner (Beer, 1995, pp. 26–27).

The here briefly discussed theory of variety has profound implications for managing and tailoring PD reference processes. As the PDP RPM ideally represents the superset of activities necessary to carry out all projects within a PD organization, acting as a repository of knowledge (Lévárdy & Browning, 2009; Browning, 2018), variety causes further structural complexity in addition to the baseline structural complexity described previously, through the inclusion of additional elements (and relationships) which only become necessary in particular situations. In regard to process tailoring, while it further motivates the necessity for adequate and properly designed models and mechanisms to handle variety[16], this also implies that the variety that can be addressed explicitly is limited, as trying to capture all possible variety represents enormous effort.

2.3.3 Managing product development processes

Due to the previously described duality of processes in PD, two different functions are necessary for PD organizations: The **management of reference processes** (process management), as well as the **management of project instances** (project management). Both functions share a common, bi-directional interface as illustrated in Figure 2-4 (Browning, 2010, p. 321): On the one hand, reference processes provide starting points for the derivation of project-specific processes (via tailoring and planning), on the other hand, project experience, learnings, and best practices are fed back to process management in order to standardize, detail and improve the reference process(es) over multiple iterations of organizational learning (cf. Browning et al., 2006, p. 118). Therefore, standard processes provide a knowledge management mechanism for a learning organization (Browning & Ramasesh, 2007, p. 233; Crowston, 2000). Both functions together constitute the lifecycle of processes in PD (see Appendix A1.1 for a more detailed PDP lifecycle model).

While both functions can and should be distinguished due to the difference in objectives, conceptual similarities lie in the executed activities and used methods. For example, both utilize

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[16] "the result of an organizational process can not be better than the model on which the management of that process is based, except by chance" (Schwaninger, 2006, p. 19)

process modeling, in order to document project-specific plans and reference processes, respectively.

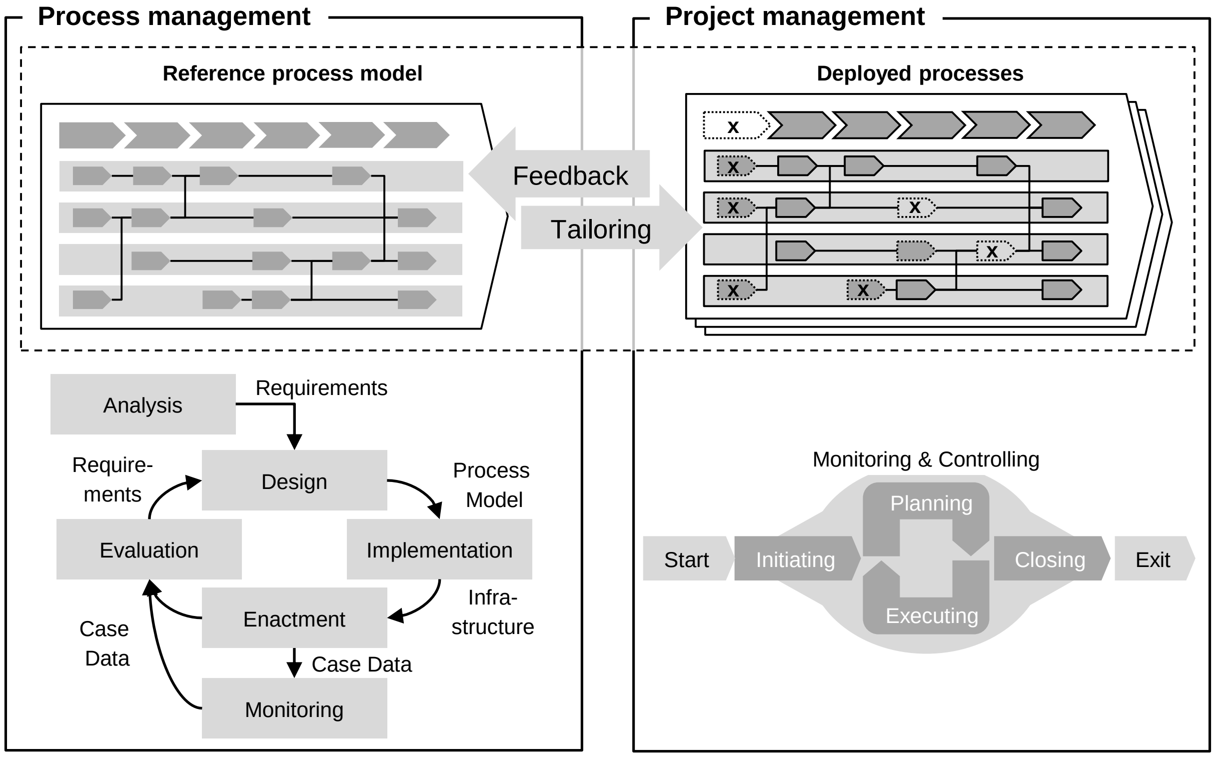

Figure 2-4: Interface between process- and project management (upper part) and respective activities (lower part, based on Mendling, 2008, p. 5; PMI, 2013, p. 50)

Process management

Process management is concerned with the creation and management of reference processes. Activities can be differentiated into **strategic** (mid-to-long-term) and **operative** (short- to mid-term) tasks. The focus of strategic tasks are process re-engineering, generation of process innovations, and the strategic design of the process organization, while operative[17] tasks address continuous improvement, low-level design of process execution, and resource management (Fink, 2003, pp. 179–180). According to Drawehn et al. (2008, pp. 10–13), typical **activities** of process management are:

- **Modeling and documenting** the procedural knowledge of an organization in a systematic, structured, and consistent manner
- **Analyzing and simulating** processes in order to improve and optimize processes
- **Monitoring and automatization,** e.g. using workflow-engines
- **Release and distribution** of process models and analysis results
- **Archiving** process models, as well as variants and versions thereof

[17] In PD organizations, responsibility for these tasks arguably lies with project management

Project management

In contrast to process management, project management is concerned with managing individual project instances of a PD organization by applying the appropriate knowledge, skills, tools, and techniques to a projects' activities to meet project requirements (cf. PMI, 2013, p. 5). Within an organization, the **project management office** (PMO) provides the governing structure to manage projects and fulfills a supportive, controlling, or directive role, depending on the chosen implementation. The PMO facilitates the sharing of "resources, methodologies, tools, and techniques." On the one hand, it provides templates, procedures and best practices, and on the other hand, collects and integrates data from different projects and monitors compliance with standards and procedures (via audits). (PMI, 2013, p. 11). In this capacity, the PMO functions as a means to exchange artifacts and procedural knowledge between individual projects.

According to the Project Management Institute (PMI, 2013, p. 5), project management consists of five interrelated process groups: **Initiating**, **planning**, **executing**, **monitoring** and **controlling**, and **closing** (cf. Figure 2-4). Of these, **planning** is the most relevant within the context of this thesis.

The ability to carry out design projects effectively and efficiently depends in no small extent on the understanding of the design managers as well as the quality and utility of project plans (O'Donovan et al., 2005, p. 61). Therefore, planning is essential (Wysocki, 2012). Kerzner (2013, p. 508) mentions four fundamental reasons for project planning: Elimination/Reduction of uncertainty, improving efficiency, obtaining a better understanding of the objectives, and providing a basis for monitoring and controlling activities. The planning subprocess contains tasks for defining, preparing, and coordinating the project plans and integrating them into an overall project management plan (PMI, 2013, p. 72). Planning can be further differentiated into different sub-activities, which in combination form the integrated project management plan (cf. PMI, 2013, p. 60, p. 73, p. 145; Kerzner, 2013, p. 510):

- Project **scope** planning
- Time planning (**scheduling**), including defining required activities and deliverables based on organizational reference processes, tailoring guidelines, and criteria
- **Cost** planning,
- **Human resource** planning (e.g. responsibility assignments),
- Creating further plans, e.g. for **risk**, **quality, procurement,** and **stakeholder management**

The selection and definition of processes and activities based on the applied **tailoring** represents input for several downstream planning activities related to time and resource planning, such as the estimation, scheduling, and monitoring of project work (PMI, 2013, 145-149). As projects unfold during their execution, plans are dynamic artifacts (Wysocki, 2012) and need to be iteratively checked, updated, and further detailed in a manner of progressive elaboration or "rolling wave planning" (PMI, 2013, p. 152). The created project management plan should include details regarding the tailoring decisions made, such as the selected processes, the level of implementation for each process, and the description of tools and techniques used in order to accomplish them (PMI, 2013, p. 77).

Besides the immediate goal of creating the aforementioned project plans, project planning should aim to create a sufficient **understanding of the "project landscape."** The thereby created advance knowledge of potential activities and their relationships (i.e. alternative courses of action) facilitates subsequent adaptability of projects in an agile manner. In combination with the use of adequate process modeling, this provides managers with “access to rich, organized, accurate, and integrated information” regarding the project subsystems introduced earlier. (Browning, 2014c, p. 22; Lévárdy & Browning, 2009, p. 605)

Collaborative project planning

As previously outlined in section 1.1.2, project planning and its subactivities require a **collaborative effort**, which is communication-intensive as it depends on inputs from project stakeholders with potentially differing views, which need to be collated and synchronized by project management. In order to address this issue, collaborative approaches have been developed, such as **Joint Project Planning Sessions** (JPPS) (Wysocki, 2012). JPPS represent intense, multi-day planning sessions, which are to be attended by different project stakeholders and moderated by an experienced facilitator. Workshop-based planning is seen to offer the following benefits (Hab & Wagner, 2017, pp. 109–112; Wysocki, 2012):

- Centralized and coordinated information acquisition through project management (group synergy)
- More accurate estimates (e.g. for activity durations)
- Increased completeness of information
- Stronger commitment to plans due to sense of ownership
- Increase of time allocated for planning and minimized distraction from daily work
- Creation of a shared vision of the project plan
- Direct visibility of planning results

2.4 Modeling and analyzing product development processes as complex systems

The following section introduces relevant modeling and analysis approaches suitable to address the complexity-related issues presented earlier. Therefore, general overviews of modeling and analysis approaches are given and concretized in light of PD processes.

2.4.1 Structural modeling of complex systems

In Systems Engineering, models are seen as indispensable for analyzing complex structures and relationships, in which consequences of an action are difficult to predict (Kossiakoff, 2011, p. 379; Lee, 2003, p. 30). Models and their structure-oriented examination are viable means to gain and increase understanding of complex systems and realities, e.g. to predict the effects of actions (cf. structural complexity, section 2.3.2) (Haberfellner, 2015, pp. 32–42, p. 133; Browning, 2002, p. 181). Particular suitable are graph- and matrix-based methods (cf. Browning, 2016) Modeling represents an essential step for systematic management and control of structural complexity (Maurer, 2017, p. 114; Heimberger, 2017, p. 34).

Models

A **model** represents a purpose-oriented, simplified representation analogous to an original, which enables deriving conclusions regarding the original object (*mapping*) (Lindemann, 2009, p. 333). Original objects can be of natural or artificial origin and can be models themselves. The attributes included in a particular model depend on the investigated problem as well as the model purpose as intended by the model creator or user (Haberfellner, 2015, p. 133). Attributes outside this purpose are not mapped, but additional descriptive attributes can be added as required (*reduction*). Models do not have general validity but fulfill a particular purpose for a) particular individuals, b) a certain timeframe, c) particular operations, or a combination thereof (*pragmatism*). (Stachowiak, 1973, pp. 131–133)

Models can be classified into different types, such as physical and **abstract** models, with the latter further differentiated into formal and non-formal models (Walden et al., 2015, pp. 183–184). Within the context of this thesis, the focus lies on **formal** models represented in the form of **graphs** or **matrices**. A models' formality allows its manipulation through the use of automated software tools (Paige et al., 2014).

The concept of a model needs to be further differentiated from its **representation** in the form of **views**, as can be seen in (model-based) systems engineering (cf. Estefan, 2008). One example is the OMG Systems Modeling Language (SysML), which provides multiple views to separately describe a systems structure and behavior (e.g. block, activity, and use case diagrams) (Yamada, 2009). Model views are used to present a models' contained information as understandable as possible, with views corresponding to one or more stakeholder concerns (Yamada, 2009, p. 1). In general, the concept of system views allows to provide manageable amounts of information to model users, thereby improving transparency as only specific aspects of a system are highlighted (e.g. by presenting only parts of a system or aggregating system elements) (Maurer, 2017, p. 121). A view displays an extracted subset of model attributes using a specific form of visualization, such as matrices, tables, graphs, or other diagrammatical depictions (Browning & Ramasesh, 2007, p. 220). Sets of model views can be integrated to form architecture frameworks (cf. e.g. the Department of Defense Architecture Framework) (Browning, 2009, p. 71).

Metamodels

Metamodels represent the basis for formal modeling. "*A metamodel is a description of the abstract syntax of a language, capturing its concepts and relationships, using modeling infrastructure*" (Paige et al., 2014). Metamodels define what can be expressed in valid models created using a particular modeling language (Seidewitz, 2003). A metamodel thus defines the language constructs required and allowed to create a particular model instance (syntax), without providing information regarding the construct application (Jeusfeld, 2009; Höfferer, 2007, p. 1625). In contrast, **ontologies** describe the specification of a vocabulary for a particular domain of interest, i. e. definitions of objects such as classes, relations, and functions (semantic) (Höfferer, 2007, p. 1625; Gruber, 1993). However, this differentiation is not always clear, and the exact relationship between both concepts is subject of scientific debate without consensus (cf.Höfferer, 2007, pp. 1624–1625; Kühne, 2006, pp. 381–382).

Defining and using metamodels provides several **advantages**, such as: Documenting and supporting the evolution of a language, fostering the creation of well-formed models, automated model transformations, formal model property checking, and determination of the level of abstraction of created models. (Paige et al., 2014, pp. 6–7; Henderson-Sellers & Gonzalez-Perez, 2010)

Graph- and matrix-based representation of structural models

The particular models utilized within this dissertation to capture structural system aspects are represented in the form of **graphs** or **matrices**. A graph $G = (V, E)$ consists of a number (n) of vertices V (henceforth called nodes) and edges E. Each edge connects either exactly two nodes or a single node with itself. (Diestel, 2017, p. 2)

Capturing multiple node and edge types requires **n-mode multigraphs** (Wasserman & Faust, 1994, pp. 36–41, pp. 145–146). These are represented using **typed attributed graphs** (Heckel, 2006; Helms, 2013, pp. 55–56; Helms & Kissel, 2016, pp. 985–986). The use of attributes for nodes and edges allows the storage of further information (e.g. the ID, name, or mean cost of a process activity). The types of nodes and edge types, and respective attributes utilized to realize a particular model are defined in its metamodel. Graphs and matrices are equivalent representations of the same model and can be transformed into each other via the graphs (G) $n \times n$ sized **adjacency matrix** $A(G)$ (Tittmann, 2003, p. 12). Representing typed attributed graphs as matrices requires the use of a combination of different (adjacency) matrices (Browning, 2016; Lindemann et al., 2009):

- **Design Structure Matrices (DSMs)** are the oldest type of matrix used to model complex systems (cf. Steward, 1981). DSMs are square matrices, dependencies between a single type of elements (domain) (Eppinger & Browning, 2012; Lindemann et al., 2009). Each matrix cell, if filled, represents a dependency[18], which can be binary or numerical, e.g. to capture weighted relationships, as well as directed or undirected.
- **Domain Mapping Matrices (DMMs)** represent mappings between two different element types (Danilovic & Browning, 2007).
- **Multiple Domain Matrices (MDMs)** are superordinate to both and used to model systems consisting of multiple element types connected by different dependencies (Maurer, 2007). An MDM describes the edge types connecting different element types[19] , and structures the individual DSMs and DMMs used to describe the actual dependencies. MDMs enable the derivation of indirect dependencies between domains through matrix multiplication of acquired DSMs and DMMs (cf. Lindemann et al., 2009, p. 105; Maurer, 2007, pp. 112–118).

Matrices are beneficial as most programming languages support their storage and processing (Illik, 2009, p. 151). DSMs are often used to model product, organization, and process

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[18] While different conventions are used, this thesis follows the convention of “inputs in columns”, meaning dependencies are read from rows to columns.

[19] Therefore, an MDM more closely represents a metamodel

structures (cf. partial project systems, section 2.3.1) (cf. e.g. Browning, 2016). Matrix-based representations also form the basis for the approach of *Structural Complexity Management* (cf. Lindemann et al., 2009).

There is debate regarding which representation is preferable. On the one hand, matrices are seen by some as more beneficial (Göpfert, 1998, p. 25). Eppinger & Browning (2012, p. 9) highlight **benefits** of a compact representation of complex networks, visualization of patterns, intuitive understandability, access to analysis techniques, and flexibility. On the other hand, matrix representations do have several **limitations** (Kreimeyer, 2010, pp. 53–54):

- Attributes of edges are representable only to a limited extent
- Logic operators in network structures are difficult to represent
- Conditions for elements and dependencies cannot be considered in existing notations (e.g. modeling commonalities/variability for variant design or alternative process paths)
- Element decomposition and hierarchy-spanning dependencies are difficult to describe consistently
- Limitations in terms of the manageable amount of data contained (Browning, 2001, p. 302)

In general, matrices are seen as more suitable for information acquisition, while (force-directed) graphs represent a more intuitive visualization (Lindemann et al., 2009, pp. 95–98). **Graph representations** are becoming more feasible and applicable as computational power and support increases, with demand driven by requirements from Big Data analyses (Maurer, 2017; Helms & Kissel, 2016; Helms, 2013; LaValle et al., 2010). These representations enable to mitigate some of the previously mentioned limitations.

Ultimately, however, the choice of representation(s) depends on the investigated problem, available data set, the intended purpose, and the experience background of the model user, prohibiting a general answer as each representation brings individual strengths and weaknesses (Keller et al., 2016, pp. 74–75; Parraguez, 2015, p. 36; Wyatt et al., 2014).

2.4.2 Modeling complex product development processes

As described in section 2.3.1, PDPs can be approached as a particular class of systems, consisting of subsystems, elements, and relationships between them. Consequently, process models as representations of these systems represent a **particular class of models**. As processes are virtual and temporal objects, approaches for their management rely on models in order to describe their characteristics and improve them (Parraguez, 2015, pp. 26–27; Buede, 2009, p. 73; Vajna, 2005, p. 369).

Based on the preceding definitions of systems, processes, and models, process models within the context of this thesis are defined as models representing the **structure (network) of PDPs** in reality through their abstract formalization as graphs, containing different types of nodes, edges, and corresponding attributes. Models of this type combined with the analysis concepts presented subsections 2.4.3and 2.4.3 support the management of PDPs in order to cope with complexity and uncertainty caused by internal and external influences (Kasperek, 2016; Browning et al., 2006; Smith & Morrow, 1999).

Value of process models and process modeling challenges

While a purely mechanistic design of innovative organizations and processes is not possible, an **appropriate amount of process structure** yields efficiency by focusing on value-adding activities (Browning et al., 2006, p. 106, p. 119; Tatikonda & Rosenthal, 2000; Spear & Bowen, 1999; Dougherty, 2001). In this capacity, process models are an essential factor contributing to a projects' success, i.e. completing on schedule, within budget, to specifications (Browning et al., 2006, p. 114). Process models can contribute to navigating and managing complex PDPs (Wynn & Clarkson, 2017), understanding areas of uncertainty and ambiguity in projects (Browning et al., 2006, p. 114; Ramasesh & Browning, 2014), and to the "engineering" of process systems (Browning & Ramasesh, 2007, p. 218). Externalized process models lay the basis to share and compare assumptions (Browning et al., 2006, p. 114), and to align process participants' mental models, in order to enable coordination, i.e. the management of dependencies between activities (Wynn & Clarkson, 2017, p. 2; Malone & Crowston, 1994). The importance of process models increases with complexity and innovation (Wynn & Clarkson, 2017; Zhang et al., 2015). In particular reference process models provide scaffolding for knowledge management (Browning et al., 2006, p. 124). In addition to these intrinsic motivations, process documentation is often mandated by external standards (Browning et al., 2006, p. 109).

Browning & Ramasesh (2007) elaborate a taxonomy of process model purposes (cf. Table 2-3). These are further detailed by Browning (2010), resulting in 28 process model concerns (e.g. identifying "ripple effects" of process changes, tailoring, filtering activities, allocating resources) related to five different roles (e.g. process owner, project planner). Process models created for one of these purposes may not be applicable for another, as the fitness of a process model depends on the alignment of its content and structure with a particular purpose (Browning, 2009, p. 75).

Table 2-3: Taxonomy of purposes for process models (Browning & Ramasesh, 2007)

Category	Purposes	
Project visualization	• Actions, interactions, and commitments	• Customized "views"
Project planning	• Making commitments • Choosing activities • Structuring the process	• Estimating, optimizing, and improving key variables (time, cost, etc.) • Allocating resources
Project execution and control	• Monitoring commitments • Assessing progress	• Re-directing • Re-planning
Project development	• Continuous improvement • Organizational learning and knowledge management	• Training • Metrics • Compliance

In order to be useful, process models in general should be "simple, robust, easy to control, adaptive, complete, and easy to communicate with" (Browning, 2009, p. 75; Little, 1970) Browning et al. (2006, p. 117) points to several general objectives for PDP models (Table 2-4), which underline the necessity for capable, extensive process modeling frameworks to capture rich content.

Table 2-4: Process model objectives (Browning et al. 2006, p. 117)

Objective	Description
Elements	Represent the variety of activity attributes required to support the spectrum of model purposes
Relationships	Represent meaningful and varied relationships between activities
Maintenance	Be quick and easy to change and update, where appropriate by respective stakeholders
Computerization	Enable computer-based model building, storage, analysis, and presentation
Views	Enable visualization and comprehension by varied users from different perspectives
Consistency	Provide a consistent representation of all relevant information in a formal structure
Planning	Support project planning, including process tailoring and activity selection, staffing, resource loading, budgeting, and scheduling
Empowerment	Enable project visualization, communication, and informed decision making at all levels
Adaptation	Support process agility and adaptation
Integration	Integrate easily with other process models in other parts of the organization and with other activity-based cost, schedule, and risk models in the organization
Simplicity/ Expandability	Built of simple elements that can collectively model more complex processes; object-oriented; holonic
Improvement	Include allowances for improvement, particularly in the form of an improvement loop
Error detection	Automatically check and flag integration problems and missing information, or provide assistance in this regard

As illustrated, there is considerable value to be found in process modeling. However, according to Browning et al. (2006, p. 109), at least four major barriers are preventing companies from establishing process documentation to describe work methods and support coordination, which often results in hostility towards process modeling:

- Too abstract and ambiguous (standard) processes, providing umbrella terms to e.g. to facilitate satisfying process conformance auditors (Browning & Ramasesh, 2007, p. 234)
- Conventional existing modeling techniques such as flowcharts or Gantt charts fail to capture important relationships and thus do not foster self-coordination of employees
- High resource and time investment in model-building creates pressure to justify return-on-investment and results in cumbersome to maintain and often anachronistic process descriptions
- Company policies force employees to work with processes that do not fit the reality of their work, causing constant cognitive dissonance

Approaches for modeling product development processes

Overall, no single best process modeling approach exists. Instead, a multitude of modeling approaches is available, offering different advantages and disadvantages (Wynn & Clarkson, 2017; Browning & Ramasesh, 2007). The majority of process modeling literature addresses **business processes** and does not consider the particularities of PDPs. A more focused body of work addresses **PDP modeling** in particular, which is for example reviewed in Browning & Ramasesh (2007) and Wynn & Clarkson (2017). These approaches emphasize PDP characteristics (cf. section 2.3.1), such as project **uniqueness** over repetition, **information as basis for activity dependencies**, **transdisciplinarity** of PD, **parallelization** and **overlapping** of activities, increased **ambiguity** and **uncertainty**, as well as the need for higher **flexibility** and **agility** in planning and execution. (Browning, 2018, p. 2)

According to Browning & Ramasesh (2007, p. 218), most PDP-focused modeling approaches use **activity networks** as their foundation. These models represent the network structure of PDP activities and dependencies between them, indicating their logical precedence within the process (PMI, 2013, pp. 156–157). The **importance of information** flows and dependencies between activities can be traced to the social nature of PDPs, with the generation of knowledge and transformation of information as the primary type of work required in order to transform system requirements into specifications (Parraguez, 2015, pp. 20–21). Many existing modeling approaches within this scope (for reference as well as project-specific process modeling) are explicitly based on abstract graph structures and representations (Browning, 2009), e. g IDEF0, IDEF3, PERT charts, value stream maps, BPMN, DSMs, Signposting (Wynn et al., 2006). Others address dependencies between activities implicitly (e.g. Gantt-Charts, cf. Browning et al., 2006, p. 75).

Further overviews and comparisons of modeling languages/techniques – for business processes and PDPs – can be found in the following references: Baumberger (2007); Heimberger (2017); Roelofsen (2011); Browning (2010); Browning & Ramasesh (2007); Aguilar-Savén (2004); Amigo et al. (2013); Wynn & Clarkson (2017); Kreimeyer (2010). The different available modeling languages and techniques emphasize different perspectives (i.e. partial systems) of processes or interfaces thereof. Organization and product subsystems are comparatively easier to model due to their directly observable elements and quantifiable relationships, in contrast to the process system (Parraguez, 2015, pp. 105–106). Table 2-5 summarizes common modeling approaches that address individual partial systems.

Table 2-5: Common approaches for modeling partial systems (based on Heimberger, 2017, pp. 27–30)

Partial system	Modeling approach
Process	Structured Analysis and Design Technique (SADT), SIPOC Diagrams, IDEF0, IDEF3, event-driven process chains (EPC), Business Process Model and Notation (BPMN)
Organization	Organizational breakdown structure (OBS), Responsibility assignment matrix (RAM/RACI-matrix), Role descriptions
Product	Different modeling techniques depending on the level of abstraction, e.g. requirements (lists, dependencies matrices, e.g. quality function deployment), functional (Use-Case Diagrams, relation-oriented function modeling), working principles (e.g. morphological box, sketches), and components (e.g. geometry models or simulation models)
Tool	Data flow diagrams, IT infrastructure diagrams
Goal	Goal hierarchies, House of Quality (Quality Function Deployment)

Based on a comparison of thirteen structure-based process modeling techniques, Kreimeyer (2010, p. 112) synthesized a **generic metamodel** consisting of a set of domains with corresponding entities (Table 2-6) and dependencies between them (not depicted), which are commonly used for process modeling and analysis. The resulting domains do not directly coincide with the partial systems described in Table 2-5 but can be mapped accordingly. The domains are equivalent to node types within graph-based models.

Table 2-6: Common domains and entities (based on Kreimeyer, 2010, p. 112)

System	Domain	Description and entities	Synonyms and further terms
Process	*Task*	Describe the execution of work done in the project	Function, method, activity, gate-way, transition, work package, etc.
	Event	Non-persistent occurrences in time representing a certain status or progress	Message, order, initial/final node, label, place
	Time	Persistent time issues	Attribute, duration, start/end/ average time, milestone, phase
Product/ Goals	*Artifact*	Intermediate and final input/output objects in the process	Input/output, object, product, data, parameter, information
Organization	*Org. Unit*	Human resources in their respective ordering	Staff, responsibility, team, pool, lane, actors, roles, committee
Tool	*Resource*	All non-human resources necessary to enable process execution	IT-Systems, equipment, knowledge

Similarly, Browning et al. (2006) attest existing modeling approaches significant **overlaps**, as approaches often integrate attributes and elements which are also addressed in different ones. They propose a generalized object-oriented framework focusing on **activities** (work packages) and **deliverables** (work products) as **primary element types** (objects) for modeling PDPs, which are enriched by attributes as required (cf. Figure 2-5). Attributes for activities as well as deliverables extend to **reference** as well as **deployed processes**, therefore enabling the management of both within the same framework. The generalized framework includes further concepts, such as **master/shadow** objects, which appear in a process multiple times at different locations. Shadow objects inherit all attributes from their master object by default, unless stated otherwise. The framework also includes **modes**, in case different variants of an object exist.

In the context of this framework, the term **process architecture** refers to the structure of activities, relationships between them, as well as the principles and guidelines governing their design and evolution (Browning, 2009, p. 75). At a minimum, three types of relationships constitute the process architecture (Browning, 2016, p. 34): 1) hierarchical decomposition of a process into activities, 2) input-output dependencies between these activities, and 3) other types of activity dependencies.

Activities

- Name
- Parent
- Constituents
- Mode
- Shadowing
- Deployment
- Version Number
- Brief Description
- Inputs
- Outputs
- Entry Criteria
- Exit Criteria
- Verifications
- Standard Process Metrics
- Deployed Process Metrics
- Tools
- Standard Roles
- Deployed Roles
- Basis for Requirement
- Rules
- References
- Standard Risks
- Deployed Risks
- Narrative Description
- Tailoring Guidance
- System Identification Number
- WBS Element Association
- Master Owner
- Standard Owner
- Deployed Owner
- Change History
- Change Notifications

Deliverables

- Name
- Parent
- Constituents
- Mode
- Shadowing
- Deployment
- Version Number
- Brief Description
- Suppliers
- Customers
- Key Criteria and Measures of Effectiveness
- Requirements
- Acceptance Criteria
- Standard Process Metrics
- Deployed Process metrics
- Format
- Medium
- Artifact
- Rules
- References
- Narrative Description
- Tailoring Guidance
- System Identification Number
- WBS Element Association
- Change History
- Change Notifications

Figure 2-5: Fundamental building blocks of PDP models with associated attributes (adapted from Browning et al., 2006, p. 122; Browning, 2009, p. 82)

The Process Architecture Framework

While the aforementioned modeling approaches address one or more partial project systems[20], they are rarely integrated into a common model (Browning et al., 2006, p. 108). The generalized framework presented above sets the basis for an integrative approach to modeling and managing PDPs, in the form of a **Process Architecture Framework (PAF)** (Browning, 2009, 2010, 2014b). The PAF concept is prompted by the fact that process information is often stored in individual process models with significant overlap, which are used by different project stakeholders. These individual instances have to be built and require constant synchronization and maintenance, or otherwise endanger effective project management (Browning, 2009, p. 70, 2014b). Furthermore, as mentioned earlier, a single process model is insufficient, on the one hand, to cater to all potential purposes, and on the other hand, to contain and convey large amounts of information in a comprehensible way (cf. model views, section 2.4.1).

Therefore, Browning (2014b, p. 229) argues that any representation of a process model as described above should merely be specialized "view" of an underlying, rich process model, which caters to the concerns and purposes of a particular model user. Views are derived from a centralized repository, set up using the generic framework described above and containing up-to-date data. A view displays only a relevant subset of the process models content and structure using an appropriate graphical notation (Browning, 2009, p. 1). Thus, the process repository itself can be almost arbitrarily complex, with this complexity being reduced through views. The concept furthermore promotes the distinction between content and representation in order to overcome the constraints of individual representations when building the process

[20] Cf. Heimberger, 2017, pp. 54–58 for discussion of system-spanning modeling approaches

model (Browning, 2018, p. 2). The PAF structures possible views according to model users concerns, with four proposed categories (Browning, 2014b, p. 236):

- **Overall** (e.g. summary of process scope and purpose, as well as a dictionary)
- **Operational** (e.g. activity schedule, views of project performance expectations, responsibility assignment, process constraints, contingencies, and tailoring guidance)
- **Content** (e.g. activity network, WBS, tools, standard roles)
- **Technical standards** (e.g. technical standards profile and forecast)

The PAF will evolve over time, due to additional views being proposed and developed by model users (Browning, 2014b, p. 236).

2.4.3 Theoretical foundation of structural analysis

The analysis and management of structural complexity using the representations described in section 2.4.1 are based on **graph** and **network theory**, which are distinct yet closely related research fields (Kreimeyer, 2010, p. 46, p. 55).

Graph theory treats graphs as abstract mathematical concepts (cf. section 2.4.1), focusing only on answering questions regarding topological aspects of structures without interpretation of the underlying meaning of the graph (Gross & Yellen, 2008; Newman, 2003, pp. 169–171; Turau & Weyer, 2015). Therefore, graph theory provides the foundation for the description and analysis of large network structures (Kreimeyer, 2010, p. 48). Building upon graph theory, **network theory** uses graphs to model and analyze real-world structures (e.g. social, information, technological or biological networks) (Stegbauer, 2010; Wasserman & Faust, 1994, pp. 93–94; Kreimeyer, 2010, p. 55). Network theory thus focuses on global properties of large-scale networks, making predictions regarding the networks' behavior by applying concepts from graph theory and statistics to describe networks (Kreimeyer, 2010, p. 55; Newman, 2003, pp. 169–171).

The analysis of complex systems focuses on **identifying and characterizing network characteristics** based on a systems **structure** (interconnectedness of elements) and **composition** (characteristics of the constituent elements and their attribute diversity) (Parraguez, 2015; Wasserman & Faust, 1994, p. 29). The focus of this thesis is on the analysis of the system structure. The composition is implicitly regarded, e.g. through the consideration of different nodes and edge types and attributes within particular analyses.

Kreimeyer (2010, p. 52) defines a **structural characteristic** as a particular constellation (i.e. pattern) of nodes and edges in a graph (cf. Maurer, 2007, p. 123; Cardoso, 2006). It gains meaning through its relation to the actual system it is a part of (must serve a special purpose in this context) (Boardman & Sauser, 2006) and possesses significance only in the context of the system it describes. Structural characteristics can be identified on different levels: **individual**

nodes (e.g. different Centralities) and **edges**, **subgraphs** (partial graphs), and the **entire network**[21] (Parraguez, 2015; Wasserman & Faust, 1994, pp. 17–21, pp. 25–26).

Metrics generally are a way to represent a “quantitative or qualitative measurable” aspect of an issue in a condensed form (Horváth et al., 2015). In the case of this work, this addresses the quantification of the aforementioned **structural characteristics**, for which an overview is given in Table 2-7. Sets of related metrics are organized in **measurement systems** (e.g. scorecards) (Kreimeyer, 2010, p. 80), which are “semantically related, […] complement each other and […] are intended to represent an empirical issue in a well-balanced and complete way” (Lachnit, 1976). Metrics for quantifying structural characteristics have been proposed by different disciplines and represent a fragmented area of research, as no consistent body of metrics, naming conventions, or taxonomy has been generated yet (Parraguez, 2015, p. 38; Kreimeyer, 2010, p. 85; Mendling, 2008, p. 114; Estrada et al., 2010). Different types of metrics can be differentiated: **Basic** structural metrics are directly derived from structural characteristics from node (e.g. connectivity of graphs using different centrality measures) and edge perspectives (paths) (Kreimeyer, 2010, pp. 138–139). **Combined and special** structural metrics are set up from these to cater to more specific evaluations, e.g. using statistical evaluation such as the mean path length of all paths in a network (Kreimeyer, 2010, pp. 140–146). Calculated metrics can be **visualized** in different ways, for example as an individual number (metric per element type, such as size or density), table (metric per pairs of node types, e.g. interfaces), portfolios or histograms (distribution of a metric for all elements of a particular type) (Kreimeyer, 2010, p. 145).

Overviews of structural characteristics (and thus, metrics) from different disciplines can be found in Behncke (2017) (focusing on cluster metrics), Parraguez (2015), Biedermann (2014), Kreimeyer (2010, pp. 61–62), Maurer (2007, pp. 199–239), and Wasserman & Faust (1994). Further properties from a network-theory perspective are collated for example by Newman (2003) and Costa et al. (2007), such as the distribution of node degrees and shortest paths (“small-world effect”, affecting the speed of information distribution) (Kreimeyer, 2010, p. 56), the network resilience (sensitivity of the network to removal of nodes), or recurring patterns (“motifs”, Milo et al., 2002, p. 824).

To support the identification of structural characteristics, various methods and means have been developed based on graph- and matrix-based **representations** and **theoretical foundations** (graph and network theory) presented above. **Matrix-based** analysis approaches are often related to optimizing system structures (Parraguez, 2015, p. 36; Browning, 2001), such as sequencing (e.g. reducing the number of feedback loops in flow networks), tearing (identifying elements obstructing sequencing), banding (rearranging rows and columns to group parallel elements), and clustering (identifying mutually related elements), using primarily DSMs (cf. Kreimeyer, 2010, p. 51; Maurer, 2007, pp. 225–240). Browning (2016) presents a recent review of examples of the aforementioned approaches applied to product, organization, and process DSMs.

[21] The overall network can be characterized by single metrics as indicated in Table 2-7 (e.g. size as the number of all nodes and/or edges), or through the distribution of node metrics, e.g. the distribution of the node centrality.

In contrast to matrix-based approaches, the direct application of **graph theory** to analyze networks allows increased flexibility and the calculation of a variety of specific **structural metrics** on different levels[22] (Parraguez, 2015, pp. 36–37). The calculation of structural metrics can be realized and automated, e.g. via **graph rewriting** using object-oriented graph grammars (Helms & Kissel, 2016; Helms, 2013). This approach allows the algorithmic evaluation and modification of graph patterns and element attributes using graph rewriting rules.

Table 2-7: Exemplary overview of general structural metrics based on Heimberger (2017, pp. 36–37), Parraguez (2015, pp. 38–43), and Behncke (2017, pp. 128–129)

Level	Metric	Description
Entire graph / Subgraph	*Size*	Number of nodes of a network
	Relational Density	Relative connectedness of the network
	Centralization	Distribution of centrality in a network
	Diversity	Number of node or edge types (for n-mode multigraphs)
	Distance	Length of shortest path between two nodes
	System Perspective (Clustering quality)	Quotient of number of dependencies within a cluster and possible dependencies within the entire system (Behncke, 2017)
	Cluster Perspective (Clustering quality)	Quotient of number of unoccupied dependencies within clusters and unoccupied dependencies in the entire system (Behncke, 2017)
Individual nodes	*Degree Centrality (Active/Passive Sum/Activity/ Criticality)*	Number of nodes connecting a node to other nodes. Further differentiation between outgoing (*active sum*) and incoming (*passive sum*) edges. Comparison of multiple nodes via *activity* (quotient of active/passive sum) and *criticality* (product of active/passive sum).
	Closeness Centrality	Structural closeness of a node to all other nodes of a network
	Betweenness Centrality	Number of times a particular node lies on the shortest paths between all other node pairs in a network
	Node Information Centrality	Combines Closeness Centrality and Betweenness Centrality by counting all possible instead of shortest paths between node pairs
	Eigenvector Centrality	Centrality of a node *k* in relation to the centrality of directly adjacent nodes
Individual edges	*Bridge edge*	Single edge connecting two subgraphs (e.g. clusters)
	Multidimensional scaling	Method to measure closeness or similarity between each pair of nodes (no actual metric)
	Information centrality nearness matrix	Alternative to multidimensional scaling (no actual metric)
	Line graph	Computational method for turning edges into nodes and vice versa (no actual metric)

[22] However, it has to be noted, that matrices can be used to calculate metrics as well, e.g. modularity metrics, active/passive sums, or centrality metrics (cf. Browning, 2016). The main difference lies in the implementation of the calculation algorithms.

2.4.4 Structural analysis of product development processes

Based on the previously introduced foundation for structural analysis of matrix- and graph-based models, this section illustrates the application of said approaches to the domain of PDP analysis. According to Kreimeyer (2010, pp. 172–177), structural analyses can contribute to eight different yet interrelated goals: Planning, Resource consumption, Quality, Flexibility, Organizational decomposition, Interfaces, Transparency, Decision Making.

The overviews of approaches given in this section are intended to be illustrative of the current state in research, rather than exhaustive.

Matrix-based structural analysis of product development processes

As described in section 2.4.3, matrix-based approaches are mostly used to analyze and optimize the **overall structure of a system** (i.e. the arrangement of elements) (Eppinger & Browning, 2012, p. 5). Matrix-based structural process analysis has predominantly focused on analyzing **organizational** and **process** (activity) DSMs (Browning, 2016). The primary analysis methods are **clustering** of product and organization networks, due to predominantly undirected/ symmetrical dependencies and **sequencing**, of process networks, due to directed or temporal dependencies (Eppinger & Browning, 2012).

Browning (2016) provides an overview of DSM, DMM, and MDM based approaches related to these three domains as well as cross-domain applications. For example, Organization DSMs are clustered in order to determine organizational structures, to optimize work allocation, or sequenced to identify cooperation groups between organizational units. Process DSMs are used for sequencing of activities, scheduling of project workflows, as well as clustering of activities or design decisions. For example, sequencing is used to reduce process duration by identifying iterations. Some existing work has compared architectures of partial systems, such as Sosa et al. (2004), comparing product with organization DSMs in order to identify the alignment of both architectures. While the described examples have focused on individual project subsystems, many applications require **cross-system** (i.e. cross-domain) **dependencies** using DMMs, such as mapping activities to individuals in order to determine organizational structures, e.g. using clustering analysis (Browning, 2016, p. 37). Recognizing the importance of inter- and intra-domain dependencies, the MDM approach has been developed to represent them simultaneously (Browning, 2016, p. 39). MDMs are used for a variety of applications, e.g. to support the management of knowledge, design decisions, and communication, with great potential seen in the area of big data (Browning, 2016, p. 39).

Metric-based structural analysis of product development processes

Several authors have applied the general concept of quantifying structural characteristics via structural metrics (cf. section 2.4.3) to the analysis of PDPs, with a selection of related work presented in Table 2-8 (using matrix or graph-based approaches). Furthermore, dedicated approaches also exist within the domain of business process analysis, but have been omitted in this overview (cf. e.g. Mendling, 2008).

Table 2-8: Overview of related work for analyzing product development processes using structural metrics (alphabetical order)

Reference	Description
Bartolomei, 2007	Application of network metrics (average node degree, average path length, clustering coefficient) to a multi-domain network (stakeholders, technical components, activities, functions, and objectives) at different times over the development project.
Batallas & Yassine, 2006	Analysis of information flows in PDP to identify critical individuals of particular roles (Degree, closeness, betweenness centrality, brokerage measures: Internal and external Coordinator, Representative, Gatekeeper, Liaison).
Bradley & Yassine, 2006	Analysis of information flows within the organizational system of the design process of a jet engine (Individual centrality, group centrality, “Key players” metric).
Braha, 2016	Realization that complex engineering systems exhibit the “small-world” property (primarily local connected and modular, with short average path lengths between any node pairs, resulting in fast information transfer capacity). Analysis of error and change propagation in complex engineering networks (based on Braha & Bar-Yam, 2007). Analysis of task network robustness and vulnerability.
Collins et al., 2009	DSM and network analysis-based approach to measuring properties of information flow in PDPs at a small engineering company. The analysis addresses the overall structure, sub-structures (clusters and density of groups), and the individual task level (influence, betweenness centrality, brokerage).
Collins et al., 2010	Analysis of task interactions in a small engineering company. Compares network properties of the PDP at two temporal instances to characterize changes. Applied metrics are: Number of nodes and links, density, transitive triplets, distance, and number of paths per distance.
Gokpinar et al., 2010	Comparing product and organization networks in order to identify coordination deficits. A coordination deficit metric is calculated by comparing the normalized weights of links between two nodes in both networks.
Heimberger, 2017	Development and application of a combined metric (“Alignment”) to analyze product-induced communication needs in complex projects and support coordination.
Jaber, 2016	Graph- and metric-based analysis of risk propagation in automotive design projects based on deliverable dependencies.
Kreimeyer, 2010	Development and application of an extensive set of simple and combined metrics for the analysis of PDP based on different domains. Metrics are operationalized using a Goal-Question-Metric approach for goal-oriented selection in process analysis.
Liberati et al., 2007	Social network analysis applied to product architecture and organizational structure in an automotive engine development project (Closeness, centrality to identify central components and cohesive subgroups).
Lo Storto, 2010	Application of centrality measures on activity DSM for the development of a car climate control. (Degree and Betweenness Centrality).
Marle & Vidal, 2016	Using network topology indicators to highlight elements due to position in the network and analyzing potential propagation (Reachability of nodes, Interfaces, betweenness, eigenvector centrality).
Mathieson & Summers, 2016	Analysis of communication in design processes using email and reporting data (using hypergraphs and bi-partite graphs).

Reference	Description
Parraguez, 2015	Application of structural metrics to analyze planned (information dependencies between activities) as well as actual (information flows between tasks carried out) design processes. Characterization of information networks between project participants of dependent activity pairs.
Piccolo et al., 2018a	Graph- and metric-based approach to analyzing the information flow between functional units in a design project, based on creation and editing of documents (using the metrics “hub” and “authority”).
Piccolo et al., 2018b	Analyzing robustness of a design process using bi-partite graphs and network analysis to analyze dependencies between individuals and activities
Schweigert et al., 2017	Metric-based analysis of graphs to identify barriers between design and simulation departments. Concrete measures are subsequently derived from a catalog to improve communication.

The overview shows that network and graph theory have been **successfully applied to the metric-based analysis of complex interdisciplinary design processes and projects** in previous work. While matrix-based approaches have a comparably long tradition in this domain, metric-based approaches are arguably younger. They have been used to characterize aspects such as e.g. risk propagation, process robustness (sensitivity to process changes), information flow, and coordination. As can be seen, approaches often use centrality metrics to quantify the importance of individuals or activities within the process networks.

In order to evaluate structural PDP characteristics using metrics, a **comparative approach** needs to be chosen, as there is no reference structure that can be used to measure characteristics in an absolute way. Therefore, structural metrics should focus on identifying structural outliers and thus possible weak spots which should receive further attention. (Kreimeyer, 2010, p. 143)

The structural significance of the used metrics **depends on the domain of application** (i.e. the selected node and edge types such as individuals, activities, or cross-domain dependencies) and the need of analysis (Kreimeyer, 2010, p. 138), therefore the individual metrics need to be selected and contextualized according to the respective application.

Furthermore, structural metrics are suitable to analyze a process model on a particular level of detail. Metrics do not necessarily yield results that are **comparable among different levels of detail**, since the number of nodes and edges does not necessarily increase/decrease proportionally with the level of detail (Kreimeyer, 2010, p. 150). Kreimeyer (2010, pp. 149–160) provides an extensive discussion of further limits and relevance of basic and combined metrics.

Within the scope of this thesis, **no new structural metrics are developed**. Instead, the basic and combined metrics provided by previous related work will be **reused and adapted** to fulfill the objective of supporting process tailoring (cf. section 5.4).

2.5 Process tailoring

Following the background on PDPs, process complexity, and corresponding modeling approaches, the following subsections present an extensive study on the concept of process tailoring. It starts from its basic definition, need, expected benefits and challenges, moving to basic methods and approaches for characterizing the deployed processes context and variance, followed characteristics of process tailoring approaches. The section concludes by characterizing the social nature of process tailoring.

2.5.1 Definition and delimitation

In general terms, tailoring is "the act of adjusting the definitions and/or particularizing the terms of a general description to derive a description applicable to an alternate (less general) environment" (Ginsberg & Quinn, 1995, p. 3). More concretely, this means adapting a standard process to **suit the characteristics of the process enactment in a particular organization or project** (Kalus, 2013, p. 3; Pedreira et al., 2007, p. 1; Yoon et al., 2001; Martinez-Ruiz et al., 2012). This is in accordance with Birkhofer et al. (2005, p. 276), who declare that for product design, it is essential to "meet the design situation" to choose and execute approaches, methods, and tools. According to Martinez-Ruiz et al. (2012, p. 229), **characteristics** of process enactment can be grouped into three general categories:

- Project factors (e.g. time constraints or risks)
- Organizational factors (e.g. the available resources, organizational culture)
- Social, legal, and political contexts affecting an organization

The **main objective** of process tailoring can be summarized as to ensure that the invested effort and process rigor for each project is in relation to the project objectives so that only the necessary deliverables and artifacts are produced, using only the necessary activities (and thus, resources) while maintaining an acceptable level of risk (Kalus, 2013, p. 25; Walden et al., 2015, p. 162). Tailoring is therefore related to managing a project's challenges and risks (Xu & Ramesh, 2008b) and increasing project value by removing non-value adding activities (cf. Zakaria et al., 2015b). Furthermore, tailoring should ensure a degree of compliance of project-specific processes with the reference process. (Kalus, 2013, pp. 25–26)

Considering the importance of process tailoring (and, by extension, project planning which builds upon the tailored deployed processes), activities involved in tailoring need to be executed in a **systematic and consistent fashion**, e.g. defining the process scope, managing process model variability, and conducting the required changes to the process model in order to adapt it to a projects' context (Martinez-Ruiz et al., 2012, p. 1). This requires **experienced actors** for carrying out tailoring. The adaptation of the reference process model itself can be **challenging** and **time-consuming** (Schatten et al., 2010, p. 66; Xu & Ramesh, 2007). If process tailoring is solely left to the expertise of project managers, it undermines its repeatability across projects (Kuhrmann, 2014, p. 2; Xu & Ramesh, 2008b).

Tailoring is an activity generally **carried out by a reference process model user**, such as project management, not the designer of the reference process model (Schatten et al., 2010, p. 66). Such a user can be assumed to be unwilling or unable to perform radical RPM adaptations, e.g. by combining different method fragments (cf. Situational method engineering below). (Kalus, 2013, pp. 25–26)

In order to be tailorable, a reference process model requires an inherent **capability of being adaptable** to the process context, with manageable effort in terms of cost and time required to apply changes (Kalus, 2013; Gnatz, 2005). This can, for example, be realized through a **modular structure** of the reference process or the use of customizable process models (cf. section 2.5.4; Meißner & Blessing, 2006; Lévárdy & Browning, 2009).

Levels of process tailoring

The general definition of tailoring can be interpreted in two fundamental ways, resulting in two different levels of process tailoring relating to the earlier elaborated duality of reference and deployed processes (section 2.3.1), as illustrated in Figure 2-6 (Eito-Brun, 2014; Kalus, 2013, p. 24; Kuhrmann, 2007, p. 6; Pedreira et al., 2007, p. 3):

- **Organizational tailoring (Level 1)**: Adapting a predefined standard process from literature, e.g. V-Model, Stage-Gate (Cooper, 2001), or Systems Engineering Lifecycle Processes (Walden et al., 2015) to an organization, creating the organizational RPM.
- **Project-specific tailoring (Level 2)**: Adapting an organizational RPM to project-specific characteristics, thereby creating a project-specific process.

According to Pedreira et al. (2007), Level 2 tailoring has been investigated more broadly. According to Kuhrmann (2007, p. 7), Level 2 can only meet project requirements up to a particular level, requiring further project-specific detailing, which cannot be formalized entirely. Meißner & Blessing (2006, p. 76) propose a similar differentiation of process adaptation levels (cf. also Whitaker, 2012), which takes this limitation into account and highlights the nature of the contextual influences on the specified levels (cf. Figure 2-6):

- **Reference process adaptation**: Consideration of the **long-term** context for providing a stable process architecture.
- **Project planning:** Consideration of the **medium-term** context, including project-context factors relevant during project planning.
- **Project situation:** Consideration of the **short-term** context, which occurs during the project and cannot be predicted, e.g. team members falling ill.

As this illustrates, different sets of contextual factors need to be taken into account for the respective tailoring decisions on different levels (Meißner & Blessing, 2006; Pedreira et al., 2007). The contextual factors may furthermore be static, e.g. for the duration of a project, or dynamic, i.e. changing over time (Gericke et al., 2013).

However, the proposed levels are not always clearly distinguishable and can be further **sub-differentiated**. For example, multiple sublevels of organizational tailoring could be identified in larger organizations, resulting in different adapted but project-independent reference processes for different recurring domains, e.g. for different business units or product lines. This activity is also called **process customization**[23], resulting in pre-tailored process variants. While a literature-based reference model could be tailored directly for project instances, the intermediate stages of process customization can be seen as a way to reduce the effort for project-specific tailoring and integrate localized best practices (cf. section 2.4.2 for the value of organizational reference process models). (Schatten et al., 2010, pp. 65–66)

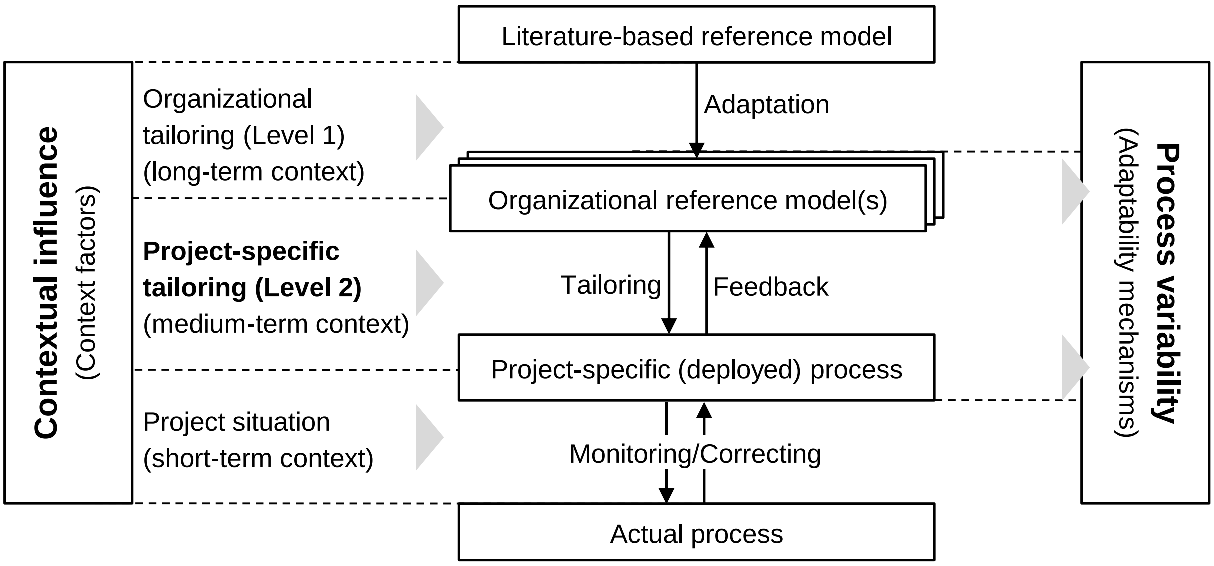

Figure 2-6: Levels of process tailoring and focus within the scope of this thesis (based on Hollauer et al., 2016; Gericke et al., 2013; Meißner & Blessing, 2006)

Delimitation from similar approaches and concepts

Based on the previous delineation of tailoring levels, the focus within this thesis lies on **project-specific process tailoring**. This can further be delineated from similar approaches.

First of all, process tailoring needs to be differentiated from **project tailoring**, as also described in project management literature (cf. PMI, 2013; Whitaker, 2014). This addresses tailoring the project management processes and organizational structures, implying a wide range of associated managerial and tool questions, for example: Management style rigidity, formality of procedures (e.g. documentation and risk management), number of design cycles before freeze, formality/intensiveness of communication (number of meetings, communication channels, etc.), selection of project leaders (and their role), members, and needs for skill development, and the distribution of responsibilities, e.g. to contractors (Shenhar, 2001). While such decisions are vital, they are not within the focus of this thesis.

[23] The terms adaption, adaptation, customization, and tailoring are often used synonymously in literature. Also, the term “tailoring” is more prevalent in the area of software engineering, with “variant management” used as an analog concept in business process management (Pillat et al., 2015, p. 113). Within this thesis, “tailoring” designates a project-specific level, while adaptation/customization subsume the other, non-project specific levels.

Situational Method Engineering (SiME) addresses the intra-organizational construction of organization- and project-specific software and information systems development methods and methodologies[24], under consideration of the particular situation, e.g. a project or an organization (Kalus & Kuhrmann, 2013, pp. 51–53; Henderson-Sellers & Ralyté, 2010; Harmsen, 1997). Steps for conducting SiME are (Harmsen, 1997): 1) *Characterization* of the situation, 2) *Selection* or *construction* of a new method fragment, 3) *Combination* of method fragments, 4) *Evaluation* of method performance.

Like process tailoring, SiME is an approach to solve the issue of selecting an appropriate methodology for an organization or a project. Tailoring is by itself a subaspect of SME, as far as it concerns the adaptation of an already constructed method. However, SiME usually focuses on the construction of organization- and project-specific "methods" through selection and combination of individual method fragments or components from a method base. SiME and its approaches are considered to be in its infancy regarding empirical, industry-based data. Kuhrmann et al. (2014, p. 1066) attest the field a large number of contributions but a disparate understanding and inconsistency in use of the basic concepts, as well as a lack of evidence regarding its practical feasibility. (Henderson-Sellers & Ralyté, 2010; Harmsen, 1997; Brinkkemper et al., 1999)

Due to the constructive approach, SiME is more in line with similar synthetic tailoring approaches (cf. section 2.5.5), instead of addressing the reduction of a pre-defined organizational RPM, during which no new RPM content is generated. However, the question which parts of a method or process can be dropped without risk is considered to be often more important (Ågerfalk & Fitzgerald, 2006). (Kalus, 2013, p. 25)

Modeling of Process Lines (PrL) (cf. section 2.5.4) is inspired by the concept of Software Product Lines and applies similar approaches in order to capture commonalities and variabilities of different RPM variants, which generally follow the same objective but with different logics (La Rosa et al., 2017; Kalus, 2013, pp. 54–55; Rombach, 2005). Different approaches and notations to realize PrL modeling have been developed, as collected in a recent review by La Rosa et al. (2017). Some of these notations include contextual factors to support variant selection, diminishing the distinction from process tailoring approaches. However, PrL modeling in a narrow sense concerns itself with designing variability mechanisms for process modeling languages, supporting the identification of process variants, specifying the scope of the PrL, and its adaptation (Hurtado Alegria, 2012, p. 23; Kalus, 2013, p. 55; Rombach, 2005). The PrL approach facilitates planned reuse, although it is unable to address unanticipated required variability (Hurtado Alegría et al., 2011, p. 2; Armbrust et al., 2009). In this capacity, PrL modeling represents an **important supporting asset** for realizing process tailoring by enabling the capture of process variability in a common model. (Cf. Martinez-Ruiz et al., 2012, p. 244)

Besides similar approaches, tailoring needs to be delineated regarding preceding and subsequent activities:

[24] Usage of terminology in this field varies depending on the authors.

- **Scoping:** A projects' scope is the work performed (tasks) to deliver a result with specified features (cf. Scope Management, PMI, 2013, p. 105), which is closely related to requirements management in systems engineering (cf. Stakeholder Needs and Requirements/System Requirements Definition Process, Walden et al., 2015). The project scope (requirements and/or the work breakdown structure) informs the selection of process elements from the RPM during tailoring but does not represent a tailoring activity itself.
- **Sizing:** The definition of activity durations, which can be differentiated into the "typical" (i.e. mean) duration for a "typical" project, or the specific duration of a particular deployed activity (cf. Browning, 2018, p. 6). While typical values can be defined for RPMs, project-specific adjustment of activity size is done based on the deployed process, i.e. the selected activities and activity modes of a particular project. Multiple typical sizes of an activity can be documented as activity modes and selected based on the corresponding rationale. Subsequent adaptation and optimization of activity durations is performed during project planning, cf. section 2.3.3 ("Estimate Activity Durations," PMI, 2013, pp. 165–172

Based on the previous elaborations, process tailoring in the context of this work is thus summarily defined as follows:

> ***Process tailoring*** *is the adaptation of a pre-existing organizational PDP RPM and its subprocesses, for deployment in different projects conducted within a PD organization. Process tailoring is based on the characterization of individual projects within the organization's project portfolio, through organization-specific, descriptive contextual factors. Process tailoring can be carried out at different points at the beginning as well as during a project.*

2.5.2 Need, benefits, and challenges of process tailoring

The motivation for tailoring can be explained through internal as well as external drivers, resulting in several benefits regarding project performance as well as project planning transparency. On the other hand, a number of challenges impede process tailoring efforts.

Need for tailoring

According to Browning et al. (2006, p. 118), standard processes generally require some amount of tailoring and/or scaling before being „**helpful for planning and controlling a project instance**," i.e. to **fit** the task and characteristics of a particular project. This is in alignment with organizational contingency theory, which suggests that no business process is equally effective under all conditions. Instead, they need to be adjusted to suit an organization's internal and external environment (cf. Thompson, 2008). The alternative of designing and modeling processes **from scratch on a per-project basis** is not feasible as it increases risk and overhead in terms of time and cost (Xu & Ramesh, 2007, p. 294; Cesare et al., 2008, p. 157; Pillat et al., 2015, p. 96; Hurtado & Bastarrica, 2009, pp. 1–2). Such an approach further defeats the purpose of documenting, managing, and reusing the knowledge contained in PDP RPMs (cf. Browning et al., 2006; Cesare et al., 2008, p. 157). Organizations require organization- or project-wide guidelines and approaches for tailoring, on the one hand to enable its systematic execution (cf. section 2.5.1) and on the other hand in order to avoid excessive process tailoring, which would incur significant overhead and be detrimental to process repeatability and consistency across projects (Xu & Ramesh, 2008b, p. 45). The need for tailoring is also acknowledged in agile methodologies through the selection of appropriate methods and practices (Kalus & Kuhrmann, 2013; Kruchten, 2013).

Besides this, tailoring is also motivated by the **need for agility and adaptability** by providing means to quickly react to changing project circumstances. As changes in projects (or programs) occur in complex environments, which obstructs the identification of change consequences (cf. section 2.3.2), a standardized yet adaptable RPM can enable adaptability by establishing a rich repository of process information as a baseline from which deviations can be derived and tested in advance, in contrast to a "no process" approach, where no pre-defined baseline is available. (Browning, 2014c)

Finally, tailoring is often externally motivated, in order to achieve **compliance with assessment models** and **standards**, such as e.g. CMMI[25] (SCAMPI Upgrade Team, 2011) or SPICE[26] (ISO/IEC 33001, 2015) for software development, or ISO/IEC/IEEE 15288 (2015)/ISO/IEC TR 24748-1 (2018) for systems engineering (cf. Walden et al., 2015, p. 162; Martinez-Ruiz et al., 2012; Chrissis et al., 2007; Pedreira et al., 2007, p. 4; Browning et al., 2006). Thereby, tailoring contributes to compliance either directly as it is explicitly mandated by the standard, or indirectly, by establishing traceability of project-specific processes to the reference processes as defined by the particular standards. Therefore, process tailoring is an important and repetitive activity for both the establishment and improvement of processes (Martinez-Ruiz et al., 2012).

Expected benefits and challenges in regard to process tailoring

Besides these direct needs motivating tailoring, several resulting benefits associated with tailoring and reference process reuse are discussed in literature. Table 2-9 gives an exemplary overview of the discussed benefits without claiming exhaustiveness. However, it needs to be stated at this point, that the stated benefits are implied, as none of the listed references studies the expected benefits in particular in order to prove them.

[25] Capability Maturity Model Integration

[26] Software Process Improvement and Capability Determination

Table 2-9: Benefits expected from process tailoring as discussed in literature (based on PE-Rogger, 2018)

Benefit	**Xu, 2005**	**Barreto et al., 2011**		**Cameron, 2002**	**Slaughter et al., 2006**	**Pedreira et al., 2007**	**Bustard & Keenan, 2005**	**Xu & Ramesh, 2007**	**Pillat et al., 2015**
Improvement of performance and reliability of work procedures	●								
Increase in productivity through predefined processes	●	●							
Ensuring specified final deliveries' quality and uniformity (effectiveness)	●	●		●	●				
Increased process control	●								
Efficiency through removal of unnecessary activities (time and cost savings)		●		●	●	●			
Increased transparency in budget planning and project time estimation						●			
Increase of efficiency through situative processes and reuse of knowledge	●						●		●
Reduction of risk and effort through reuse and adaptation of existing processes	●							●	
Improved communication between project members through defined responsibilities	●								
Simplified training of new project members through clearly defined structures	●								
Employee satisfaction via execution of tasks which contribute to project progress						●			
Reduced rework		●							

Contrasting the expected benefits stated and described in the literature, a number of challenges simultaneously hinder the successful application of tailoring and need to be handled within organizations. A condensed, exemplary overview of these challenges as discussed in literature is presented in Table 2-10 without claim to exhaustiveness and weight of individual challenges. As can be seen, a number of challenges are associated with information, its generation as well as provision at the right level of quality. Another common theme is the lack of concrete and applicable support.

Table 2-10: Challenges hindering the application of process tailoring (based on PE-Rogger, 2018)

Challenge	Lapouchnian et al., 2007	Bustard & Keenan, 2005	La Rosa et al., 2017	Jaufman & Münch, 2005	Park et al., 2006	Xu, 2005	Browning, 2010	Kalus & Kuhrmann, 2013	Pedreira et al., 2007	Hurtado Alegria, 2012	Graviss et al., 2016	Yoon et al., 2001	Martinez-Ruiz et al., 2012	Xu & Ramesh, 2008a	Valenca et al., 2013
Knowledge- and time-intensiveness of tailoring					●	●								●	
Knowledge/understanding regarding process, context, and modeling notations required			●							●					
Inadequate provision of information required for tailoring decisions (e.g. activity dependencies/attributes)							●								●
Distribution of the tailoring activity within the organization (e.g. different hierarchical levels)									●						
Availability of experience and know-how regarding tailoring from employees/experts					●			●		●	●				
Automatization poses high requirements regarding the precise definition of context factors and impacts					●					●					
Methods for designing, describing, and using tailorable process models required	●	●	●	●											●
Prevalence of ad-hoc approaches for tailoring (impede repeatability, cause errors, and increase time/cost required)									●	●	●				●
Lack of concrete, consistent, and generally applicable tailoring procedures or frameworks									●				●	●	
Only generic guidelines available in standard literature (e.g. PMBoK, SE Handbook)											●				
Lack of approaches for the construction and maintenance of customizable process models			●												●
Ensuring consistency between RPM and tailored process and configuration correctness												●			●

2.5.3 Analyzing and documenting the context of deployed processes

This subsection focuses on discussing the term "context." Based on this, general methods to facilitate the analysis and documentation of the deployment context are outlined.

Process context

The term context is defined as the "interrelated conditions in which something exists or occurs" (Merriam-Webster, 2016). Within the scope of this thesis, this relates to the sum of project characteristics and their assumable values within the PD project portfolio of a particular organization. As described previously, the consideration of contextual characteristics of the deployed process instances is critical in order to formulate appropriate tailoring operations. The ability to express the required flexibility of a process in terms of its varying project contexts and corresponding impacts is considered a critical aspect of process metamodels (Kuhrmann, 2014).

Various synonyms for the term context are used in literature (cf. Guertler, 2016, p. 70), e.g. **situation** (Ponn, 2007, p. 43; Hales & Gooch, 2004, p. 1; Fabrizio, 2006, p. 158), **boundary condition** (Albers & Braun, 2011, p. 11), **influencing factors** (Hales & Gooch, 2004, p. 39), **business drivers** (Milani et al., 2016, p. 58), or **influencers** (Martínez-Ruiz et al., 2013). Within the scope of this work, the term "**context**" is used to describe the sum of factors influencing a particular project.

Methods for process context acquisition and documentation

In order to facilitate the investigation of a deployed processes' context, different means for analysis have been proposed[27]. Within the context of this work, these approaches have been grouped into two categories:

- Methods for the **acquisition** of contextual factors
- Methods for the **description and documentation** of contextual factors

In order to support the **acquisition** of a process context, several authors have proposed **generic collections and classification schemes** of context factors, which can be used to classify projects. These approaches range from simple classification schemes using as little as two factors, e.g. "technological uncertainty" and "system scope" (Shenhar, 2001), to extensive collections with hierarchical decomposition on multiple levels (review-based compilation of 239 context factors in Gericke et al. (2013)). Further collections and schemes can be found in: ISO/IEC/IEEE 15288 (2015); Kronsbein et al. (2014); Kalus & Kuhrmann (2013); Ehrlenspiel & Meerkamm (2013); Langer & Lindemann (2009); Rosemann et al. (2008); Du Preez et al. (2008); Ponn (2007); Ulrich & Eppinger (2008); Hales & Gooch (2004); Skalak (2002); Shenhar (2001); Dvir et al. (1998); Maffin et al. (1995).

While generic collections provide a starting point to investigate project contexts, they are abstract and need to be interpreted and adapted on a case basis. While they are extensive, they cannot claim completeness. Furthermore, they do not generally provide guidelines on how these factors affect the tailoring within a particular organization, with the exception of Kalus & Kuhrmann (2013), who provide generic impacts of individual context factors on software processes, and Ulrich & Eppinger (2008), who provide generic impacts on interdisciplinary PDPs.

In order to address the shortcomings of generic collections, methods are necessary to **acquire organization-specific context factors**. Such methods are based on **interviews and observations** within the particular organization and process (e. g. Badke-

[27] The discussion of context analysis methods in this section is based on work performed in PE-Gantenbein 2017

Schaub & Frankenberger, 2004), supported through additional methods such as: **Guiding questions** (e.g. Lindemann, 2009, pp. 29–32), **morphological boxes** (Vom Brocke et al., 2016), analysis of contextual influences on process **sub-goals** (Rosemann et al., 2008), or the analysis of contextual influences on process **performance indicators** (Ploesser et al., 2009).

While these acquisition methods allow for a more specific acquisition of context factors, they are still generic and require adaptation to the task at hand, as they have not been designed with the objective of acquiring information to support tailoring in mind.

After process context information has been acquired, it needs to be **documented** appropriately. Hurtado et al. (2011) provide an overview of existing approaches to document the process context and identify the most relevant proposals, such as *Key-value pairs*, *markup scheme models*, *graphical models*, *object-oriented models*, and *logic-based models*. Context models can be represented as text, tables, lists, or using domain-specific languages. In context models, the context is commonly decomposed into individual **variables** (cf. “factors” above), which can assume a range of corresponding **values**, as illustrated in Table 2-11.

Table 2-11: Examples of context variables and values (based on Hurtado Alegría et al., 2011, p. 13)

Dimension	Variable	Values
Project	Project Type	[new development, extension, maintenance]
	Duration	[short, medium, large]
	Problem Knowledge	[clear, ambiguous, unclear]
Team	Team Size	[very restricted, typical, unclear]
Product	Product Complexity	[high, medium, low]
	Quality Relevance	[high, regular, minimum]

Context modeling[28] can be traced back to the root concept of *Domain Engineering* (Reinhartz-Berger et al., 2013), and more specifically, *Feature-Oriented Domain Analysis*, which generates *Feature Models.* Its original intention was to increase software reuse by identifying and encapsulating commonality and variability (Czarnecki & Eisenecker, 2005; Kang et al., 1990; Kang & Lee, 2013, p. 26). Within the scope of process tailoring, feature modeling can be used to model project context factors and their dependencies (cf. Figure 2-7) (Kalus, 2013).

The purpose of **feature models** is to “extract, structure and visualize the commonality and variability of a domain or set of products,” originally to facilitate software reuse (Thörn & Sandkuhl, 2009, pp. 132–133). Various notations and metamodels to implement feature models exist, which are visualized as *feature diagrams*. In general, feature diagrams are depicted as *feature trees* in graph-based notation, with vertical assignments of features to groups, as well as cross-tree constraints. Features can be *mandatory*, *optional*, as well as selected from a set of *alternative features*. Furthermore, features can be *concrete* or *abstract*,

[28] In a similar manner, feature modeling represents the fundamental basis for modeling variant rich processes, cf. section 2.5.4.

representing a logical concept to group concrete features. Additionally, cross-tree constraints can be added to these basic concepts, for example, in case the selection of one feature *requires* the selection of another, or two features are *mutually exclusive.* (Thörn & Sandkuhl, 2009)

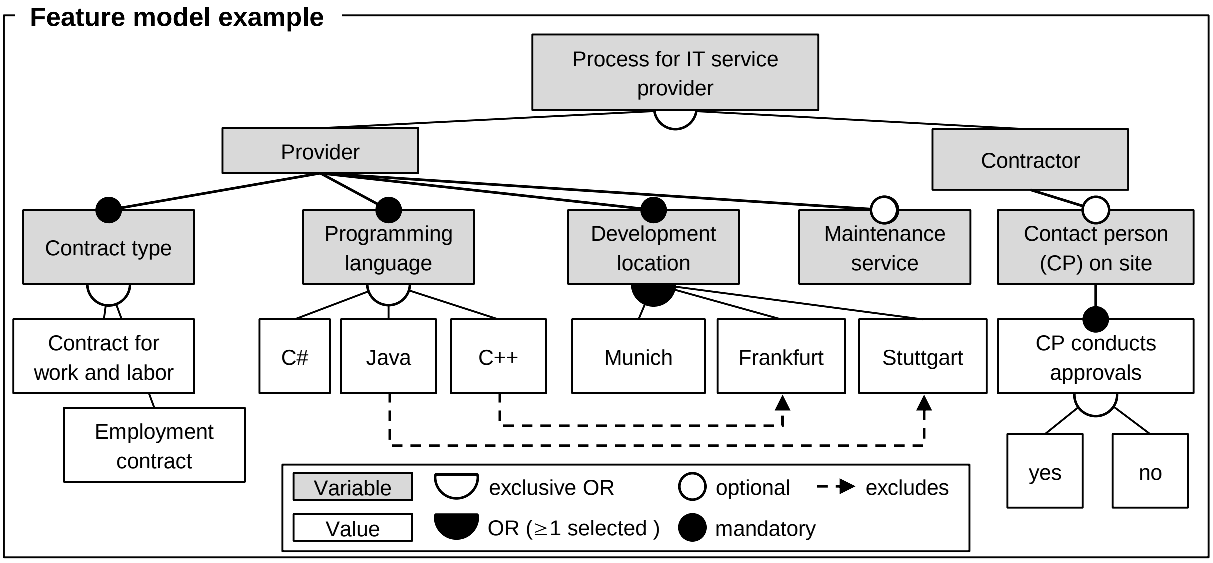

Figure 2-7: Fictional example of a context model as a feature diagram (based on and translated from Kalus, 2013, p. 193)

2.5.4 Modeling process variability

With the preceding section focusing on the context aspect of process tailoring, the following section illuminates the corresponding aspect of process variability to capture tailoring impacts.

Process variability modeling

The **tailorability** of an RPM is characterized by its ability to be adaptable to different project contexts (cf. section 2.3.2), while simultaneously ensuring compliance with the RPM (Golra, 2014, p. 10; Sadiq et al., 2007). In this context, several similar system properties need to be differentiated[29]: **Adaptability** and **flexibility** are generally defined as the ability of a system to be intentionally changed by a system-internal respectively -external change agent (de Weck et al., 2012, p. 7). **Modularity** is seen as enabler for increasing system adaptability and flexibility (de Weck et al., 2012, p. 7) and a prerequisite for increasing **reuse** (Cameron, 2002), i.e. the use of a process in a new context in order to minimize the effort for its redevelopment (Golra, 2014, p. 9). Within the scope of this thesis, the embodiment of differences between process instances in a common RPM is termed **variability** (cf. La Rosa et al., 2017, p. 3; Valenca et al., 2013, p. 7, and "variety" as an aspect of complexity, section 2.3.2).

[29] The terms and concepts related to adaptability, flexibility, and related properties are used with different nuances by different authors.

As process tailoring approaches are often realized using **variant-rich process models** (Martinez-Ruiz et al., 2012, p. 244), this section focuses on how process variability can be documented and managed. This relates mainly to model-based approaches, which extend process modeling approaches (cf. section 2.4.2) with variability-capturing mechanisms, such as variation points (La Rosa et al., 2017, p. 38).

Two fundamental ways to capture variant-rich processes are **multiple-** (fragmented) or **single-** (consolidated) model approaches (Milani et al., 2016; Milani, 2015; Hallerbach et al., 2010; Hallerbach, 2009; Valenca et al., 2013, p. 12): In a multiple-model approach (cf. also "templates" in Table 2-15), each process variant is modeled separately with only loose coupling between models, e.g. through element names, resulting increased modeling and maintenance effort and consequently redundancy and inconsistency (Milani et al., 2016, p. 55; Hallerbach et al., 2010, p. 523). A single-model approach combines multiple variants, e.g. by using conditional branching (Hallerbach et al., 2010, p. 523). The single-model approach creates larger and more complex models, which may be difficult to understand, analyze, and evolve (Hallerbach et al., 2010, pp. 523–524; Milani et al., 2016, p. 56). Furthermore, regular branches cannot be distinguished from particular variant branches (Hallerbach et al., 2010, p. 523). Therefore, selecting an approach requires a trade-off (Milani et al., 2016, p. 56).

In order to enable a purposeful creation of manageable single, variant-rich process models, the concept of **Process Lines** (PrL) has been proposed, by transferring the concepts of Software Product Line Engineering to process models (cf. also section 2.5.1) (Kalus, 2013, pp. 54–55; Rombach, 2005; Washizaki, 2006; Kuhrmann et al., 2016, p. 53). PrL are sets "of processes in a particular domain or for a particular purpose, having common characteristics and built based upon common, reusable process assets" (Washizaki, 2006). Besides the mentioned references, further examples for research in this area and overviews can be found in e.g. Kuhrmann et al. (2016), de Carvalho et al. (2014), Ternité (2010), and Simidchieva et al. (2007).

PrL allow the capture of commonalities and variabilities of different variants of a reference process through variation points. Variation points are for example activities, which can be changed in regard to the project contexts, e.g. by replacing them with candidate activity variants (Washizaki, 2006; La Rosa et al., 2017). Similar to the previously described approaches for context modeling (cf. section 2.5.3), these approaches are based on the concept of Domain Engineering and Feature-based Domain Analysis (Hurtado Alegria, 2012, pp. 51–55; de Carvalho et al., 2014).

PrL approaches are described as suitable only in well-defined domains with "few and well-known alterations" to support planned reuse and focus on element operations, with changes in sequences and flows addressed only in a limited fashion or not at all (Pillat et al., 2015, p. 113). Besides, tailoring must also be able to deal with unanticipated variability (Pillat et al., 2015, p. 113; Armbrust et al., 2009). Creating PrL models requires considerably more information than creating a single process instance, and in case of complex customization decisions, the combination of PrL with context models (domain models) is preferable (La Rosa et al., 2017). Several authors conclude that existing software PrL concepts are still immature, e.g. in terms of taxonomy and empirical validation (cf. Kuhrmann et al., 2016; de Carvalho et al., 2014).

Approaches for process variability modeling

Regarding approaches for the creation of adaptable/customizable variant-rich RPMs, three fundamental model types can be differentiated[30] (Kalus, 2013, p. 24; Chroust, 1992, 2000, p. 284; La Rosa et al., 2017, pp. 2–3):

- **Umbrella**[31] models, capturing all possible process behaviors (also "variability by restriction," Least Common Multiple, or "configurable process models").
- **Core** models, representing only the most common behavior (also "Variability by extension," Greatest Common Denominator).
- **Modular** models, based on a library of building blocks for assembling project-specific processes according to specified rules(cf. also SiME; Lévárdy & Browning (2009); Bichlmaier et al. (1999).

The three types are not always clearly distinguishable, as approaches can combine variability by extension and restriction (La Rosa et al., 2017, p. 3), and both can contain degrees of modularity. Umbrella and Core models represent two extremes and carry certain benefits and disadvantages, as depicted in Table 2-12.

Table 2-12: Benefits and disadvantages of umbrella and core models (cf. La Rosa et al., 2017, pp. 38–39)

Type	Benefits	Disadvantages
Umbrella (restriction)	• Particularly suitable for stable variant sets • More widely supported • Approaches offer correctness checking	• Each variant addition requires a model update • Leads to larger models • Updating large models is error-prone
Core (extension)	• Particular suitable for growing variant sets • Easier maintenance due to extendability	• More difficult to reconcile with correctness checking (requires constraints for extensions) • Captures only a subset of process variant behaviors, additional behavior remains hidden

Based on this differentiation, La Rosa et al. (2017) provide a comprehensive review of process variability modeling, mainly in the area of business processes, based on a selection of 66 publications related to 23 current approaches subsumed to 11 groups (Table 2-13). These approaches can be used to create PrLs. As these approaches are a supporting aspect[32] but not the main focus within the scope of this work, only a brief overview is given in this subsection, foregoing the description of individual approaches, which can be found in the source.

In their criteria-based comparative analysis (cf. Appendix A1.3 for evaluation criteria), the authors found that all groups of approaches support variability through restriction, with five

[30] Cf. also "reductive" and "synthetic" tailoring in Table 2-15.

[31] In the referenced german sources, the term "Dach" ("roof") model is used.

[32] The approaches informed the development of the metamodel in this thesis, cf. sections 5.3 and 6

approaches simultaneously realizing variability by extension. Most approaches are based on conceptual instead of executable process models. The majority of approaches supports customization via context models (abstraction), which is particularly relevant in the face of complex and independent customization decisions. Only two approaches provide operative guidance for customization decision-making in order to avoid inconsistent or irrelevant decisions. All except one group have been at least partially implemented, and all except two provide formal definitions. Seven approaches have been at least partially validated. According to the authors, *C-iEPCs* (customization by restriction in conceptual process models) and *Templates and Rules* (omitting customization guidance) are closest to fulfilling all criteria. (La Rosa et al., 2017, pp. 36–39)

The authors further identify several **gaps and challenges** in relation to the analyzed approaches. Only a few approaches offer user guidance and iterative feedback during customization. In particular, they do not address which customization options provide the best performance in a particular situation. Similarly, Valenca et al. (2013, p. 12) conclude that the process configuration itself is generally performed in an ad-hoc manner guided by experience, with context analysis mainly performed in order to elicit variability instead of supporting the configuration itself. Furthermore, there currently is a lack of methods supporting the design and update of customizable models, which deal with the increased information requirements involved in building customizable process models. Initial approaches focus on algorithms for constructing customizable process models from separate process model variants and event logs. Lastly, there is a lack of empirical, comparative evaluations concerning the suitability of different approaches in different settings. (La Rosa et al., 2017, pp. 38–39)

The described approaches mainly focus on the realization of variant-rich, customizable (and thus, tailorable) process models in the form of umbrella and core models. They generally do not explicitly address modularity-based approaches, although the group of *fragment customization* approaches is most closely to the traditional notion of process modules. Examples for **modular RPM approaches** in PD can be found for example in the work of Bichlmaier et al. (1999) („Process building blocks“), Lévárdy & Browning (2009) (provision of a superset of activities and variants thereof, along with rules for their selection and composition based on the current project state), the FORFLOW RPM (Roelofsen, 2011) and work related to the *Signposting*[33] approach (e.g. Clarkson & Hamilton, 2000; Wynn et al., 2006). In terms of PDP modularization, Seol et al. (2016) describe a DSM-based[34] approach based on process flow. Furthermore, modularization of PDPs needs to take interdependencies with the organizational (Piller & Waringer, 1999, p. 37; Renner, 2007, pp. 43, 71) as well as the product structure (Sanchez & Mahoney, 1996, p. 64; Göpfert, 1998, p. 149) into account.

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[33] The *Signposting* approach allows for dynamic selection of activities during project execution and is thus more closely related to the situational tailoring level, cf. Figure 2-6, section 2.5.1.

[34] However, it can be argued that most process clustering and modularization approaches, e.g. as listed in Browning, 2016, Table IIIA focus on analyzing and optimizing project-specific processes.

Table 2-13: Groups of approaches for modeling process variability (based on La Rosa et al., 2017, p. 10. See reference for further information regarding the individual approaches)

Mechanism	Description	Main approaches
Node configuration	Variation points are configurable nodes that are assigned different customization options (retain, remove, select customization option).	C-iEPCs
		Configurable Workflows
		ADOM
Element annotation	Elements of the customizable process model are linked to a domain model and selected by instantiating the domain model.	Configurative process modeling
		Superimposed variants
		aEPCs
Activity specialization	Abstract activities are defined as variation points and replaced by one of multiple specialized variants	PESOA
		BPFM
		Feature Model Composition
Fragment customization	Change operations to add, delete, or modify fragments of the customized model	Provop
		Template and Rules

Within the scope of this work, the focus lies on umbrella models and corresponding modeling approaches, as they are closest to the stated objective of tailoring organizational RPM to project-specific characteristics. Modular approaches serve to augment the approaches described in this section, e.g. for describing individual process elements.

2.5.5 Description and classification of tailoring approaches

After clarifying the general concept of process tailoring, the underlying need for it, associated benefits and challenges, and the foundations of context and variability modeling, this section describes and classifies general approaches for implementing process tailoring. An evaluative overview of identified concrete tailoring support approaches relevant within the scope of this thesis is given in section 4.2.

Tailoring approaches – General description and requirements

Based on a literature review, Martinez-Ruiz et al. (2012) have formulated a set of 25 requirements for tailoring support approaches (cf. Appendix A1.4). Based on bibliographical data, it can be inferred that interest in managing process variability (at least in software engineering) is rising (Martinez-Ruiz et al., 2012, p. 237). They also conclude that there is to date no unified approach, consensus, or industry standard[35] on how to tailor processes in a controlled and consistent manner (Martinez-Ruiz et al., 2012, p. 230). In order to carry out process tailoring as defined in section 2.5.1, a plethora of **specialized tailoring approaches** has been developed (cf. also section 4.2). It is important to mention that besides these specialized approaches, **other methods** can conceivably contribute to process tailoring by generating important information, such as e.g. risk/value analyses (cf. e.g. Browning, 2014a).

[35] The statement is based on the current state in software engineering, but is by extension also valid for iPD

While such methods arguably would allow more detailed and situation-specific tailoring, these are not within the focus of the reviews performed within the scope of this work, as for example, they do not focus on reuse of the knowledge gained.

Process tailoring generally requires an analysis regarding which elements of the process are required for a project (e.g. stages, reviews, artifacts, or content thereof) (Graviss et al., 2016, p. 276). The following general strategies for selecting process elements from a baseline RPM for a particular project are conceivable (cf. Browning & Ramasesh, 2007, p. 224):

- Activity selection based on their ability to reduce key uncertainties and risks and enable important decisions
- Selection of lower-level activities based on the decomposition of design subproblems to be solved
- Grouping of activities based on the intensity of their interaction
- Adaptation/Re-selection of the most appropriate activities due to the current project state
- Ongoing activity selection based on rules and policies

The development of systematic tailoring support is generally based on the **assumption that tailoring knowledge can be documented and reused** (cf. He et al., 2008). It is hypothesized, that "*a precisely defined tailoring model (incl. context and parameters) allows for the definition of better (e.g., appropriateness, precision, and validity) project-specific processes, as compared to an ad-hoc tailoring, and supports more efficient project operation (e.g. by enhancing decision-making processes)*" (Kuhrmann, 2014). Besides a sound understanding of the process context for defining tailoring criteria, this requires upfront work in order to anticipate the required flexibility and adequately design the process to be tailored in terms of process modules, configurations, and appropriate tailoring constructors (cf. Martinez-Ruiz et al., 2012).

Procedures for tailoring implementation and application

Tailoring approaches can be decomposed into sequences of steps describing what needs to be done in order to implement and apply them. This subsection aims to discuss and compare a selection of existing approaches, which explicitly provide such sequences. As a result, a generic procedure is presented in Figure 2-8, which is suitable as a basis for the development of a tailoring approach within this work (cf. section 5). The concrete scope and elaboration of the steps vary between different tailoring approaches, depending on their particular focus.

The ISO/IEC TR 24748-1 (2018) standard describes tailoring of project-specific processes within the scope of systems and software engineering. While the standard omits steps related to the documentation of tailoring knowledge across project instances, it emphasizes process tailoring based on project characteristics and highlights the solicitation of inputs from affected project stakeholders. How these steps are to be carried out is only generally outlined.

In contrast, the approach proposed by Kalus (2013) focusses on a tool-oriented implementation of tailoring via configurable process models based on feature models, hence emphasizing the documentation of tailoring knowledge via its implementation in corresponding tools. Conversely, how tailoring is to be carried out is only addressed briefly.

	ISO/IEC 24748-1 (2018)	Kalus 2013	Graviss et al 2016	Hurtado Alegria 2012	Xu & Ramesh 2008	Zakaria et al 2015
Preparation		Analyze need	Identify initial tailoring considera-tions			
Acquisition of org. tailoring knowledge	Identify project character-istics Solicit inputs from affected parties		Refine set of tailoring considera-tions for an organization	Process feature analysis Context analysis Process scoping		Value-based factor (VBF) identification VBF assessment Map rated VBF with proc. element
Documentation of organizational tailoring knowledge		Agree on variability points Implement tools Agree on tailoring criteria Define content	Define tailoring considera-tions for organization Establish rule set	RPM design Implement transforma-tion strategy		Process element assessment Value prioritisation (element ranking)
Tailoring application	Select standards, strategy, stages, processes, and activities Document adaptation and rationale	Adapt RPM	Apply model to new project and validate	Project specific context analysis Apply transforma-tion strategy	Evaluate project goals/ environment Assess challenges Determine tailoring for process elements Tailor process	Tailoring recommen-dation Tailor process
Project execution & review					Execute process Validate process	

Figure 2-8: Comparison of steps for tailoring implementation and application from different approaches

Graviss et al. (2016) describe the tailoring of systems engineering lifecycle processes based on “tailoring considerations” (i.e. project characteristics), with the adaptations documented in organization-specific rule sets. The approach focuses on the rule-based documentation of tailoring knowledge using tables and matrices. Tailoring itself is described as the act of “a systems engineer,” but without concrete guidance or support.

Hurtado Alegria (2012) describes an approach explicitly derived from Domain Engineering and built on the PrL concept. In a preparatory sequence, the process to be tailored and relevant context variables are acquired and analyzed in terms of variability and documented in corresponding models, forming a set of tailoring rules, which is later applied for particular projects ("process scoping"). Tailoring itself is presented as the configuration of processes via rule-based model transformation, based on the values of project characteristics.

Xu & Ramesh (2008b) propose similar steps but do not explicitly address cross-project documentation of tailoring knowledge. In addition to project goals and environment, expected development challenges (acquired using a questionnaire) are an important factor in their approach. Additionally, they address the need for validation and evaluation of the tailored process and its effectiveness after project conclusion.

Zakaria et al. (2015a) propose a tailoring framework, which uses empirically derived value-based factors as input for the tailoring activity. Similar to project characteristics in other approaches, these factors are mapped to process elements, in order to assess process elements in regard to their value contribution for particular projects. The process is subsequently tailored in response to this assessment, a step which is not elaborated in detail.

In an effort to provide a comprehensive overview, Figure 2-8 combines the discussed procedures to highlight the different yet equally relevant aspects. Within the scope of this work, the described steps have been grouped into the phases "general preparation," "acquisition of required tailoring knowledge," "documentation of tailoring knowledge," "application of tailoring," and "project execution & review." This intentionally forms a generic end to end procedure in order to emphasize the importance of all aspects.

Tailoring operations: Operators and tailored process elements

In order to formally document the change operations performed on the RPM, several **direct tailoring operators** have been proposed, as summarized in Table 2-14.

Martinez-Ruiz et al. (2012, p. 243) identified *adding* and *removing* as the most common change operators (in 81.25% of surveyed studies), followed by the generic *modification* (43.75%). In a similar fashion, tailoring of SE Lifecycle processes according to ISO/IEC/IEEE 15288 (2015) focuses on deleting unnecessary or unwarranted process elements but also allows for additions and modifications (Walden et al., 2015, p. 162). Other operations exist, such as the definition of relationships or *constraints* between different elements, or the *replacement* of elements. Besides these direct operators, the authors have identified **indirect mechanisms** in a minority of studies, such as: Process *patterns*, which are to be applied when contextual requirements are met, *Parametrization*, where values are assigned to process parameters during tailoring, *Inheritance*, which enables tailoring of the parent process by defining child processes extending parent properties, as well as *encapsulation* and *decision* nodes. (Martinez-Ruiz et al., 2012, pp. 242–244)

The operators can, in principle, be applied to all **process element types** in all partial project systems (cf. section 2.4.2), depending on the used notation. For example, Xu & Ramesh (2008b, p. 41) describe tailoring of tasks, sequences, artifacts/documents, roles, and iterations. Martinez-Ruiz et al. (2012) identify *activities*, *roles*, and *artifacts* as the most frequently tailored elements (in descending order). Other tailored element types are subprocesses, resources, or techniques and practices. Through the analysis of patterns between commonly tailored element types, they identify **activities as central elements,** according to which other elements are varied. Regarding structuring elements, variability in control and data flow, e.g. through grouping, are identified as most common. However, 19.35% of investigated approaches omit structural variability. Based on the PrL concept (cf. sections 2.5.1 and 2.5.4), element variability (variation points) can be defined as *optional* (may or may not be present in the process), *mandatory* (must be present in the process), or *alternative* (alternative elements can be placed in the variation point) (Martinez-Ruiz et al., 2012, p. 245).

Table 2-14: Direct tailoring operators from existing tailoring support (based on PE-Langner, 2017)

Operator	**Akbar et al., 2012**	**Kang et al., 2008**	**Dai & Li, 2007**	**Graviss et al., 2016**	**Martinez-Ruiz et al., 2012**	**Yoon et al., 2001**	**Xu & Ramesh, 2008b**	**Bender & Gericke, 2016**	**Pereira et al., 2007**	**Pillat et al., 2015**	**Frequency**
Add	●	●	●		●	●	●	●	●	●	9
Delete	●	●	●		●	●	●	●	●	●	9
Replace	●	●			●		●			●	5
Merge	●		●	●		●		●			5
Modify	●			●	●		●				4
Split			●			●		●			3
Repeat				●							1
Downsize							●				1
Expand							●				1

Simultaneous modifications of multiple process elements can be combined in *crosscutting* variations, complementing individual or *single* adaptations (Martinez-Ruiz et al., 2012, p. 19). Hence, different cardinalities of mappings between context factors and process variations are possible, resulting in different levels of complexity, as shown in Figure 2-9.

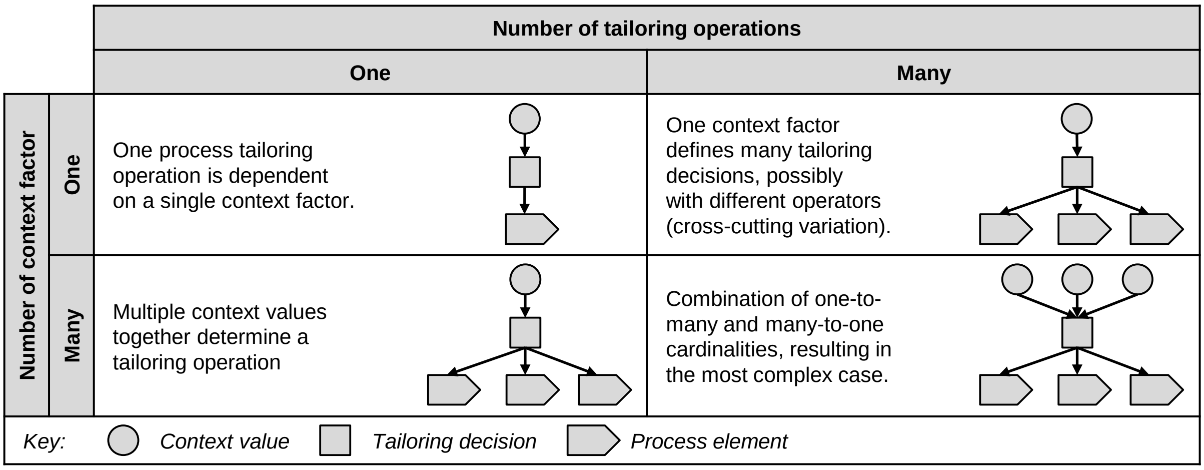

Figure 2-9: Possible cardinalities of context-process relationships (based on Hurtado Alegria, 2012, p. 57)

Classification of tailoring approaches

Regarding existing tailoring support approaches, Martinez-Ruiz et al. (2012, pp. 248–249) conclude that most approaches focus on providing assistance during tailoring using either tool-based support, storage of tailoring knowledge for reuse, or rules which guide the tailoring applicant. However, approaches differ in their respective emphasis (cf. also Figure 2-8). Based on the review of related work, Table 2-15 shows a classification of tailoring approaches. The individual characteristics are subsequently discussed, highlighting benefits and disadvantages.

Tailoring approaches can be commonly classified as being of **reductive, synthetic, or generic** nature (Chroust, 2000; Henderson-Sellers & Ralyté, 2010, p. 462; Kalus, 2013, p. 206). **Reductive** approaches start from a comprehensive RPM encompassing all elements necessary for all project instances, subsequently removing unnecessary elements for a particular instance using tailoring operators (see also section 2.5.4). Conversely, **synthetic** approaches start from individual method fragments in a method repository, creating the project-specific process through combination and are thus similar to SiME (cf. section 2.5.1) (Kalus, 2013, p. 25). **Generic** refers to the use of one fragment as a parameter for the generation of another one[36]. In comparison to reductive approaches, synthetic approaches represent a (partial) generation of new project-specific processes, and thus not an adaptation in a classical sense (Kalus, 2013, p. 25). Since the starting point for the tailoring approach in this work is are pre-defined, organizational RPMs, only reductive approaches will be regarded further.

Kalus (2013, p. 206) differentiates **informal** and **formal** (synthetic and reductive) approaches and mentions agile approaches as representatives for informal tailoring approaches. According to Pedreira et al. (2007), a **formal** (or systematic) approach using rules or guidelines can decrease the dependency of the tailoring results on skills and preferences of the tailoring applicant and can potentially be applied by a more inexperienced user. In contrast, **informal**

[36] The author's original intention for the term "generic" is unclear (Henderson-Sellers & Ralyté, 2010, p. 462).

approaches, e.g. in the form of workshops or brainstorming, are easier to apply in smaller companies as they provide a lower entry barrier. Different degrees of formality can be identified in existing approaches. Pedreira et al. (2007) mention Hanssen et al. (2005) as an example for an informal, workshop-based approach: Three common project types were defined, and the reference process (Rational Unified Process) was adapted in a facilitated workshop. (Pedreira et al., 2007)

Table 2-15: General classification of tailoring approaches

Characteristic	Value	Description
Starting point (Chroust, 2000; Kalus, 2013; Henderson-Sellers & Ralyté, 2010)	Synthetic	Tailoring through a combination of individual method fragments (cf. e.g. Situational Method Engineering)
	Reductive	Tailoring through the removal of unnecessary elements from a superset of activities or an overarching process model
	Generic	Use of a process fragment as input to generate another fragment
Degree of Formality (Pedreira et al., 2007; Kalus, 2013)	*Formal*	Formal, prescribed tailoring process and methods, e.g. based on rules or guidelines
	Informal	Simple, pragmatic process, using informally defined process models and tailoring guidance.
Form of execution (González et al., 2014)	Templates	Predefined process variants, from which the most appropriate is selected based on the project situation
	Automated configuration	Automated, model-based configuration of processes; Requires the definition of the context, the organizational process with variability, and the transformation rules
Time of application (Karlsson & Hedström, 2009; Fitzgerald et al., 2003; Chroust, 2000)	*Upfront (Static)*	Tailoring at the beginning of a project as part of project planning
	Tailoring "on the go" (Dynamic)	Tailoring during project execution, as processes/activities are encountered and in response to dynamic project changes
Knowledge representation (Helms, 2013, p. 26; Ittner, 2006, pp. 114–115; Graviss et al., 2016; Park et al., 2006)	*Rule-based*	Procedural knowledge representation: Rules represent if-then relations documenting the transition from an initial to a modified state. Rules often contain expert knowledge for problem-solving in the form of heuristics.
	Model-based	Declarative knowledge representation: Representation of knowledge in theoretical models of how a situation is or should be.
	Case-based	Drawing from analogies through the identification, adaptation, and application of similar, previous situations.
Model basis **(La Rosa et al., 2009)**	*Single model*	Use of a process line as a repository for context and process information
	Multiple models	Use of multiple, disparate models for context and process information
Context support (Hurtado Alegria, 2012, pp. 74–75)	*Context-based*	Selecting process variations based on context characteristics
	Manual tailoring	Tailoring the process without the aid of context characteristics

Key: *Focus within the scope of this thesis in regard to the intended tailoring support is highlighted in italics*

González et al. (2014) experimentally compare **automated** with **template-based** (cf. section 2.5.4) tailoring as intermediate steps between “no tailoring” and the definition of a new process for each project. **Automated** tailoring computes a project-specific process based on mechanisms prescribed by the particular tailoring method, while **template-based** tailoring uses predefined process variants. In their experiments, the authors have found automatic tailoring to be advantageous in terms of appropriateness of the resulting processes for the project situation. However, automatic tailoring involves sophisticated tools and high complexity in constructing the necessary models. They also conclude template-based tailoring has advantages, as long as the predefined process variants correspond to the most frequent project types, which requires careful specification in advance. They argue that the construction of predefined templates is comparatively easier. A certain risk of selecting an inadequate process remains, which requires additional manual tailoring. (González et al., 2014)

However, while being accessible, **template-based** tailoring also incurs increased effort for creating, maintaining, and evolving separate model variants, depending on the number of variants (cf. section 2.5.4) (Hallerbach, 2009, pp. 44–47; Hallerbach et al., 2010). It further limits the amount of variability that can be considered and hinders scalability (Graviss et al., 2016). Conversely, other authors consider automated approaches based on model transformations to be fast to apply, but the resulting processes to be inaccurate, requiring further adaptation (Pillat et al., 2015).

A further differentiation can be made regarding the **time of tailoring application**: Either **upfront**, by identifying an overarching set of project characteristics during initial project planning at project start, or **ongoing (“on the go”)**[37], during project execution as processes and activities are encountered and performed, or a projects characterization changes (Slaughter et al., 2006; Cameron, 2002; Fitzgerald et al., 2003, p. 70; Ferratt & Mai, 2010, p. 167). However, both are not mutually exclusive, with the latter representing modifications of the initially tailored process at project outset (Chroust, 2000), requiring short feedback loops (Karlsson & Hedström, 2009, p. 491).

If applicable, tailoring approaches also differ in the employed knowledge reuse mechanisms. While **case-based approaches** do have their strengths, they require an extensive knowledge base containing information about previous cases to be feasible (Helms, 2013, p. 37; Ittner, 2006, p. 114). For process tailoring, this means the tailored deployed processes and corresponding characterizations. Acquisition and maintenance of this data represent a challenge, due to the average length of development projects and requires suitable management systems (Graviss et al., 2016; Pillat et al., 2015, p. 113; Ittner, 2006, p. 114). Additions and alterations due to unforeseeable process and project characterization changes can cause the case basis to deteriorate and require re-training the selection and adaptation mechanism, e.g. a neural network (Park et al., 2006; Hurtado Alegria, 2012, p. 21). Rule-based approaches are seen as more adaptable and thus more reusable (He et al., 2008), albeit expert knowledge has to be externalized and generalized beforehand. Graviss et al. (2016) argue that using a rule-based

[37] In this context, Rupani (2011) further differentiates between planned, upfront “customization” and localized “deviation” during project execution. However, as ongoing tailoring within the scope of this thesis is also planned, this differentiation is not further used within this work.

approach to process tailoring can reduce the manual effort for tailoring SE processes. Several existing approaches already use hybrid rule- and model-based knowledge representation to automate tailoring (e.g. Hurtado Alegría et al., 2011; Pereira et al., 2007). Due to these considerations, **case-based approaches are not considered further within the scope of this thesis**, focusing instead on rule- and model-based approaches, which are seen as more suitable to codify expert knowledge. Case-based approaches have additional potential to extend review and improvement capabilities of tailoring approaches in future work (cf. Helms, 2013, p. 37)

Tailoring approaches can be further differentiated whether they capture the relevant tailoring knowledge in one **single** or **multiple** separate models. For example, context variables and values can be documented separately from process variants (cf. “templates”) or a process line, e.g. in the form of questionnaires (La Rosa & Dumas, 2008). The **use of a single model** to capture process and context knowledge is seen as beneficial for the scope of this work, as it mitigates data inconsistency and maintenance issues.

While most tailoring approaches are based on some form of explicit project **context** classification, **manual** tailoring without explicit, a priori context consideration is also possible. The process is tailored manually, for example when no suitable classification or rules are defined based on the implicit knowledge of the executing role. In this case, the thus gathered information can be documented later re-integrated in order to extend the context description and PrL. (Hurtado Alegria, 2012, pp. 74–75)

The attempt at a high-level characterization of tailoring approaches illustrates that a **broad spectrum of different approaches** has been developed thus far, stemming from different perspectives. The classification scheme and associated consideration of benefits and disadvantages allow to focus the selection of approaches relevant within the scope of this work (cf. section 4.2) and therefore focuses on relevant discerning characteristics. It is not intended to be exhaustive, as for example, it does not account for different concrete notations used for knowledge representation.

2.5.6 The role of stakeholders and the social nature of process tailoring

After characterizing the different possibilities of tailoring approaches, it is important to emphasize the **importance of stakeholders** and the associated **social aspects of process tailoring**.

Formalized systems development methods are a means to document and communicate **knowledge about the systems development process** ((Henderson-Sellers et al., 2014, p. 53; Ågerfalk & Fitzgerald, 2006) cf. also sections 2.2 and 0). Methods and processes are **social constructs**, which embed various assumptions about people and systems development (Henderson-Sellers et al., 2014, p. 53; Introna & Whitley, 1997; Russo & Stolterman, 2000). SiME has been described as a “social process” by Henderson-Sellers et al. (2014), which needs to take human factors such as values, attitudes and knowledge into account when constructing and adapting a “method”, as a method is only accepted and used if it is perceived as useful by its practitioners (Riemenschneider et al., 2002). This can be extended to process tailoring and deployed processes in iPD.

ISO/IEC/IEEE 15288 (2015) and ISO/IEC TR 24748-1 (2018) highlight the **importance of affected stakeholders in soliciting inputs regarding process tailoring decisions** (e.g. system stakeholders, interested parties, contributing organizational functions). Affected parties should be involved in adaptation decisions as they can help ensure that the tailored processes are feasible and useful. Moreover, project stakeholders can bring experience from previous projects. “Failure to include relevant stakeholders” is a common tailoring pitfall (Walden et al., 2015, p. 165).

Karlsson & Hedström (2009) and Karlsson (2008) describe method tailoring as a **form of “negotiation,”** and thus a highly social activity dependent on the cooperation between coworkers. The acceptance of a method (or process) is ultimately dependent on the opinions of developers’ coworkers and supervisors towards using it (Riemenschneider et al., 2002). Negotiation is necessary due to **different stakeholders holding and promoting different, often conflicting values** influencing the design of the process (Karlsson & Hedström, 2009). Karlsson & Hedström (2009, p. 498) thus depict tailoring as more complex than either 1) a highly rational process with project members as passive information providers or 2) an unstructured process based on individual choices by developers. Their study, based on Actor-Network-Theory, indicates that tools and approaches for method engineering should enable all project members to be “drivers” of the tailoring process, in order to let them address their particular needs for tailoring design decisions. On the other hand, tailoring is not a consensus process and does not guarantee that the emergent method will be followed by all project stakeholders.

2.6 Conclusions from background and fundamentals

The body of chapter 2 has clarified the following vital concepts as foundations for the subsequent work in this thesis: **Knowledge** as the fundamental resource required for both process modeling and tailoring, the **modeling and management of processes** (reference as well as deployed), the systems perspective on processes and associated **structural analyses** using matrix- and graph-based methods, as well as the different facets of **process tailoring** as the main focus of this thesis. Aspects of particular relevance for process tailoring, such as the acquisition and documentation of process context and variability, characterization of existing tailoring approaches, as well as the role of stakeholders have been highlighted.

Process modeling has been shown to be an important means for documenting process knowledge. The resulting process models support the subsequent management, analysis, and improvement of complex processes in PD. Therefore, process models are an essential vehicle for the successful management of development projects. As such, process modeling is also a **prerequisite to enable project-specific tailoring** of RPMs, or as Kuhrmann (2014) states: “You can’t tailor what you haven’t modeled.”

The available work on **structural analysis of process models,** using matrix- or graph-based approaches, provides a comprehensive toolbox to increase the understanding regarding a particular process’s structural characteristics and its resulting behavior, e.g. in regard to its robustness when performing particular changes to its structure. In particular, structural metrics enable the quantification and condensed presentation of structural characteristics of a given process. Furthermore, specialized, stakeholder-dependent **model views** can be defined to further reduce this complexity and facilitate comprehension. This work is considered to be of particular relevance in light of the **increasing PD process complexity**, e.g. due to increasing product complexity, number of involved disciplines and stakeholders, as well as the diversity of development goals. The existing work in this area, therefore, presents an **important methodical foundation** for the development of the tailoring support within this thesis.

While related work on process modeling and structural analysis can be considered well-established in the domain of iPD, work on **process tailoring** in this area has so far been less prevalent, although the influence of a projects' contextual characteristics on the underlying process is widely acknowledged (cf. e.g. Gericke et al., 2013). Process tailoring has been shown to be an important, yet fragmented research subject, with many contributions originating from the field of software engineering. It is adjacent to similar subjects and research areas, such as SiME and process variant management. Partial overlaps, for example, the use of context models to document the rationale of tailoring operations, complicate the delimitation of the subject. The characterization of current tailoring approaches provides a **starting point** for the development of the tailoring approach within this thesis. Tailoring approaches, while generally pursuing the same objective, have been shown to be diverse in their embodiment (cf. section 2.5.5), e.g. in terms of the utilized knowledge representation. The general classification allows further focus on approaches relevant within the scope of this thesis (cf. chapter 4).

The subsequent chapter 3 elaborates on the empirical aspects of the DS I, which serve to further inform the specification of an adequate support for tailoring complex PDPs in this work through the derivation of the supports' objectives and requirements. Based on the study presented in chapter 2 and the requirements in section 3.3, related tailoring approaches are presented and evaluated in chapter 4, after which the tailoring support is derived in chapter 5 and subsequently elaborated in chapters 6 and 7.

3 Empirical studies and requirements derivation

Chapter 3 presents the derivation of requirements regarding the tailoring support to be developed, in order to outline the rationale for the design of the tailoring support. Besides the theoretical basis outlined in the previous section, empirical sources have been used to inform the derivation of requirements. Therefore, first, the procedure and empirical sources are presented, followed by the derived empirical implications, before the specific core challenges and objectives to be addressed by the tailoring support are presented. To conclude the chapter, the final requirements for the design of the tailoring support are presented.

The final set of requirements subsequently form the basis for the analysis of related approaches (chapter 4) as well as the development of the tailoring support (chapter 5).

3.1 Elicitation of empirical implications

The first subsection of chapter 3 presents the empirical sources and derived implications for the subsequent formulation of support requirements, thereby augmenting the problem situation as derived from literature. Therefore, the procedure is presented first, followed by the derived implications per empirical study.

3.1.1 Procedure and empirical sources

Figure 3-1 presents the iterative procedure for deriving the tailoring support requirements: The challenges and gaps regarding process tailoring, as identified in the background and fundamentals, formed the starting point for further empirical studies, review of related work, and the eventual tailoring support development. The initial problem statement was further concretized through implications derived from the empirical studies. While the overall objective guided the research program, **applications of the tentative support** in evaluation case studies (DS II) and interviews further supported the successive clarification and adjustment of the tailoring support (Iteration 1) and the requirements (Iteration 2) (cf. section 8.1). For this, a tentative tailoring methodology has been defined, which was subsequently elaborated with supporting methods and adjusted in conjunction with the requirements clarification. This approach allowed to integrate new requirements in response to practical insights from the application case studies. For example, the **communication-intensiveness of tailoring and associated challenges** could only be discovered after the development and application of an initial methodology and metamodel (Iteration 3).

In conclusion, the applied procedure allowed for the necessary flexibility to react and adjust to insights from case studies while at the same time delineating an initial focus. The derived **final requirements** (cf. section 3.3) translate the problem description and overall support objective into concrete guidelines for the design of the tailoring support.

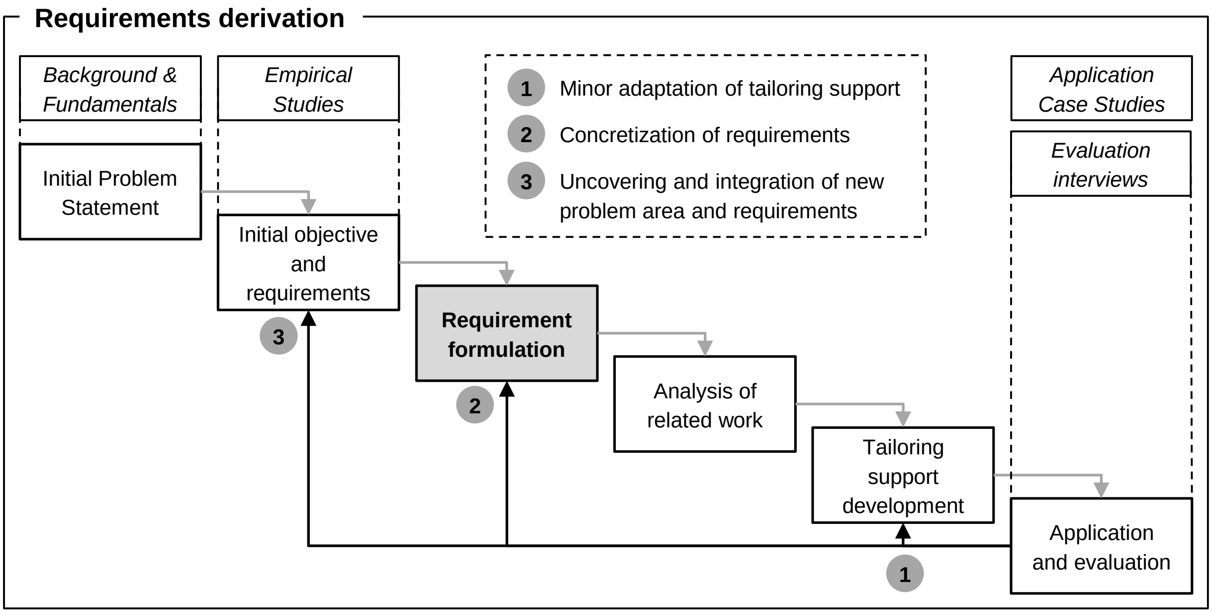

Figure 3-1: Procedure for derivation of requirements on the tailoring support

Five different types of empirical sources were used for the elicitation of implications and subsequent requirements derivation over the course of this work. These sources partially have been presented in Hollauer et al. (2016):

- **Workshop observation:** A process design workshop has been observed without involvement, which contributed to the RC and initial requirements definition
- **Exploratory case studies:** Three exploratory case studies have been conducted without applying any tentative tailoring support, in order to increase the understanding regarding the research subject (cf. Appendix A4.1, case studies X, Y, and Z)
- **Interview studies:** Two interview studies with process and project management experts in different PD companies contributed to generating initial insights into the current state of practice and issues regarding process design and tailoring
- **Focus interviews:** Two focus interviews independent of case studies helped illuminate focus issues (social aspects and structural complexity)
- **Application case studies/interviews:** The formative nature of the application case studies (DS II) contributed data for potential improvement and additional support requirements through observation, interviews, and lessons learned. This allowed to concretize and formulate problem areas not yet covered in related work (cf. also evaluation in chapter 8).

Since the **empirical sources are subject to different environments** and the individual observations and interview statements require interpretation, implications from the empirical sources were derived through **inductive reasoning**, starting with specific evidence found within the empirical studies and generalizing from there (Collis & Hussey, 2014, p. 342). **Triangulation** of different data sources and research methods has been applied in order to reduce bias and increase the validity and reliability of the derived requirements (Collis & Hussey, 2014, p. 71). Findings nonetheless reflect the opinions of a limited group of respondents and investigation subjects. While the derived implications therefore have to be considered within that limitation, some general themes can be identified due to the broad spectrum of respondents.

3.1.2 Empirical studies and derived implications

Based on the procedure for requirements elicitation described above, the primary empirical sources and derived insights are presented within this section.

Workshop observation

The observed workshop was tasked with the design of a process for new product development for an equipment supplier in the mobility industry. The off-site workshop lasted two consecutive days and involved 25 individuals from the company. The objective of the workshop was to define quality gates as well as activity descriptions within three separate stakeholder groups, which were to be collated at the conclusion of the workshop. The workshop was based on a process draft, developed by a consulting agency five years prior, but never implemented. Tailoring was not an explicit subject of the workshop. However, during the workshop, possible variabilities of the process to be defined emerged and were discussed by the participants but not explicitly documented. The resulting process model was generic and defined only on the level of overarching design phases and milestones, due to compromises participants had to make and disagreements regarding the level of detail as well as details to be contained in the process model. Table 3-1 summarizes the insights derived from the workshop observation regarding tailoring in practice. (Cf. Hollauer et al., 2016, p. 2025)

Table 3-1: Key implications from workshop observation

Key implications for objective and requirements derivation
Process design involves high effort and a large number of stakeholders
Implicit knowledge regarding the required situative adaptation of process models is available and expressable
Decisions for process adaptation are recurring
Processes are abstracted due to compromises, disagreements, as well as the lack of means to model variability

Interview studies

Two non-overlapping, qualitative, and semi-structured interview studies have been conducted, with an increasing focus on process tailoring. The organization and key insights (cf. Table 3-2) of the individual studies are subsequently summarized[38]. Semi-structured interviews have been chosen due to their suitability to test and deepen existing knowledge and generate hypotheses, particularly regarding innovative topics and complex systems (Kurz et al., 2009, p. 465), as

[38] For more details, please refer to the corresponding publications.

they allow the clarification of questions and further inquiries. The two studies and their corresponding topics are:

- **Study A:** Usage of process models in small-to-medium sized enterprises (SME) (Research project “A^{2}TEMP,” Hollauer et al., 2016, pp. 2012–2024)
- **Study B:** Current process tailoring practice and needs in companies of differing size (PE-Kajbring, 2016).

Within **study A**, semi-structured on-site interviews have been conducted regarding the design and use of process models in five small-to-medium-sized enterprises (SME) with a mechatronics background. All involved companies either had a PDP RPM defined or were actively working on its development. Only one company showed a rudimentary tailoring process, where tailoring decisions made by project leaders have to be documented in a corresponding template. However, the tailoring activity itself is not further supported.

Based on the previous studies, **study B** has been conducted to investigate the basic needs, challenges, and current approaches used regarding **process tailoring in industry** (cf. PE-Kajbring, 2016). During the study, experts from 10 companies ranging from very small to very large were interviewed, with questions focusing on the specific implementation of process tailoring within their respective organizations. In the case of one very large company, three interviews were conducted. Only one of the interviewed companies mentioned having a framework to explicitly support the adaptation of the RPM to specific projects, in this case, based on project assurance plans and different templates for different projects (n=1). The other interviewed companies either do not have a framework (n=6), the existence of a framework is unknown (n=1), or the adaptation is explicitly mentioned as being based on experience without further support (n=2). All interview partners agreed that the planning phase of a project is essential but very time-consuming. Tailoring itself has been mentioned to be very dependent on the experience of the project manager. Benefits of increased flexibility through tailoring have been evaluated ambivalently by interview partners, with some partners wishing more flexibility, and others expressing concerns that inexperienced project managers might be overwhelmed by too much flexibility. Another concern is the effort involved in tailoring. Companies are using indicators to measure the magnitude of projects, primarily budget (most frequent), project schedule, or team size. Level of technology, innovation, complexity, number of produced units and risk were also mentioned as relevant but are rarely applied. The interview study indicated that particularly larger organizations are aware of tailoring and acknowledge its necessity, while at the same time having experienced issues adapting the RPM. While the interview study itself did not investigate the underlying issues and challenges associated with process tailoring, it nonetheless allowed the derivation of implications regarding the development of tailoring support.

Table 3-2: Key implications from interview studies

Study	Key implications for objective and requirements derivation
A)	Process models in practice are regarded as inflexible yet need for adaptation is recognized
	Projects can be organized in recurring groups/categories
	Overall lack of systematic, explicit process tailoring in interviewed organizations

Study	Key implications for objective and requirements derivation
B)	Adaptation of RPM largely unsupported and dependent on project manager experience
	Project planning is considered important and "time well spent"
	Commonly application of more complex ("oversized") RPM on less complex projects
	Tailoring decisions use quantitative project measures, e. g. budget, project, schedule, or team size
	Some project properties and their process impact are difficult to measure (e.g. complexity and risk)
	Increased flexibility through tailoring can overwhelm less experienced project managers

Individual focus interviews

The third empirical source consists of two semi-structured focus interviews with subject matter experts (with previous tailoring experience) independent from the previous studies, in order to further deepen the understanding regarding two specific problem areas, namely the **structural complexity** of PDP RPMs, as well as **social aspects** related to process tailoring:

- **Interview partner A**: Process manager in an SME (internal supplier of mechatronic components for household appliances)
- **Interview partner B**: Head of project management office in an SME (mechatronic safety equipment for surge protection)

Interview partner A corroborated that the **structural complexity** of the RPM to be tailored, caused by the number of activities and involved disciplines and stakeholders as well as their various dependencies, hinders the application of process tailoring in practice. The interview partner explicitly mentioned examples of process tailoring approaches in literature to be too simplistic in comparison with process models encountered in daily practice.

Interview partner B emphasized the necessity for **communication and organization** between project stakeholders during tailoring, as well as the reliance on extensive, contextual, and implicit process knowledge. The interview partner has likened tailoring to a "negotiation" among project stakeholders (cf. also section 2.5.6), in particular between project leader and team. The tailoring decisions made for a particular project instance should furthermore be explicitly documented and released by the respective project leader in order to differentiate them from other reasons for process changes.

Table 3-3: Key implications from focus interviews

Study	Key implications for objective and requirements derivation
A	Structural complexity hinders tailoring by decreasing transparency and obscuring tailoring effects
	Structural complexity is caused by the number of activities, dependencies, and involved disciplines/ stakeholders.
B	Tailoring requires intensive communication within the project team.
	Tailoring requires contextual and implicit process knowledge from individual process participants
	Tailoring represents a form of negotiation between the project leader and the project team.
	Tailoring decisions for a particular project instance should be explicitly documented (traceability)

Formative application case studies

As stated above, the application case studies served to test and improve the developed tailoring support iteratively, thus also informed the definition and concretization of requirements and helped to uncover currently unsatisfied needs in industry. While the evaluation of the tailoring support is explicitly addressed in chapter 8, key implications with a **strong formative effect** on the tailoring support objective and requirements are presented in Table 3-4. Data points used to formulate requirements are **observations** by the applicant of the tailoring support, as well as **interviews conducted within the scope of the individual case studies**. The interviews were prepared in collaboration between the author and the students involved in the case studies, based on the identified state of the art. The interviews themselves were conducted personally in the interviewee's natural environment by the students involved in the respective case studies (Keuneke, 2005, p. 255).

Table 3-4: Key implications from formative application case studies (DS II)

Study	Key implications for objective and requirements
Over-all	Different initial situations (RPM available/not available) need to be considered
	Different process architectures/hierarchies need to be considered
	Different process modeling approaches (formal/informal) with different levels of detail are used
	Context factors depend on the organization as well as the investigated subprocess
	Process tailoring requires considerable effort, making approaches for effort reduction necessary
	RPMs are dynamic and change over time
A.1	Common process understanding required for context factor and commonality/variability acquisition
	Existence of a baseline RPM increases effectiveness of information acquisition
B.1	Sound understanding of process and recurring tailoring decisions as a prerequisite for tailoring
	Process tailoring should be applied by experts, not in an automated manner
	Corresponding tools and implementations should support, not replace, expert decision making
	Process tailoring can contribute to improving project planning (scheduling/budgeting)
C.1/ C.2	Asymmetrical knowledge distribution in organizations (different knowledge carriers with different knowledge, e.g. in-depth regarding individual activities vs. process overview)
	Documentation of tailoring decisions as simple as possible to be applicable
	Organization and management of tailoring process required (Governance)
	Strong social aspects; involvement of different stakeholders in tailoring activity required
	A reductive tailoring approach is preferable, starting from an oversized/"100%"-RPM
	RPMs need to be selectively extendable at review points
	RPMs are not always tailorable from the start (due to e.g. level of abstraction/granularity)
	Process element interfaces and dependencies are crucial when making tailoring decisions
	Communication is necessary between project stakeholders during tailoring decision making
D.1	Tailoring decisions can be identified from implicit and explicit knowledge
	Different interview techniques for different stakeholders (e.g. project managers vs. designers)
	Different rules and dependencies can be defined between as well as within context and process

3.2 Scope and objectives of the intended tailoring support

Based on the challenges and implications identified from literature and empirical studies, this section presents the resulting scope and objectives of the process tailoring support to be developed for complex PDP. Figure 3-2 visualizes the focused problem areas (cf. section 1.1.2), the impact and objective of the tailoring support to be developed, and its resulting expected benefits.

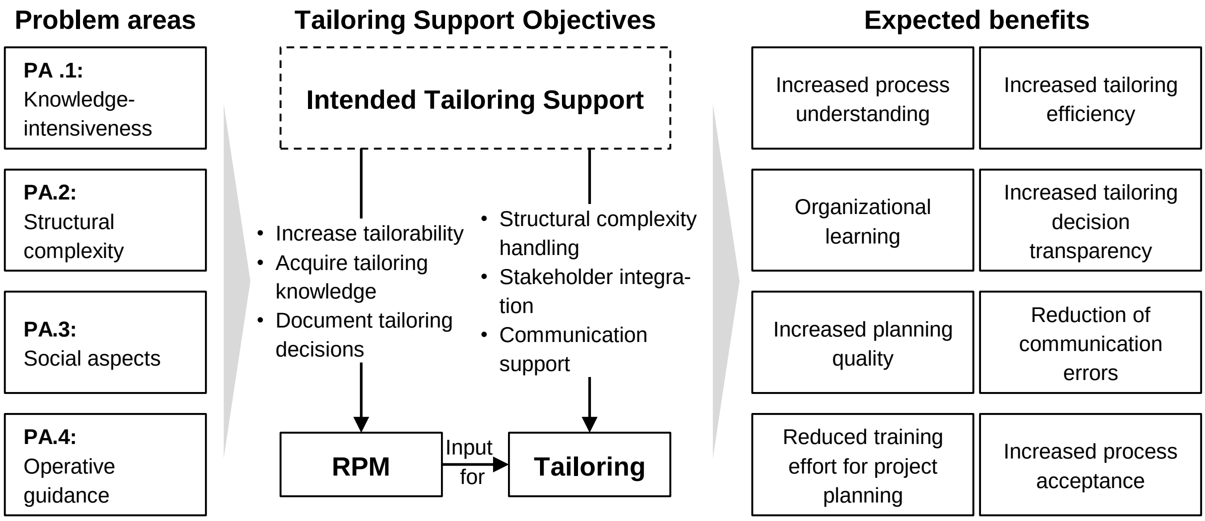

Figure 3-2: Problem areas, derived support objectives, and expected benefits of the tailoring support

The tailoring support particularly focuses on **mature organizations** with an iPD background and **complex and extensive PDP RPMs**. The envisioned tailoring support should support such companies to implement **explicit, project-specific** tailoring of the PDP RPM, with a particular focus on the identified problem areas.

The tailoring support should support an **initial build-up of tailoring knowledge**, as well as the **design and execution of the tailoring activity**. The tailoring support should provide a **low entrance barrier** regarding company-specific implementation.

By focusing on the overall process structure, in particular **activities and their dependencies**, the tailoring support addresses a **macro-level**, **top-down** perspective. This macro-level represents the level of the overall process network. It is targeted since structural complexity becomes visible at this level and can be investigated using structural metrics. The support should aid applicants in **handling structurally complex** PDP RPMs during tailoring, by generating and providing relevant information in a concise and accessible way. Conversely, the tailoring support is not intended to address an in-depth assessment and optimization of individual PD activities in terms of e.g. the cost-/benefit contribution to a project.

Support of the tailoring activity itself primarily addresses the identified **social aspects**, particularly the **communication-intensiveness**, by: Aiding the **identification of relevant stakeholders** for inclusion in tailoring decision-making regarding a particular project, actively **integrating** and **engaging** them in the tailoring activity, **providing relevant structural**

information to facilitate collaborative tailoring decision-making, and **fostering** and **structuring communication** between them.

The support consequently needs to support the creation of a **suitable knowledge basis** for decision-making by documenting recurring tailoring decisions in a reusable and analyzable format. To support the elicitation of distributed tailoring knowledge, the tailoring support needs to provide suitable acquisition methods, which can be selected and adapted based on the availability of information sources within a particular organization.

Furthermore, the tailoring support should include means to **increase the tailorability** of the RPM in case of an unfavorable initial situation, to increase the feasibility and applicability of the tailoring support.

While the automated generation of tailored, project-specific process models is explicitly out of scope, non-value adding activities within the tailoring support should be **reduced** as much as possible, in order to present a manageable required effort, e.g. by automating structural analyses. Due to expected changes in RPM, context, and relevant tailoring decisions, the tailoring support should also address aspects related to the **continuous review and improvement** of the documented tailoring knowledge by defining adequate feedback channels.

3.3 Summary of tailoring support requirements

Based on the previously elaborated background (chapter 2), empirical studies (section 3.1), and derived support objectives, the final set of requirements for the development of the tailoring support is presented in Table 3-5.

The requirements are categorized according to the following rationale: First, **general requirements** on the tailoring support are formulated. Based on the support objectives presented in the previous section, the overall tailoring support is decomposed into different **constituent elements**, resulting in the following requirements groups:

- **Operative guidance (Procedure),** which structures the activities required to be taken within the scope of the tailoring support and provides a framework for the further constituent elements.
- **Knowledge documentation,** which supports the capture of tailoring-relevant knowledge in a manner compatible with the objective of handling structural complexity.
- **Structural analysis**, which is to be applied to the documented tailoring-relevant knowledge in order to aid in handling tailoring of structurally complex RPMs.
- **Operationalization concept**, which details how to carry out tailoring for particular project instances considering social aspects, e.g. stakeholder integration and communication.

The derived requirements are used within the scope of this work to analyze existing related work regarding their suitability and to identify current gaps (chapter 4), as well as to guide the development and evaluation of the intended tailoring support (chapters 5 through 7).

Table 3-5: Final set of requirements for tailoring support development with indication of origin

ID	Requirement	E	L
General requirements			
G1	Support reductive tailoring of oversized RPMs and subprocesses	●	●
G2	Broad applicability through independence from specific products or industries		●
G3	Focus on structurally complex PDPs and corresponding RPMs	●	●
G4	Low barriers to implementation (compared to existing tailoring support)	●	●
Requirements regarding procedure			
P1	Structuring of required activities to support the initial introduction of process tailoring	●	
P2	Adaptability in regard to specific boundary conditions from the application situation	●	
P3	Provide support for the individual steps to be carried out	●	
P4	Support review and continuous improvement of the tailoring knowledge	●	
Requirements regarding knowledge documentation			
D1	Rule- and model-based documentation of recurring tailoring decisions	●	●
D2	Adaptability in regard to process modeling language and input information	●	●
D3	Establishment of an integrated knowledge basis for decision support during tailoring	●	●
D4	Compatibility of the modeling approach with selected analysis approach (cf. section 2.4)	●	
D5	Capture necessary process dependencies for analysis and impact assessment of tailoring decisions	●	
Requirements regarding structural analysis			
A1	Use and analysis of structural information as input for process tailoring support	●	
A2	Generation and provision of condensed information to support decision-making during process tailoring as well as its preparation	●	●
A3	Definition and contextualization of analysis methods to establish meaning in the context of tailoring	●	
A5	Automation of analyses	●	
A5	Flexibility in regard to input data	●	
Requirements regarding operationalization concept			
O1	Support the integration of process stakeholders during process tailoring	●	
O2	Support communication and coordination during process tailoring	●	

Key: *E = Empirical source; L = Literature-based source*

4 Related work

The following chapter presents the analysis of currently available related work regarding process tailoring. First, the investigated research areas and applied review procedures are outlined (section 4.1). The first research field focuses on approaches for supporting process tailoring using rule- and model-based knowledge documentation and their suitability to address the identified problem areas (section 4.2). On this basis, a second review is carried out, focusing on approaches for the analysis and visualization of tailoring knowledge (section 4.3). A third review, on workshop-based process tailoring approaches, concludes the review of related work (section 4.4).

The characterization of current approaches, as well as identified limitations and research gaps, form the guidance for the development of the intended tailoring support in the subsequent chapter.

4.1 Investigated research areas and review procedure

Process tailoring has been discussed in general in section 2.5.1, with a classification of tailoring approaches presented in section 2.5.5. Building on this, chapter 4 focuses on the identification of existing tailoring support approaches, and the analysis of their correspondence to the objectives and requirements outlined in sections 3.2 and 3.3. The objective of this review is to investigate the suitability of related approaches to fulfill these requirements, in order to identify remaining gaps, which need to be further addressed.

Investigated research areas

In order to enable a systematic review, the research areas relevant within the scope of this work (cf. Figure 1-2, p. 10) have been categorized into **areas of relevance** and **areas of contribution** (Blessing & Chakrabarti, 2009, pp. 63–66). The areas of relevance receive no direct contribution, but a thorough understanding (cf. chapter 2) is essential for the subsequent development of the tailoring support (cf. chapter 5). Areas of contribution are **process tailoring** and the systematic **analysis of process tailoring knowledge**. The development of tailoring support within this work aims to contribute to these areas directly.

Chapter 3 investigates these areas of contribution**,** identifying and discussing related approaches in order to characterize the current state of research regarding process tailoring support to identify remaining research gaps to be addressed by the subsequently developed tailoring support.

In the first step, approaches for **supporting process tailoring** in the form of methods, models, and tools have been selected and analyzed. In the second and third steps, approaches regarding the **systematic analysis of tailoring knowledge** and **workshop-based process tailoring** have been investigated, due to the specific problem areas targeted in this thesis (cf. section 1.1.2).

Review procedure

Since the research area of process tailoring is on the one hand rather fragmented, and on the other hand has overlaps with adjacent areas, e.g. process context and variability modeling, multiple literature reviews have been conducted in order to cover each of them adequately and enable cross-referencing (cf. Table 4-1). Starting from an **initial explorative review** (Hollauer & Lindemann (2017)), an initial set of approaches and research areas for further consideration have been identified. Subsequently, **thematic reviews** for these research fields have been conducted. The thematic reviews have been conducted in master theses under close guidance and supervision from the author. This strategy was chosen in order to capture multiple perspectives on the state of the art and prevent systematic errors (Kitchenham, 2004). The findings from the individual reviews have subsequently been used in order to select approaches, on the one hand, to analyze the state of the art and remaining research gaps, and on the other hand to identify partial support for the developed tailoring support (chapter 5).

Table 4-1: Reviews conducted per research area and topic

Subject (section)[56]	Research area	Documented in
Process tailoring support (section 4.2)	Process tailoring (initial, explorative)	Hollauer & Lindemann, 2017
	Process tailoring	PE-Langner, 2017
	Context modeling	PE-Gantenbein, 2017
	Process variability modeling/management	PE-Rogger, 2018
Analysis of tailoring knowledge (section 4.3)	Graph-based analysis of tailoring knowledge	PE-Kölsch, 2018
Workshop-based tailoring (section 4.4)	Workshop-based collaborative process tailoring and planning	PE-Rast, 2018

For the individual reviews, guidelines provided by established frameworks have been followed (Kitchenham, 2004; Okoli & Schabram, 2010; Fink, 2013; Webster & Watson, 2005). The **objective** for each review was to find suitable approaches in the respective research fields, which support process tailoring as defined within this thesis. **Process tailoring**, as well as process variability modeling/management, each have been investigated in a separate review, as they proved to be the most expansive areas. For each of the reviews, the applied **keywords** have been documented using a review strategy matrix, as have the number of identified approaches per database. The reviews included journal-, conference-, and book articles, using keywords in German and English. **Relevance criteria** have been defined per individual review, in order to generate relevant and manageable sets of results. Only accessible references were considered, and duplicates removed. After the keyword-based search, forward and backward publication-based search has been applied in order to identify further approaches of interest. As applicable, **identified review articles** have been used to further the review (e.g. Martinez-Ruiz et al., 2012; La Rosa et al., 2017). The data regarding the review procedures, as well as the results for each conducted review, can be found in Appendix A1.2.

4.2 Approaches for supporting process tailoring

Within this subsection, relevant related approaches concerning support for process tailoring are presented, with the intent to characterize the strengths and limitations of existing approaches.

This section is structured as follows: First, the review procedure and selected inclusion and exclusion criteria are presented (section 4.2.1). Subsequently, the selected approaches are briefly described to illustrate their respective objectives, structure, and applied mechanisms and technologies (section 4.2.2). The identified approaches are compared in section 4.2.3, drawing conclusions and implications regarding strengths and limitations, which guide the development of the tailoring support within this work.

4.2.1 Selection of relevant existing approaches

The selection of approaches supporting process tailoring is based on the conducted reviews, as presented in Table 4-1. The majority of results was generated from the initial explorative review and the review in PE-Langner (2017). Although originally developed as an approach for managing process variants, the PROVOP approach (Hallerbach, 2009), as identified through the reviews in PE-Gantenbein (2017) and PE-Rogger (2018), was also included in the selection, due to its comprehensiveness and similarity to other tailoring approaches.

The reviews were generally conducted as outlined in section 4.1: The keyword searches targeted approaches regarding process tailoring in the areas of business process management, software engineering, and PD. The variations of keywords and databases used for the reviews are documented in Appendix A1.2. During the publication-based search, the results have been extended using a forward and backward search. Several review articles were identified and used as further input, e.g. the literature review by Martinez-Ruiz et al. (2012) previously identified 32 relevant approaches between the years 1991 and 2009. Further reviews are provided by Martínez-Ruiz et al. (2013) and Hurtado Alegría et al. (2014) for process tailoring and La Rosa et al. (2017) for process variability modeling.

Since the individual reviews generated larger sets of results, the **inclusion and exclusion criteria** in Table 4-2 were used for the final selection of existing approaches. The criteria are based on considerations laid out in section 2.5 and the requirements in section 3.3. The following examples illustrate the criteria application:

- Situational Method Engineering (SiME) approaches have not been considered in this review as they primarily focus on synthetic tailoring
- ISO/IEC TR 24748-1 (2018) provides a sequence of activities but lacks a knowledge representation component and is thus excluded
- Asadi et al. (2010) has been excluded as the proposed process patterns focus on model-driven software architecture development and it lacks a clear prescriptive tailoring support

Table 4-2: Inclusion and exclusion criteria for the selection of process tailoring approaches

	Criterion	Derived from
Inclusion	Project-specific tailoring (“Level 2”)	Section 2.5.1
	Provision of a prescriptive and reproducible approach (e.g. Methodology, framework, model, method)	Section 1.2.1 (Overall objective)
	Model- and/or rule-based approach for knowledge representation	Sections 2.5.5 and 3.1
	Potential for general applicability in iPD practice (generalizability, low degree of abstraction, low prerequisites for application, industrial evaluation).	Section 1.2.1 (Overall objective)
	Focus on reductive tailoring	Section 2.5.5
	Publication date between 2006 and 2017	-
Exclusion	Approaches utilizing case-based knowledge representation	Section 2.5.5
	Approaches addressing “Level 1” tailoring	Section 2.5.1.
	Collections of empirically or theoretically derived context factors	Section 2.5.3/ A3.4.4
	Approaches focusing on synthetic tailoring	Sections 2.5.1 and 2.5.5
	Approaches focusing solely on the creation and modeling of process lines and variant management	Section 2.5.4
	Purely descriptive publications (case studies, literature reviews, surveys)	Section 1.2.1 (Overall objective)
	Approaches for tailoring project management techniques and methodologies	Section 1.2.1 (Overall objective)

4.2.2 Description of relevant approaches

This section briefly describes each selected approach, highlighting strengths as well as limitations. The approaches have been clustered according to principal authors in case of multiple publications and sorted chronologically due to the latest publication of each cluster.

Software-assisted tailoring of process descriptions (Ittner, 2006)

Ittner (2006) presents an approach to support the development of software systems to tailor software development processes. The approach comprises several elements: The formalization of tailoring decisions as rules by defining a formal (mathematical) model using deontic logic operators, a weighting system based on fuzzy logic, and an optimization algorithm for assessing and selecting tailoring configurations for a given situation. In contrast to other approaches, no metamodel in the form of a class diagram or similar is given. The deontic logic operators allow expressing when a tailoring option is necessary as well as feasible. The defined formal language is implemented in a Java-based prototype and applied to a small process example.

The approach is distinguishable from others, as it introduces fuzziness in the otherwise quite strict rule-based knowledge representation (Ittner, 2006, p. 115). The approach requires a software implementation to be applicable, which is not described in detail. The approach is also notable in that different types of tailoring decision-makers are derived based on the available data and knowledge regarding a tailoring decision, as well as how a software system can target to support these different types (Ittner, 2006, p. 128).

Neural network based tailoring (Park et al., 2006)

The approach by Park et al. (2006) addresses tailoring automation. The intention is to create a learning system with which more process tailoring steps can be automated, as more knowledge is gained. This is achieved by using a neural network instead of static tailoring rules. The method consists of three phases: 1) Process filtering, 2) Process reconfiguration, 3) Process feedback.

The filtering phase is automated using a learning neural network. For preparation, a flexible generic process must be developed in phase 1, consisting of an assembly of task components with attributes such as input and output artifacts (used to connect the tailored process). Besides this, the project context model must be defined and learning data provided. A limitation of this approach mentioned by the authors is the availability of sufficient learning data regarding tailoring results, which they alleviate by defining a synthetic learning set consisting of probable context factor combinations. For this learning set, “environment constraint rules” are defined, which are used to constrain relationships among context factors. Furthermore, “task subtraction rules” are defined in order to capture prior expert knowledge regarding tailoring. This data was augmented with externally acquired data from 181 cases from different companies. The synthetic and real learning data is fed into the neural network, where the relationships between project configuration and task appropriateness are calculated, finalizing the preparations.

Actual tailoring is then done by manually assessing the project context and feeding it into the neural network, generating the degree (interval between 0 and 1) with which each task can be adapted or is filtered out, depending on the threshold criteria set by the project manager.

Process reconfiguration is performed based on the filtered process elements and the input-/output-relations defined for each process element through “Process Configuration Rules.” During the final phase of process feedback, team members can grade the appropriateness of each task.

Process tailoring based on knowledge reuse (He et al., 2008)

The presented approach describes a process to be followed for tailoring software development processes. The process is split between the roles of “process engineer” and “project manager” and addresses the identification of organization-specific context factors as drivers of process variance.

The acquired tailoring knowledge is organized in packages of which each contains a specific “process driver” (i.e. context factor) along with the required modifications of the process. The packages are described using a provided metamodel and insert or adapt elements such as activities or iterations into the development process. The metamodel describes so-called “work definitions” consisting of work products (artifacts), activities, and roles.

Besides the documentation, the approach addresses a “conflict resolving model” for conflicts between packages that might occur when multiple packages are applied during tailoring. This model addresses two aspects: Where does the conflict occur? What action should be taken to resolve the conflict? The proposed model differentiates between conflicts regarding the same element (work definition) or a hierarchical decomposed element (e.g. replacing a sub-activity within a work definition). The conflict resolving model thus shows how to handle possible conflicts between different combinations of impact types, whether they address the same hierarchical level or a level and corresponding sub-level.

While the approach is evaluated using a literature-based software development reference model (Rational Unified Process) and details have been omitted, it is assumed that the basic methodology can also be used for organization-specific standard processes.

Risk management through process tailoring (Fontoura & Price, 2007; Fontoura & Price, 2008)

This work presents a metamodel ("Knowledge Base Class Diagram"), which integrates process aspects (element types) with risk factors, which are quantified and tracked using a GQM approach. Thus, tailoring is presented as an approach to managing project-specific risks in software development, by identifying risks beforehand and adapting the process based on the project-specific selection of relevant risks.

Besides the metamodel, initial operational guidance is given for acquiring the risk factors, deriving process impacts, and implementing the framework in practice. This guidance takes the form of a process model that covers the roles of process engineer and project manager, structuring the activities required in order to conduct the tailoring approach. For example, in order to identify project risks, the use of checklists (from literature and experience) within interviews and group sessions is advised. Risks are then to be prioritized (due to the large possible number) according to the probability and severity of occurrence. The foundation of the tailoring task itself is a framework from which process instances can be derived, consisting of a knowledge base, tailoring guidelines, and process configurations. The knowledge base comprises risks, instances of process elements, activity diagrams describing activity sequences per discipline, organizational and process patterns, rules to associate patterns to risks, preventive actions describing how process elements are to be deployed in the stored patterns, as well as goals, questions, and metrics for risk tracking. Process configurations represent predefined process models to act as starting points to define organizational reference processes. The tailoring guidelines are textual descriptions of how to further tailor each process element.

Software process tailoring (Xu & Ramesh, 2008b; Xu & Ramesh, 2007, 2003)

A generic model derived from empirical studies (grounded theory from case studies (Xu & Ramesh, 2007, p. 320)) is given to guide process tailoring efforts (Xu & Ramesh, 2007, p. 316; Xu & Ramesh, 2008b, p. 41). The model describes the iterations occurring during project tailoring, between the activities "Set project goals," "Assess/Adjust environmental factors," "Evaluate challenges," and "Tailor process." The authors stress the continued monitoring of the process tailoring strategies as well as the environment (Xu & Ramesh, 2007, p. 320). The model is focused primarily on process tailoring in order to manage a variety of challenges during development, related to the categories "Resource," "Communication," "Requirements management," "Political," and "Technical." Based on these challenges, several generic tailoring strategies are provided in order to address them, e.g. "Evaluate technologies (add)" to address technical challenges. This results in a set of 30 generic tailoring operations (Xu & Ramesh, 2008b). In earlier work, a tool to capture process tailoring knowledge has been developed, which is not referenced in the later publications (cf. Xu & Ramesh, 2003). The tool is used to capture context factors leading to necessary tailoring of the RUP.

Killisperger (Killisperger et al., 2009, 2010)

This line of research pursues the development of a framework, which allows instantiation of processes on multiple levels from a "standard process" via a "high-level instantiation," a "detailed instantiation" towards a final "implementation of the instantiated process." The high-level instantiation represents a pre-configured process based on information available at project start, which is stable throughout the project, such as general project characteristics (e.g. size of a project or required level of reliability of the resulting software product). The detailed instantiation is then frequently conducted during the project to tailor upcoming activities. In order to define instantiations, operators are defined, e.g. deleting activities or connecting resources with activities. These operators are applied in batch on the high-level instantiation and individually on the detailed instantiation. A metamodel for the required architecture is developed in order to realize this concept.

Systematic approach to process tailoring (Pereira et al., 2007; Pereira et al., 2012)

The approach focusses on describing a metamodel consisting of "elements, relationships, and well-formedness rules" to ensure consistency of the resulting process (Pereira et al., 2007, p. 1). The approach is itself targeted at tailoring the RUP. The well-formedness rules aim to constrain tailoring based on the underlying process model in order to maintain process consistency. Within the publications, the rules are informally described in the form of tables, since according to the authors UML (Unified Modeling Language) is not expressive enough to cover all rule descriptions. Tailoring within the scope of this approach consists of the operations addition and deletion, which are detailed for each metamodel element type (Activities, workflow detail, artifact and sub-artifact, and discipline). The approach thus gives guidelines, what needs to be considered during tailoring, when tailoring decisions are made for each instance of an option-element type combination. The approach is implemented in a software prototype and applied to the RUP standard model.

Model-Driven Engineering based tailoring (CASPER) (Hurtado Alegria 2012)

The work presented in this subsection is the subject of several publications, constituting one of the most extensive lines of research found in this field (Hurtado & Bastarrica, 2009; Hurtado et al., 2011; Hurtado Alegria, 2012; Hurtado Alegría et al., 2011, 2014). The main contribution of the work is an approach for the automation of process tailoring in software engineering based on the paradigm of Model-Driven Engineering (MDE). The approach provides a methodology (CASPER[39]) derived from Domain Engineering (cf. Czarnecki & Eisenecker, 2005), in order to define rules for an automated transformation of an RPM into a project-specific model (Hurtado Alegria, 2012, p. 37).

[39] Context Adaptable Software Process EngineeRing

Different formal metamodels are employed for defining the base process, process variability, and the process context. Model transformations are then used to define tailoring operations, describing how the RPM is to be instantiated for a specific context configuration, i.e. which elements should be copied to the instantiation or omitted. The approach is based in SPEM 2.0 for the definition of process models, UML for context models (resulting in a "Software Process Context Model," SPCM), and the Atlas Transformation Language (ATL) for the model transformations (Hurtado & Bastarrica, 2009, p. 2). These transformations are written in software code and enable practitioners to design new tailoring rules incrementally. A project-specific process is generated through the recombination of the partial tailoring transformations embodied in the transformation rules, during which selected elements are copied to a new model (Hurtado Alegría et al., 2011, p. 4) Variability is described as "process features" within the process model (Hurtado Alegría et al., 2011, p. 2). The approach has been evaluated in a medium-sized software engineering company, with tailoring rules impacting the selection of activities (Ortega et al., 2012). Furthermore, an approach to analyze and validate process models (AVISPA[40]) is developed but not directly related to the tailoring approach, as no relationship is elaborated (cf. Hurtado Alegria, 2012, p. 78).

While in principle applicable, the author notes the following limitations regarding the approaches' evaluation (Hurtado Alegria, 2012, 119, 144):

- The organization-specific definition of the context model requires more guidance and empirical support. In order to alleviate this limitation, a context configuration tool has been developed (Ortega et al., 2012).
- The transformation rules can become quite complex, partly due to the programming as well as the content (e.g. rule cardinalities).
- The ATL approach is considered unusable due to the high programming effort. A higher level of abstraction is suggested to facilitate rule definition.
- The addition of feedback loops to iteratively validate, enhance, and extend the tailoring knowledge (context, process, and rules) is suggested.
- The scalability of the approach for larger companies is not yet proven (Hurtado Alegría et al., 2014).

The approach has been extended by Silvestre (2015), addressing some of the limitations regarding the complexity of model transformations through tool support for rule definition, which in turn generates model transformations, essentially hiding the complexity involved. The approach is based on a "Variation decision metamodel" supporting rule definition. According to the authors, applicability is not guaranteed for more complex processes for larger companies.

Feature-based tailoring (Costache et al., 2011; Kalus, 2013; Kalus & Kuhrmann, 2013)

The developed tailoring approach for software engineering provides a modeling technique for characterizing projects based on feature model notation, together with generic context factors (Kalus & Kuhrmann, 2013) and tailoring operators collated from literature. The feature-based

[40] Analysis and Visualization in Software Process Assessment

tailoring method, as presented in Kalus (2013), is independent of the chosen standard process and the underlying metamodel (in the publication called "methodology"). Within the developed method, guidelines are given for the definition of the context model, variability points, as well as the development of a tool to apply feature-based tailoring. Furthermore, example cases are given for evaluation and to illustrate the generic and abstract concepts (Costache et al., 2011; Kalus, 2013).

The approach focuses on the software implementation aspects to create context-configurable process models via the aforementioned feature modeling approach but does not elaborate on how to carry out the tailoring activity itself.

Activity-based software process lines tailoring (Lorenz et al., 2014)

The approach presented is based on the use of process lines, which improves the consistency and compatibility of the resulting tailored process, according to the authors. The process line approach is combined with the selection of process elements using project characteristics. The underlying metamodel is based on the SPEM as well as the RUP and documented using UML. In order to derive suitable process elements for a project, the Analytic Hierarchy Process (AHP) is used, and the approach is implemented in a web-based prototype.

The approach is specifically targeted at tailoring to conventional ("planned") and agile deployed processes, based on the respective characterization (cf. Lorenz et al., 2014, p. 1364). For project characterization, the "Octopus Model" is used, resulting in pre-defined context variables. Process architecture elements are classified into optional and mandatory as well as concrete and abstract elements. Abstract elements form variation points, which can be replaced with concrete elements. Concrete elements themselves cannot be varied. In order to organize the process line, partitioning according to disciplines is proposed. Activities are selected due to prioritization according to the AHP.

While the general approach is outlined, details such as the use of the AHP are omitted. The developed approach is evaluated using two academic case studies.

BPMNt (Pillat et al., 2015; Pillat et al., 2012)

The explicit main contribution of the BPMNt approach is the integration of tailoring capabilities into the existing Business Process Model Notation (BPMN) (Pillat et al., 2015, p. 112). This is achieved through the extension of the BPMN metamodel to include tailoring relationships currently defined in the Software & Systems Process Engineering Metamodel 2.0 (SPEM 2.0) (Pillat et al., 2012, p. 1; Pillat et al., 2015, p. 98). The approach thereby focuses on extending the "activity" element type, addressing relationships for the decomposition of activities and inheritance between activities. These are further enriched using tailoring operators, for example for when process elements are added (extension), contribute to (copying), replace other activities, or are deleted. This is realized through the introduction of the new class "TailoredBaseElement," from which tailorable elements are instantiated. Applying the modeling language allows the definition and representation of intricate relationships between process elements and effects between them due to tailoring (e.g. the deletion of entire activity hierarchies, or the extension/replacement of individual sub-activities).

The approach is used to model both the standard process model and the derived tailored model by only describing the differences to the standard process model (variability), effectively documenting the effects of the tailoring decisions (implicitly) made. It can thus be characterized as an approach to capture and model the outcome of a specific tailoring situation (i.e. a tailored process variant), traceably documenting its relationship to the base model and avoiding the creation of independent instances for tailored processes. Modeling of the process context or a specific project configuration as a basis for tailoring decisions is not described (Pillat et al., 2015, p. 112).

While the approach addresses the need for tailoring operations in order to derive the final, tailored model, guidance on how these operations are to be derived and subsequently performed is not given. The authors evaluate their approach to be of high effort and error-prone due to the amount of manual work required. Furthermore, the approach currently only supports ad-hoc tailoring, omitting the use of context factors for tailoring rationale. Possible interferences between tailoring operations are also currently difficult to predict a priori, and compliance with the standard process is not guaranteed, which would require the inclusion of process constraints. (Pillat et al., 2015, p. 112)

Value-Based Software process tailoring framework (Zakaria et al., 2015a)

Zakaria et al. (2015a) propose a conceptual process tailoring framework based on the assumption that a project-specific process should only contain value-adding activities related to project goals or stakeholder satisfaction. The framework structures the activities required to tailor an organizational reference process per this assumption. The approach uses 28 so-called "value-based factors" derived from a literature review as well as an exploratory survey in the Malaysian public sector. These factors need to be rated by a project manager for specific projects. The elements of the process are subsequently mapped to the rated value-based factors and rated. Based on a prioritization of the value-based factors, a tailoring recommendation is derived as input for the tailoring decisions made by the project manager. The inputs are a process element recommendation, a tailoring operation recommendation (add, delete, modify), and a tailoring rationale recommendation that justifies the impact. This input will then be used to tailor the process. As supporting measures, assessment criteria (for assessing value-based factors and process elements) and tailoring operation criteria (recommending suitable tailoring operations) are developed. As mentioned by the authors, the framework is currently in early stages. Details on the prioritization of process elements as well as an evaluation are not provided.

Tailoring systems engineering processes (Graviss et al., 2016)

The approach presented by Graviss et al. (2016) represents one of the few approaches originating from the domain of systems engineering. The approach acknowledges and builds on the research performed in software engineering (predominantly rule-based approaches), yet deliberately chooses to follow a simpler approach, e.g. omitting CBR approaches and extensive software implementation. The approach consists of a methodology in which an initial set of tailoring considerations is supplied (derived from an analysis of the INCOSE Systems Engineering Handbook), from which a subset is selected for a particular organization. Based on this subset of considerations, a rule set is then developed, linking the selected tailoring considerations with the organizational reference process. The rule set is realized as a matrix, essentially representing a Domain Mapping Matrix (cf. Lindemann et al., 2009), using conditions as tailoring operators: “Standard,” “Tailored,” and “Deleted.” “Tailored” subsumes other operators, such as merging stages or reviews, or repeating activities.

The approach has been evaluated in an industrial case study, effectively reducing the manual effort required to tailor an organizational process.

PROVOP (Hallerbach, 2009; Hallerbach et al., 2010)

The PROVOP (Process Variants by Options) approach aims to address the limitations of conventional single- and multi-model approaches for managing multiple process variants by realizing a configurable PrL (cf. section 2.5.4). The approach addresses all process lifecycle phases: Process modeling, configuration, execution, and maintenance/evolution. Therefore, a base process (e.g. the most common variant, or a core- or umbrella process model) is extended with so-called “variation points,” onto which change operations can be executed (insert, delete, modify, move).

The approach is a form of “fragment customization,” as change operations are grouped to form “options” (cf. La Rosa et al., 2017 and section 2.5.4). Options can be applied in combinations, are predefined, but do not guarantee correctness. Options can further be applied directly or on the basis of context factors (static, i.e. fixed after application or dynamic, i.e. changeable after application). It is possible to define dependencies between context factors as well as options, in order to prevent illegal configurations.

The approach is predominantly applied to business processes. Examples from iPD are a standard automotive engineering change management process and a process for verification of virtual prototypes.

4.2.3 Comparison of relevant approaches and conclusions

Section 4.2.3 compares the identified relevant approaches using specific assessment criteria. In order to compare the relevant approaches, first the assessment criteria are described. The comparison itself is then presented in Table 4-3 and subsequently discussed.

Assessment criteria for comparison

The applied assessment criteria are derived from the identified problem areas which are targeted in this work (section 1.1.2) and concretized in the objective (section 3.2) and requirements (section 3.3).

Focus: The determination of the focus is based on the sequence of steps in tailoring approaches (Figure 2-8, p. 62) and the main contribution of the approach. Besides this, several approaches focus on the *implementation* of software systems with tailoring capabilities (e.g. Kalus, 2013).

Origin: Approaches can originate from *Software Engineering*, *Systems Engineering*, *iPD* (without further specification), and *business process management*.

Primary tailoring mechanism: The selected approaches have been analyzed in terms of how tailoring is carried out. This can be realized through complete *automation* based on a project characterization, interactively with *software assistance*, or *manually*. Not all approaches explicitly specify the tailoring mechanism. As can be seen, most approaches pursue an automated or software-assisted approach in order to reduce tailoring effort.

Input: The required input for the tailoring approach specifies whether the context and process knowledge modeled as part of the approach is pre-defined (e.g. generic context factors or a literature-based process), or whether this input is acquired organization- and process-specific. Most approaches follow the latter approach. However, the process model to be tailored needs to be stored in the tailoring knowledge repository. Process models are commonly seen as static, with changes induced by tailoring needs generally not addressed.

Knowledge: Knowledge-related aspects describe whether 1) an approach provides a suitable, graph-/matrix compatible **metamodel** to document process and context knowledge and 2) whether methods for the **acquisition** of the relevant – often implicit – tailoring knowledge are provided. While a large number of well-developed metamodels are available, acquisition methods are less common and, when mentioned, often not elaborated.

Guidance: Operative guidance indicates whether approaches provide an explicit **sequence** of steps to be followed to apply and implement the approach, as well as whether concrete **methods** and support are given to carry out these steps. While most approaches define such a sequence, the individual steps or often abstract and do not describe applied methods in detail (cf. acquisition methods below).

Structural complexity: As this work focuses on structurally complex PDP RPMs, the existing approaches have been analyzed whether they provide means for handling this complexity. None of the selected approaches explicitly addresses this criterion. Instead, structural complexity is mostly managed implicitly through modeling and storage in corresponding software systems.

Social aspects: The final criterion indicates whether social aspects, such as communication with and between project stakeholders, are addressed in the approach. Besides a reference for differing tool support depending on the user's data availability and experience (Ittner, 2006, p. 128), and a remark that tailoring can be carried out in workshops with a project's team (Kalus, 2013, p. 161), social aspects are not further addressed.

Comparison of related tailoring approaches

Table 4-3 shows the comparison of the selected tailoring approaches according to the described distinguishing criteria. The comparison is accompanied by a discussion and the derivation of guiding conclusions for this work. The assessment is based on the author's opinion.

Table 4-3: Comparison of relevant tailoring support approaches

						Problem areas					
	General aspects			Input		Knowledge		Guidance			
Approach[41]	Focus	Origin	Primary tailoring mechanism	Context	Process	Metamodel	Acquisition	Sequence	Methods	Structural Complexity	Social aspects
Ittner, 2006	Implementation	SW	Automated	F	F	◑	○	○	○	○	◑
Park et al., 2006	Preparation	SW	Automated	F	F	◑	○	●	○	○	○
He et al., 2008	Conflict resolution	SW	SW-assisted	F	F	●	○	●	◑	○	○
Fontoura & Price	Preparation	SW	N/S	F	F	◑	○	○	○	○	○
Xu & Ramesh	Preparation	SW	N/S (manual)	F	F	○	◑	●	◑	○	○
Killisperger et al.	Implementation	SW	Automated	F	F	◑	○	●	○	○	○
Pereira et al.	Preparation (Modeling)	SW	SW-assisted	F	F	◑	○	●	○	○	○
CASPER	Preparation (Modeling)	SW	Automated (ATL)	F	F	●	◑	●	◑	◑	○
Feature-based Tailoring	Implementation	SW	Automated	F	F	●	◑	●	○	○	◑
Lorenz et al. 2014	Preparation (Modeling)	SW	SW-assisted	P	P	●	○	●	○	○	○
BPMNt	Preparation (Modeling)	SW	Automated	F	F	◑	○	◑	○	○	○
Zakaria et al., 2015a	Preparation	SW	N/S (manual)	P	F	○	○	●	○	○	○
Graviss et al., 2016	Preparation	SE	N/S (manual)	P	P	◑	○	●	◑	○	○
PROVOP	Preparation	BP, iPD	Automated	F	F	●	○	●	○	○	○

Key:

Software development (SW),
Systems Engineering (SE),
Business process (BP),
Interdisciplinary Product development (iPD)

SW = Software, N/S = not specified

F = Flexible, organization-specific input, P = Pre-defined input

yes ●, no ○, mentioned but not described or incomplete (metamodel) ◑

yes ●, no ○, mentioned but not described ◑

yes ●, no ○, partially ◑

[41] Name/acronym of the approach, or core authors are used as reference in case of multiple publications. The order of approaches mirrors the order of the preceding subsections.

The comparison shows that tailoring support approaches generally exhibit a large variety in their characteristics (cf. also Table 2-15, p. 66) and originate predominantly from software engineering. The selected approaches mostly **focus on the elaboration of the model- and rule-based knowledge documentation**, providing extensive metamodels with considerable expressiveness based on various existing modeling languages and formalisms. The developed metamodels for formalizing tailoring knowledge in an object-oriented manner are well established, built on previous work such as *tailoring tables* (cf. Ginsberg & Quinn, 1995, p. 34), and generally compatible with or transferrable to matrix- and graph-based approaches. Most metamodels provide means to document the process, process variability, and process context, as well as rules to formalize tailoring operations. These metamodels are often derived from Domain Engineering approaches (e.g. Feature Modeling), which in turn also originates in Software Engineering. In this capacity, the description of most approaches focusses on preparatory work, aiming at the creation of configurable RPMs and the implementation of systems capable of tailoring RPMs in an automated or software-assisted manner.

Due to this focus, most approaches concentrate on addressing technical issues and are arguably **targeted less at directly supporting tailoring practitioners**, such as project managers, but at **providers of process management software**, due to the technical expertise, knowledge, and implementation effort required. The presented approaches depend on specific technologies for implementation, e.g. the Atlas Transformation Language for model transformation (Hurtado Alegria, 2012). Thus, tailoring practitioners profit only indirectly, when they get to use the implemented tailoring systems, which first need to be integrated within an organization. Consequently, how the activity of tailoring an RPM is to be actually carried out is **only touched upon briefly** in most approaches, for example, because it is done automatically based on the characterization of a particular project. Zakaria et al. (2015a) describe "tailoring recommendations" as input for project managers, but do not elaborate on how tailoring is done based on this information.

While most approaches structure the required steps and activities (cf. section 2.5.5), the descriptions of these steps are often abstract, **without providing concrete methods**. In particular, methods on how to **acquire** the necessary, organization-specific (i.e. contextual) tailoring knowledge required for creating the knowledge base are often omitted or mentioned without further elaboration. The provided procedures can be used as starting points for further detailing. Simultaneously, most approaches start with an existing (pre-defined), organization-specific RPM, which is assumed to be a static boundary condition and subsequently tailored using tailoring rules formulated with organization-specific context factors. How to deal with RPMs that are not immediately suited for tailoring and require adaptation in order to accommodate tailoring needs is generally not addressed.

None of the approaches provide explicit support for **handling the structural complexity of PDP RPMs**. Instead, this complexity is dealt with implicitly through software-assisted modeling and interaction with process and context information, as well as tailoring rules. However, no approaches could be identified which aim at increasing insight, comprehension, and understanding by tailoring practitioners in regard to the acquired and modeled knowledge. One exception is the AVISPA-approach presented by Hurtado Alegria (2012), which represents an approach similar to structural analysis as discussed in section 2.4.3 in order to visualize process model error patterns. However, the relationship between tailoring and AVISPA is not elaborated. It is not intended to support the tailoring activity itself, as its objective is to analyze and validate process models. It could, however, serve to analyze the quality of RPMs and deployed processes before and after tailoring. This approach contributed to the decision to review work related to the structural analysis of tailoring knowledge in subsequent section 4.3.

While software support is nonetheless essential for supporting the management of complex processes and projects, an overreliance on software and automation can be **detrimental to fostering process understanding,** as the tailoring knowledge is “locked” in the repository, which does not necessarily encourage regular examination. The tailoring knowledge stored in the repository becomes obscured, e.g. by hiding vital dependencies. In the case of process configurators, it only becomes visible as the final result, i.e. the deployed process. It is less accessible and needs to be updated regularly in order not to deteriorate. As the empirical implications (section 3.1) show, such a high degree of automation is **not necessarily desired by practitioners**, as it can ignore valuable experience and implicit knowledge from project managers and other stakeholders. Automation approaches do not aim at fostering communication during tailoring, as tailoring is reduced to a configuration task. Furthermore, tailoring rules not included in the repository are **inaccessible and inapplicable during automated or software-assisted tailoring**, which represents a severe restriction in complex and dynamic environments. While model- and rule-based approaches are very suitable to document expert knowledge, tailoring processes purely based on rigidly defined rules can only be as accurate as the modeled knowledge allows. The tailored processes thus represent suggestions of limited accuracy, which subsequently need to be discussed regarding their suitability and fine-tailored on a case basis (cf. also section 2.5.5).

The selected approaches are described as being **suitable for highly variable process models**. While the expressiveness of the modeling languages is considerable and should be able to deal sufficiently with a multitude of situations, their **capacity for scaling is often not elaborated** and mentioned as a limitation. Evaluation examples are often focused on proving the modeling approaches’ feasibility, and therefore often of small-scale, not representing the scale and complexity of RPMs in practice, which impedes their acceptance (cf. section 3.1).

In light of the outlined focus of the selected approaches, **none explicitly address social aspects** during tailoring, such as supporting collaborative tailoring through the integration and coordination of, as well as communication between tailoring stakeholders. However, the importance of stakeholders and corresponding social aspects has been emphasized previously in literature (cf. section 2.5.6) as well as corroborated through empirical studies in this work (cf. section 3.1).

Conclusions and implications for this work

As the comparative evaluation shows, no identified and selected approaches conform to the applied selection criteria and address the targeted problem areas. The identified approaches mostly address technical issues related to the implementation of configurable process models, albeit through a variety of approaches and technical solutions. Tailoring practitioners, such as project managers, only indirectly benefit from these identified approaches, which heavily depend on software implementation in order to become applicable.

Consequently, approaches are required which provide **more direct tailoring support for practitioners**, independent of particular tailoring-capable process management software implementations and modeling languages. Also, approaches are necessary, which more adequately **address the identified problem areas**, especially aiding practitioners to tailor structurally complex, large-scale PDP RPMs by providing corresponding information, as well as supporting social, stakeholder-related aspects of tailoring related to the communication-intensiveness.

The selected approaches do however provide extensive and expressive metamodels, as well as generic sequences and activity descriptions, which can be used as a basis to formulate such an approach. Further, more focused reviews are necessary to identify candidate solutions to address the identified gaps, which are elaborated in the subsequent sections 4.3 and 4.4.

4.3 Approaches for structural analysis of tailoring knowledge

Based on the identified problem areas and the previous analysis of general tailoring approaches, a further review was conducted in order to identify approaches focused on the analysis of tailoring knowledge using graph-based approaches. This section is based on work performed in the unpublished student thesis PE-Kölsch (2018), with extracts published in Hollauer et al. (2018b).

4.3.1 Selection of relevant existing approaches

The identification of approaches is based on a systematic literature review following a keyword- and publication-based search. Due to the graph-oriented nature of most process models as well as the possibility to express context factors and tailoring rules as graph-/matrix-based representations (as evidenced by approaches presented in section 4.2.2), this review focuses on the utilization of graph-based analysis approaches for analyzing tailoring knowledge, in order to generate additional information from acquired and modeled tailoring knowledge. For the review, **three iterations with expanding scope** have been conducted, due to a lack of results in the previous iteration. The individual scopes and corresponding number of results per iteration are presented in Table 4-4. The data for all conducted iterations is given in Appendix A1.2.5 (keywords and results).

Table 4-4: Performed search iterations and corresponding results

Iteration	Scope of iteration	No. of results
1	Graph-based analysis of modeled tailoring knowledge	0
2	Graph-based analysis of knowledge documented in rule form	2
3	Analysis of knowledge documented in rule form without specified analysis form	12

4.3.2 Discussion of results

Within all three iterations, no approaches could be identified which directly address the stated objective of analyzing modeled tailoring knowledge utilizing graph-based approaches. However, the approaches which have been identified after completing the third search iteration utilize social network analysis and structural metrics (cf. section 2.4.3). The vast majority of the identified approaches investigate the handling of knowledge (management, sharing, transfer, etc.) within organized social networks (organizations, research groups), as opposed to the structure of modeled knowledge, which is the objective within this work. Zhiyang & Lu (2009) come closest to this objective by utilizing knowledge documented using a Wiki platform as the subject of their analysis by calculating the Degree Centrality, average path length, and clustering.

4.3.3 Conclusions and implications for this work

Since the scope of the investigation can be considered comprehensive, the lack of results in this review indicates that this particular avenue of research has thus far not been widely considered. However, **analyzing tailoring knowledge via graph-based means is seen as a feasible approach to support tailoring of structural complex processes** for three reasons.

First, a majority of process modeling languages used in practice exhibit a graph-like structure (cf. section 2.4.3). Therefore, in practice, many **process models are already depicted as graphs** or networks of multiple node and edge types.

Second, the structural analysis of PDPs and PDP models via graph- or matrix-based approaches has been **established in previous work** to be feasible as well as beneficial, e.g. in order to identify critical process elements such as bottlenecks. In particular, structural metrics can be used to provide a condensed overview of structural characteristics, which can potentially satisfy the need for relevant information during tailoring.

Third, besides process models, **context information, as well as tailoring-relevant dependencies between context and corresponding process model, can be expressed using graph-/matrix-based formalisms**. This is indicated through the modeling approaches described in the previous section: For example, Graviss et al. (2016) use a matrix-based approach to formulate tailoring rules, while Hurtado Alegria (2012) presents an extensive metamodel which can be transformed into a graph-based representation. The “Feature Model”-approach underlying many context modeling techniques is also often represented via graphs.

Based on this reasoning, graph-based structural analysis will be used as a candidate solution and adapted, in order to **address the identified problem areas** in the following ways: By generating condensed information about tailoring operations, which is required when making tailoring decisions regarding structurally complex processes, and by identifying vital communication needs between tailoring stakeholders.

4.4 Approaches for workshop-based tailoring

The comparison of existing tailoring support approaches has shown that current approaches do not sufficiently address social aspects, such as stakeholder integration, coordination, and communication. Therefore, another review has been conducted in order to identify approaches that can be utilized to address this gap.

4.4.1 Selection of relevant existing approaches

In order to fulfill the requirements regarding the support of social aspects in the form of coordination and communication between tailoring stakeholders, **workshop-based approaches have been selected for further review**. Collaborative workshops are generally seen as beneficial in project planning due to the reasons described in section 2.3.3. Hence, the objective of this review is to identify whether suitable, workshop-based approaches exist, which can be utilized to realize collaborative process tailoring.

In order to increase the scope of the review, the search included keywords targeting at identifying workshop-based approaches for process tailoring as well as project planning (cf. data in Appendix A1.2.6). To identify relevant results, only prescriptive approaches describing the workshop-based implementation of tailoring were considered. Simultaneously, advancements of software reference processes (e.g. Extreme Programming, Rational Unified Process, etc.) were excluded.

4.4.2 Discussion of results

The systematic review only yielded ten results with low relevance for the objective at hand, as while referencing process tailoring, no workshop-based approaches were described.

A concluding, open search for "Tailoring Workshops" led to the identification of the *Disciplined Agile Delivery*[42] (DAD) framework (Lines & Ambler, 2015, 2018b, 2018a). The DAD framework is an agile process framework for software delivery and can be characterized as an extension of the SCRUM framework by combining different agile methods such as Kanban, Lean Software Development, and others. The authors describe the framework as "*a people-first, learning-oriented, hybrid agile approach to IT solution delivery. It has a risk-value delivery lifecycle, is goal-driven, enterprise aware and scalable*" (Lines & Ambler, 2015). DAD is therefore intended to be a hybrid approach focusing on software delivery, i.e. construction of software from an initial concept (Lines & Ambler, 2015).

The DAD framework uses tailoring workshops in order to guide development teams through the adaptation of the framework in order to define a model for cooperation and create a shared

[42] Over the course of this work, the name of the framework has been changed from "Disciplined Agile Delivery" to "Disciplined Agile" to reflect its increasingly expanding scope. The term "Disciplined Agile Delivery" is continued to be used within this work, as it remains the central aspect referenced here. (cf. http://www.disciplinedagiledelivery.com/introduction-to-dad/)

vision, choosing and adapting a lifecycle (i. e. process), discussing process goals, roles, and responsibilities. The description of tailoring workshops stresses their nature as a facilitated discussion instead of enforcing project leaders' views as well as the documentation of the tailoring decisions made. The tailored process does not have to be optimal but can be adjusted at a later point during a project. (Lines & Ambler, 2018a)

While in principle suitable, the described tailoring workshop concept diverges from the objective in this work in three important aspects, which require adaptation:

- Tailoring workshops are used to tailor a pre-defined agile framework with a focus on software engineering.
- Tailoring workshops do not address the adaptation of organizational PDP RPMs in iPD. Consequently, the issue of how to handle structural process complexity is not addressed.
- Tailoring workshops use a set of fixed context factors ("scaling factors") as input, not acquiring and utilizing organizational-specific context factors or tailoring rules.

4.4.3 Conclusions and implications for this work

Although the review did not yield relevant results regarding prescriptive approaches for addressing social aspects during tailoring, the general indication given by the DAD framework is that workshops should provide a suitable basis to address the identified lack of social aspects in existing tailoring approaches (see also classification in section 2.5.5, Hanssen et al., 2005). Workshops can be expected to provide a suitable platform for integrating project stakeholders, fostering communication between project stakeholders affected by tailoring decisions, as well as subsequent collaborative decision making[43].

Despite the described deviations from the objective, tailoring workshops as described in the DAD framework serve as the basis for the formulation of an adapted workshop-based process tailoring support within the context of this work.

In order to facilitate workshop-based tailoring of structurally complex PDP RPMs, relevant and condensed information regarding needs to be provided during their preparation and execution (cf. section 4.3.3). Therefore, the workshops need to be applied in combination with a suitable form of knowledge documentation and structural analysis in order to prepare the required information for decision-making.

4.5 Summary and conclusions from related work

The conducted review of related work showed that within the set review parameters, a number of approaches for supporting process tailoring exist, mainly using a model- or rule-based form of knowledge representation for documenting contextual tailoring rationale and operations in reductive tailoring of organizational RPMs (cf. section 4.2). These selected and presented tailoring support approaches generally describe similar steps and activities required for their implementation, which are used as a basis for the tailoring support developed within this work.

[43] As identified in case study C.2, in some instances workshops are already used for tailoring (cf. section 8.2)

However, the focus of the selected approaches is mostly set on describing the **metamodels** utilized for knowledge documentation and **solving technical issues** associated with the corresponding implementation. They also aim at complete or partial automation of the tailoring activity based on the documented knowledge. In this capacity, the tailoring approaches are arguably intended more to support the implementation of tailoring capabilities in tailoring tools and process management systems through corresponding companies and experts, and less to directly support tailoring practitioners in carrying out tasks associated with tailoring, such as project managers. The approaches do not provide operative support for applicants on how to actually carry out the necessary tasks during tailoring. Instead, tailoring activities are reduced and abstracted through the introduction of software support for automation. While this can increase efficiency, it does not necessarily improve comprehension of the process to be tailored and limits the applicable tailoring to previously documented information. The identified approaches, however, do provide a comprehensive and tested basis of metamodels for the documentation of tailoring knowledge, such as the process, context description, and tailoring operations.

None of the identified approaches address all identified **problem areas**, the importance of which has been corroborated via a combination of literature as well as empirical studies. In particular, the selected approaches do not sufficiently address how to support the handling of structurally complex process models during tailoring, as well as how to support social aspects of tailoring, such as dealing with the communication-intensiveness and collaborative tailoring. For example, the presented tailoring approaches are evaluated to be able to handle high variability in processes and document the associated knowledge. However, scaling of these approaches to handle extensive processes with a high number of elements and dependencies is not elaborated, as evidenced by evaluation examples, which are generally of small-scale, representing local subprocesses with a limited number of elements and involved stakeholders. Therefore, tailoring support is needed which is specifically designed to address these gaps. Due to this insight, further reviews were carried out in order to identify approaches suitable to address these gaps, which can be integrated. These two focused reviews only generated **limited results**, further corroborating that support to address these gaps is currently also limited. Nonetheless, they provide valuable directions for the development of tailoring support.

The **structural complexity** can be addressed through the use of structural analysis methods. In particular structural metrics are suitable due to the rationale described in section 4.3.3. Using **structural metrics**, relevant information for tailoring decision making regarding structural process complexity can be generated from the acquired and modeled tailoring knowledge and subsequently provided to tailoring stakeholders in a condensed manner.

The described social aspects can be addressed through a **workshop-based approach**, based on the reasoning outlined in section 4.4.3. The concept of tailoring workshops, as outlined in the DAD framework, is used as a basis for the definition of a tailoring workshop concept. As it diverges from this thesis' objective, adaptations are necessary.

The derivation of the overall tailoring support and its constituent elements is outlined in the subsequent chapter.

5 Derivation of the constituent elements of the tailoring support

Chapter 5 details the derivation of the tailoring support, its conceptual design, and constituent elements. This chapter intends to bridge the gap between existing related work and the developed tailoring support by outlining the rationale guiding the development of each constituent element. On the one hand, partial solutions for tailoring support are already available, such as constructs for the documentation of tailoring-relevant knowledge. On the other hand, other aspects are based on existing work resting within other research areas, but novel with regard to process tailoring, such as the metric-based structural analysis. Hence, the tailoring support represents a combination, transfer, and adaptation of different aspects from existing work, resulting in newly developed elements, which specifically address the identified gaps in existing tailoring approaches.

The detailed description of the tailoring support is subject of chapters 6 and 7, respectively elaborating the metamodel and the methodology, which integrates all constituent elements.

5.1 Constituent elements of the tailoring support

The overall structure of the tailoring support conforms to the general definition of a **methodology** as proposed by Estefan (2008): It represents an overall **procedure**, structured using phases, steps, subprocesses, and roles ("collection of processes") with supporting **methods** (e.g. for information acquisition), a **metamodel** ("modeling basis"), and **tools** (e.g. for structural analysis). An initial version of the procedure presented in Hollauer et al. (2016) acted as a framework which has since been iteratively detailed and improved upon by subsequent research activities, causing e.g. alterations in the order and focus of the activities and resulting in the developed constituent elements as depicted in Table 5-1 (cf. Hollauer et al., 2018c). Table 5-1 further indicates to which of the specified **problem areas** (PA) and **research questions** (RQ) a constituent element contributes and in which section it is derived as well as described. For example, the tailoring role model contributes to PA 3 and 4, as it integrates project stakeholders and facilitates the implementation of the tailoring methodology.

Within chapter 5, the elements are described separately, focusing on their derivation. Subsequently, the metamodel and the methodology are elaborated in chapters 6 and 7, with the description of the constituent elements integrated into the methodology. Figure 7-1 (p. 126) gives a graphical overview of the constituent elements, their relationships, and position within the overall tailoring methodology. The constituent elements are subsequently not presented in their order of development but in an order to maximize understandability.

Table 5-1: Constituent elements of the tailoring methodology

Name	Description	PA	RQ	Der.	Descr.
Procedure	Structure of phases and activities required to implement and conduct workshop-based tailoring.	4	1	5.2	7.1.2 7.1.3
Tailoring role model	Roles define responsibilities for executing the methodology as well as process tailoring.	3, 4	1	5.2	7.1.4
Information acquisition methods	Catalog of methods supporting the acquisition of context factors and process variability.	4	2	5.2	7.3
Tailoring workshop concept	Workshop concept for collaborative process tailoring by integrating relevant stakeholders	3,4	4	5.2	7.6
TSM Metamodel	Metamodel for graph-based documentation of acquired tailoring knowledge.	1	3	5.3	6 7.4
Analysis framework	Submethodology for metric-based quantification and visualization of structural characteristics.	2, 3	5	5.4	7.5
Key: *PA = Problem area; RQ = Research question; Der. = Section of derivation; Descr. = Section of description*					

5.2 Development of the procedure and supporting methods

The first constituent element described in this section is the overall **procedure**, which offers operative guidance for the user, and provides the framework for integrating the other constituent elements. Supporting elements derived within this section are: The **tailoring role model**, **information acquisition methods,** and the **tailoring workshop concept**. The development of the metamodel and analysis framework are described separately in subsequent sections.

Procedure: Derivation of the phase structure

The methodology is intended as a modular guideline (Braun, 2005, p. 153), which can be adapted to different application situations. Therefore, a **baseline procedure** has been developed, which provides a sequence of phases indicating the standard procedure (cf. section 7.1.1). From this baseline methodology, three adapted sub-classes have been derived based on situations encountered in the application case studies, illustrating possible adaptations in practice (cf. section 7.1.2). As shown in section 7.1.2 and applied in several case studies (A.2, A.4 E.1, F.1), the methodology can also accompany the design of a new process reference model. In this case, it aids in increasing the understanding regarding the process to be developed and its variances from the beginning. The methodology in this function is intended to extend, not replace, existing approaches for process design, such as SIPOC sheets or flowcharts.

As depicted in Figure 5-1, the baseline procedure is derived from a combination of the **comparative analysis of related procedures** (cf. section 2.5.5) and the approach of *Structural Complexity Management* (StCM) (Lindemann et al., 2009). The latter is chosen due to the similarity in objective, as the structure of the documented tailoring knowledge is analyzed in order to derive additional insights for application during workshop-based tailoring. While

StCM initially focused primarily on product design, it has been shown to be applicable to process analysis (e.g. Kreimeyer, 2010).

Iterations within and between phases are possible and sometimes necessary, for example within information acquisition as well as between modeling and information acquisition. The methodology allows for such iterations, which are explained in A3.2. The procedure is further structured using **quality gates**, which contain vital questions to assess progress and define the deliverables required to proceed.

Based on this procedure, the individual phases have been adapted and elaborated with corresponding methods, in order to support their execution. These methods address the lack of operative support in existing approaches, for example regarding information acquisition. The individual phases are outlined in section 7.1.1 and elaborated in sections 7.2 to 7.6.

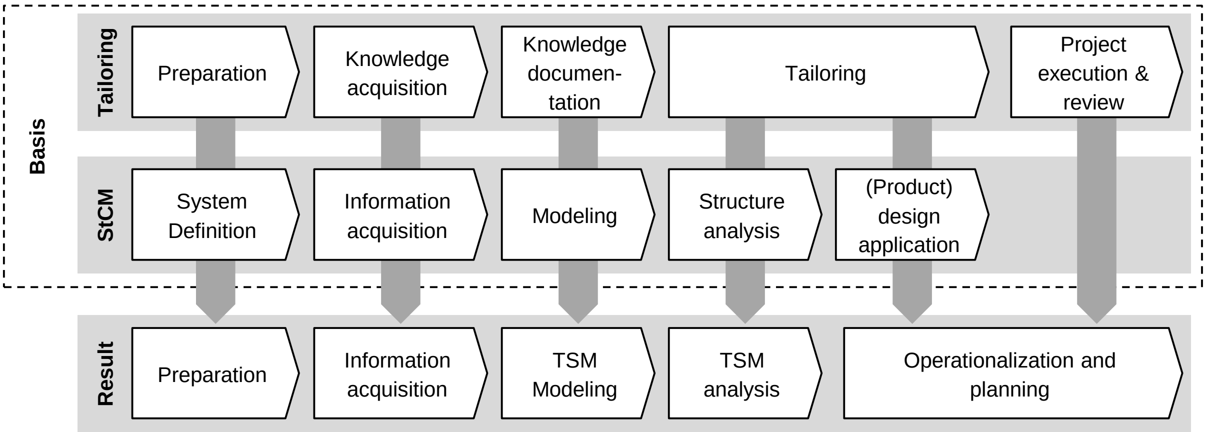

Figure 5-1: Derivation of procedure for tailoring methodology based on existing tailoring procedures (cf. section 2.5.5) and Structural Complexity Management (cf. Lindemann et al., 2009, p. 64)

Tailoring role model

The implementation of the methodology and process tailoring is facilitated by a **tailoring role model**, which groups activities and skills required within the scope of the methodology into different roles. The roles are independent of individual role holders (Gulliksen et al., 2006) as well as pre-defined roles in organizations, although possible role owners are suggested.

As depicted in Table 5-2, the composition of the tailoring role model has been derived from two similar models in the literature. The table shows the comparison of two existing role models based on their equivalent role descriptions. The roles are categorized according to the associated management function. Similar to the focus of existing tailoring approaches (cf. section 4.2.3), the role models focus on supporting the creation of tailorable process models, their software implementation, and software-based adaptation. Eventual **end-users of the tailored process** (i.e. project stakeholders) only receive minor attention.

Table 5-2: Description of roles associated with process tailoring in related work

Mgmt. function		Role model	
Process	**Project**	**Kalus (2013, pp. 145–146): Feature-based tailoring**	**Hallerbach (2009, p. 60): PROVOP**
●		**Process Engineer:** Responsible for the development and maintenance of the RPM. Has profound knowledge of RPM structure, content, and editing tools.	**Base process modeler:** Defines the base process and variation points
			Context modeler: Defines context model with variables, values, and constraints
			Variant modeler: Defines change operations and options
●	●	**Developer:** Creates RPM content, based on feedback from the RPM application.	
(●)		**Technical Developer:** Implementation of the RPM and associated tools.	**Implementer**: Implements the process in an IT-System and creates workflows.
	●	**Process User:** Adapts the reference process during project initialization (usually the project leader)	**Variant responsible**: Configures process variants manually or context-based
	●		**Operator**: Operates the IT system/workflow during execution
	●		**End-User**: Uses the IT-System/is a participant of the workflow

Key: *● = Associated of role to function (assessed within the scope of this work); (●) = Not relevant within the scope of this work*

The role model developed in this thesis follows a similar logic but emphasizes the integration of project stakeholders during workshop-based tailoring. Detailed roles related to the technical implementation of tailoring support are therefore omitted, while project stakeholders tasked with executing activities during projects are explicitly included, as they have vested interests in the resulting tailored process, and thus, the tailoring activity. Within the scope of this thesis, the following roles have been defined: **Tailoring Expert, Tailoring Organizer**, and **Tailoring Stakeholder.** The roles are presented in Table 5-3 and structured according to their level of overview, which corresponds to the department and organizational level of hierarchy with which they are associated. The defined roles are described in section 7.1.4.

Table 5-3: Process-related functions (cf. sections 2.3.3 and 2.5.6) and derived tailoring roles

Mgmt. function		
Process	**Project**	**Derived tailoring role**
●		**Tailoring Expert:** Member of process management (process manager, process owner), tasked with carrying out the tailoring methodology, coordinating acquisition, modeling, and review of tailoring knowledge.
	●	**Tailoring Organizer:** Member of management for a particular project (project leader, planner, etc.) tasked with carrying out workshop-based tailoring.
	●	**Tailoring stakeholders:** Stakeholders of a particular project with vested and possibly conflicting interests in how a process is tailored for the particular project.

Per organization, each role can be held by one or several individuals. Conversely, in smaller organizations, individuals can hold several roles simultaneously, such as the role of tailoring expert as well as tailoring organizer. The individual roles are further detailed by describing their characteristics (cf. Gulliksen et al., 2006; PMI, 2013, p. 262), such as responsibilities, authority, and required skills and expertise. Further characteristics have been defined specifically with the tailoring methodology in mind, such as the level of required overview and insight regarding the TSM, and specific information concerns/requirements of a role regarding tailoring.

Information acquisition methods

In order to address the lack of operative support for **information acquisition,** a catalog of methods has been compiled from literature and the conducted evaluation case studies. The methods for information acquisition address the identification of knowledge regarding **process variability** as well as **context factors**.

Regarding the acquisition of **context factors**, a structured literature review was conducted which identified two general groups regarding methods for the acquisition of a processes' application context (PE-Gantenbein (2017), cf. section 2.5.3 and Appendix A1.2.3):

- **Identification based on generic lists** (e.g. Du Preez et al., 2009; Gericke et al., 2013). Approaches of this group use lists of generic context factors to support the acquisition of organization-specific context factors. Most approaches use a single- or multi-level categorization of context factors, with the final number of context factors ranging from less than 25 (Ponn, 2007) to 239 (Gericke et al., 2013).
- **Discursive identification** (e.g. Lindemann, 2009; Badke-Schaub & Frankenberger, 2004). Methods of discursive identification use supporting questionnaires, or investigate diverging performance indicators (Ploesser et al., 2009) or influences on process goals (Rosemann et al., 2008) in order to characterize process contexts.

Literature-based approaches can support the initial reflection and formulation of possible context factors, but are insufficient to give concrete insights into organization- and process-specific context factors (Hollauer et al., 2018c). The two identified method groups serve as a basis for further detailing and concretization. As part of developing the tailoring methodology, specific acquisition methods have been created and tested, in response to the availability of process, project, and context data within the individual investigated case studies. As a consequence, the group of discursive methods has been further split into methods using **implicit** (such as interviews and observations) as well as **explicit information** (Figure 5-2), with explicit information further segregated into RPM (e.g. pre-defined process variants etc.) and project (e.g. project plans, requirements documents etc.) related information.

The same groups are used to structure methods for the **identification of process model variability**, thus forming a framework of eight categories for information acquisition methods. The identification of variabilities in organization-specific PDP RPMs in the form of generalized lists was not further investigated. Methods from literature as well as empirical studies are further used to fill the individual categories. For example, in case study D.1, project-plans in a machine-readable format were available, prompting the use of statistical analysis in order to identify the frequency of activity execution over the investigated projects as well as the likelihood of activities occurring together in projects. In cases C.1 and C.2, previously documented tailoring rationale was available as checklists, and in case C.1 a priori defined process variants have been compared for variabilities. In further cases (E.1 and F.1), no such information was available, prompting the sole use of interview techniques as well as observations to access implicit information. The information acquisition is further supported by existing methods such as **stakeholder analysis**. The collated and developed methods for information acquisition are described in section 7.3.

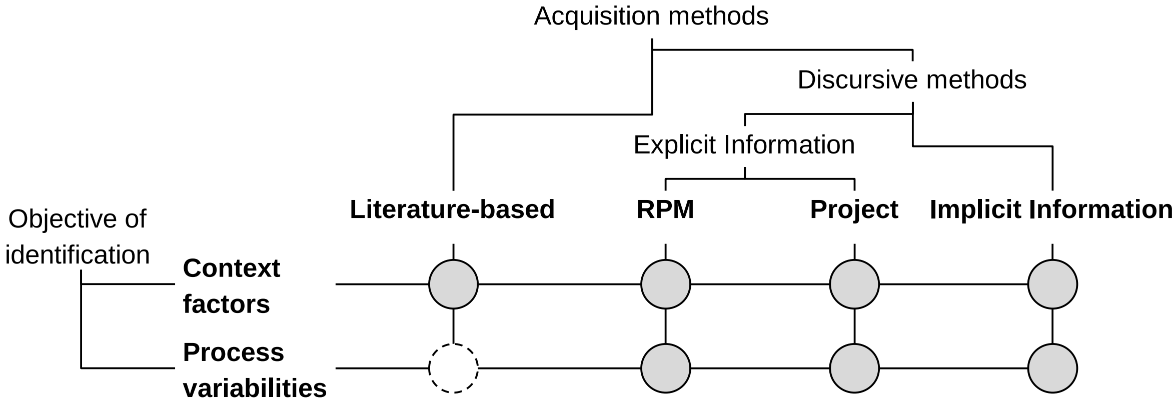

Figure 5-2: Possible categories of information acquisition methods

Tailoring workshop concept

In order to satisfy the requirements regarding social aspects, a **concept for tailoring workshops** has been developed to facilitate collaborative decision making between tailoring organizers and relevant tailoring stakeholders. Workshops have been selected as they allow participants to focus on a defined objective by being removed from regular work, integrate different perspectives, and increase the acceptance of the measures defined within the workshops (Lipp & Will, 2001, p. 16; Beermann et al., 2015, p. 7).

As the literature review indicated, workshop-based collaborative process tailoring is not yet extensively covered in literature. Only the DAD framework (Lines & Ambler, 2015) has been identified to describe a concept for process tailoring workshops (cf. section 4.4). This concept has subsequently been adapted in the context of this thesis to better address tailoring of organizational PDP RPMs and to integrate contextualized knowledge as described by Xu & Ramesh (2008a), in the form of organization-specific context factors, tailoring rules, and the situated integration of tailoring stakeholders and their implicit knowledge. The workshop concept has further been developed based on best practices described in literature (cf. e.g. Ruedel, 2008; Hamilton, 2016). A first iteration of the workshop concept has been developed based on the DAD framework and tested in case study E.1 (PE-Saad, 2018), which was subsequently refined and applied in case study C.1 (PE-Rast. 2018). The development of the workshop concept is based on requirements derived from literature and refined based on interviews (N=11) conducted during case study C.1 (cf. Table A-50, Appendix A3.7.1).

The workshop concept is applied in phase 5 of the methodology. Within the workshops, analysis results from phase 4 are applied in the form of reports (containing e.g. prioritized tailoring rules, relevant stakeholders with common tailoring concerns) The developed tailoring workshop concept is documented in the form of a **procedure and a checklist**, providing guiding questions and heuristics to support activities for the preparation and execution of individual workshop instances. Furthermore, workshop materials and methods are suggested.

The developed tailoring workshop concept is described in section 7.6 and has been applied and evaluated in case studies C.1 and E.1 (cf. sections 8.2 and 8.3).

5.3 Development of the TailoringSystemModel metamodel

This section outlines the reasoning and procedure for the development of the metamodel (cf. section 2.4.1) to document tailoring knowledge.

By applying the metamodel as part of the methodology, the organization- and process-specific **TailoringSystemModel (TSM)** is created in phase 3. The developed metamodel is described in chapter 6 and its application in Phase 3 of the methodology in section 7.4. The metamodel is represented in two ways (cf. chapter 6 and Appendix A2.2): A **hierarchy** defining inheritance relationships between node- and edge-types and detailing the corresponding attributes, and as an **MDM** (Lindemann et al., 2009, pp. 67–78), detailing the edge types connecting the different node types. Details regarding the individual element classes along with attributes are provided in Appendix A2.2.

Regarding the scope of the metamodel, a trade-off had to be found between extensiveness and understandability. Therefore, the metamodel represents a **core metamodel**, which needs to be adapted on an individual case basis, especially in regard to the nomenclature and hierarchical structure utilized within the process and organizational domain. Further tailoring operators can also be included at a later date.

The **development** of the metamodel has been guided by established procedures for the development of metamodels, ontologies, and knowledge-based systems, in particular, Noy & McGuiness (2001). Based on these, the **procedure** presented in Figure 5-3 (left side) has been defined, which extends existing procedures by the choice of representation, clarification of modeling constructs, and empirical testing. Steps 1-6 of this procedure have been carried out iteratively, adapting the metamodel to new insights, mainly due to input from case studies and requirements originating from the TSM analysis (additional element types and attributes). In consequence, the metamodel has been **progressively elaborated and detailed**, as indicated in Figure 5-3 (right side).

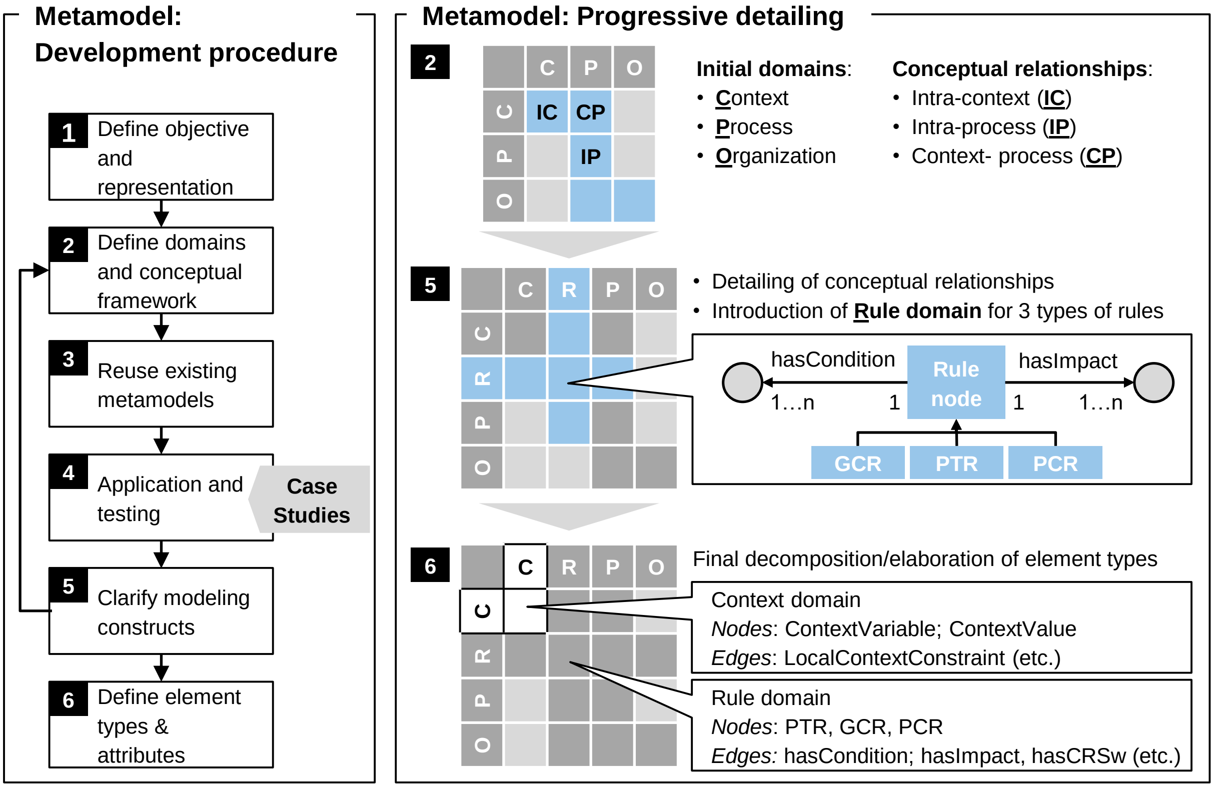

Figure 5-3: Metamodel derivation: Procedure (left, based on Noy & McGuiness, 2001) and progressive detailing (right)

Step 1: Define objective and representation

The scope of the metamodel is derived directly from the overall objective of the tailoring methodology (step 1), within which the metamodel fulfills the following **objectives:**

- Support the externalization and re-distribution of tailoring knowledge to foster reuse
- Provide a syntax for documenting of context-based tailoring operations (rules)
- Document dependencies between context factors (e.g. constraints)
- Document tailoring-relevant process and organizational dependencies
- Enable a systematic structural analysis of the TSM to support collaborative tailoring

In light of these objectives and the intended application for complex PDP RPMs, models are expected to comprise a large data volume (cf. Lindemann et al., 2009, pp. 4–5; van Beek & Tomiyama, 2008, p. 169). Matrix-based representations can quickly become inadequate in regard to the manageable amount of data (Browning, 2001, p. 302). Within the scope of this thesis, the implementation has been chosen to be based on **typed attributed graphs** for data storage, which allows the automation of analyses via **graph rewriting** (Helms, 2013, pp. 55–56; Kissel, 2014; Heckel, 2006). A typed attributed graph allows to assign attributes to both node and edge types. This approach also enables the translation of the graph into a matrix representation in order to use corresponding analysis methods (Lindemann et al., 2009, p. 98). The metamodel represents a **domain-specific language** (Paige et al., 2014, p. 2), which is implemented within this thesis using the software Soley Studio[44].

Step 2: Define domains and conceptual framework

The metamodel objectives lead to the definition of the initial metamodel domains (step 2), namely the **process** and its application **context**. The **organizational domain** has been included due to the explicit focus on project stakeholders within this thesis.

As a basis for further elaboration of the metamodel, a **conceptual framework** has been defined in MDM notation, depicting which high-level, **conceptual relationships** are required within and between these domains, as illustrated in Figure 5-3 (right side). These conceptual relationships can be of **intra-domain** (connecting nodes within one domain, e.g. the context), as well as **inter-domain** (connecting nodes between two different domains) nature. This framework forms the basis for further progressive detailing in steps 3 and 5.

Step 3: Reuse existing metamodels

In step 3, existing metamodels for all defined domains have been analyzed to identify candidate node and edge types for the elaboration of the domains (step 4). The metamodels investigated in this step originate from general process modeling and analysis, process tailoring, context modeling, and process variability modeling. A table of the main contributing metamodels and the covered domains can be found in Appendix A2.1.1.

The elaboration of the **process** domain is rooted in previous work by Kreimeyer (2010), Heimberger (2017), and Browning (2014b). A basic process metamodel is used, comprising a reduced subset of process element and dependency types, focusing on activities as the element types encountered most often in process models within the case studies and addressed most often by existing tailoring approaches (Martinez-Ruiz et al., 2012). Activities allow to encapsulate process variability, for example, due to different applied methods, created deliverables, or further attributes (e.g. incurred costs). Temporal and logical dependencies between activities are expressed through precedence. The hierarchical decomposition of activities is described via “isPartOf”-dependencies.

The main approaches from **process variability modeling** (cf. sections 2.5.4 and 4.1) used here are activity modes (Lévárdy & Browning, 2009), and PROVOP[45] (Hallerbach et al., 2010), which also uses a feature-model based approach to model process element variants. These approaches formed the basis for extending the process domain with variability modeling constructs.

The **organizational domain** is elaborated based on Heimberger (2017, p. 92). Node types relating to individuals, roles, and organizational units are used and connected to activities.

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[44] www.soley.io

[45] “Prozessvarianten durch Optionen” (engl.: Process variants by options)

Metamodels for the **documentation of process contexts** frequently reference **feature modeling** (cf. sections 2.5.3 and 4.1). The thus identified approaches have also been used to define candidate element types and attributes required for the context domain of the metamodel.

Existing tailoring approaches have been primarily used to identify candidate element types to elaborate the dependencies between the context and process domains. As the focus lies on reductive tailoring, primary tailoring operators (cf. section 2.5.5) are the removal of process elements and the selection from different process element variants. More complex operators have been omitted for this thesis but could be included in future extensions, e.g. moving activities within the process network. The introduction of the rule node type to accommodate the formulation of more complex rule cardinalities is elaborated in step 5 (cf. section 2.5.5).

Step 4: Application and testing

The elaboration of the metamodel has been accompanied by testing within the conducted application case studies (A.2, A.3, A.4, B.1, C.1, D.1) (step 6). Tests of the initial metamodel established that some of the conceptual relationships **require more complex graph patterns** to allow more complex rule cardinalities (cf. section 2.5.5, Figure 2-9), leading to a further elaboration of the metamodel in step 5.

Step 5: Clarify modeling constructs

In step 5, the high level, conceptual relationships, namely intra-context, intra-process, and context-process relationships, were further differentiated, decomposed, and detailed by defining graph modeling constructs to realize the individual relationships, while taking the insights from step 4 into account (cf. PE-Philipp, 2017). This analysis of each conceptual relationship as defined in the modeling framework resulted in two different modeling constructs for their implementation:

- **Dependencies:** Simple edge types connecting two nodes
- **Rules:** A pattern consisting of a rule node and two edges of different types, pointing to elements corresponding to rule condition and impact as depicted in Figure 5-3

The generic rule pattern allows the formulation of complex rules using graph elements. It requires the introduction of the **rule domain,** which contains node types for formulating different inter- and intra-domain rules, namely **Process Tailoring Rules** (PTRs), Global Constraint Rules (GCRs), and Process Constraint Rules (PCRs) (see Figure 5-3, right side). An overview of the conceptual relationships and the derived modeling constructs is presented in Table 5-4, which omits other dependencies as derived from existing metamodels, e.g. precedence dependencies between process activities (cf. chapter 6 for a complete description of the metamodel). An extended version detailing the decomposition to individual element types is presented in A2.1.2. This form of implementation has been chosen to trade off expressiveness with model complexity. Future adaptations are possible in order to extend simple dependencies to rules, should the need arise (e.g. to model Local Context Constraints as rules instead of dependencies).

Table 5-4: Decomposition of conceptual relationships (cf. also Appendix A2.1.2)

Conceptual relationship	Modeling construct	Type	Description
Context-Process	*Process Tailoring Rule (PTR)*	R	Documenting tailoring decisions based on selected context values and corresponding process impacts
	Generic Impact (GI)	D	Not yet further specified impact of a context variable on process element(s) (for documentation purposes)
	Generic Impact (GI)	D	Not yet further specified impact of a context value on process element(s) (for documentation purposes)
Intra-Context	*Local Context Constraint (LCC)*	D	Affiliation of a context value to its parent context variable
	Global Constraint Rule (GCR)	R	Requirement or exclusion of a context value based on the selection of other context values
	Context Constraint	D	Hierarchical decomposition of context variables. (May be temporary and concretized into DTC or GCR)
	Decision Tree Constraint (DTC)	D	Signifies the required evaluation of a context variable based on a selected value of another context variable
Intra-Process	*Process Constraint Rule*	R	In- or exclusion of process elements or activity modes depending on the existence of other process elements (Analog to GCR)
Key: *R = Rule pattern; D = Dependency (simple edge)*			

Step 6: Define element types and attributes

In step 6, the resulting modeling constructs from step 5 are further decomposed, and analytical attributes resulting from the analysis framework are added, resulting in the final set of node and edge types. For the resulting element types, sets of **attributes** have been defined, allowing a more detailed description and characterization of the elements. The attributes have been clustered into the following groups: Basic information, tailoring information (required while carrying out process tailoring), and structural analysis information (required for the analysis of the TSM). The attributes are further differentiated between manually documented and automatically calculated. For example, **tailoring operators** (delete, select) are attributed to *hasImpact*-dependencies connecting the PTR node with the impacted process element. Additional attributes can be added as needed on a case basis. Overviews of attributes per element type are provided in Appendix A2.2.

5.4 Development of the structural analysis framework

The structural analysis framework bridges the gap between the **formalization** of the tailoring knowledge and its **application within tailoring workshops** (Figure 5-4). The development of the analysis framework is documented in PE-Kölsch (2018) and previously published in Hollauer et al. (2018b). The analysis framework and its application are described in detail in section 7.5.

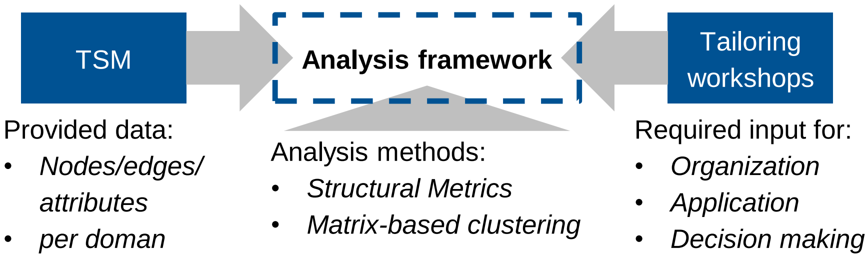


Figure 5-4: Development of the analysis framework to bridge gap between phases 3 and 5 of the methodology

The analysis framework is based on the **identification and quantification of structural patterns with significance for tailoring** in the TSM using structural metrics. For this purpose, collections of structural characteristics developed in previous work are reused here, particularly Kreimeyer (2010), Lindemann et al. (2009), and Heimberger (2017). Structural metrics have been chosen to provide a "more condensed overview" of a given structure compared to structural characteristics or the structure itself (Kreimeyer, 2010, p. 163). Therefore, they have the potential to effectively support decision making during the preparation and execution of tailoring workshops. Additionally, the analysis framework makes use of **matrix-based** clustering for the analysis of communication needs of tailoring stakeholders.

Procedure for the development of the analysis framework

The procedure for developing the analysis framework is based on the development of a framework for general structural process analysis as outlined in Kreimeyer (2010) and follows a similar **Goal-Question-Metric (GQM)** paradigm (cf. Figure 5-5) (Basili et al., 1994). The resulting analysis is requirements-driven instead of opportunistic, since relevant questions are defined beforehand (Maurer, 2007, p. 93). The overall objective pursued by the analysis framework is to **enable the preparation and execution of workshop-based tailoring**, by deriving required information from the TSM.

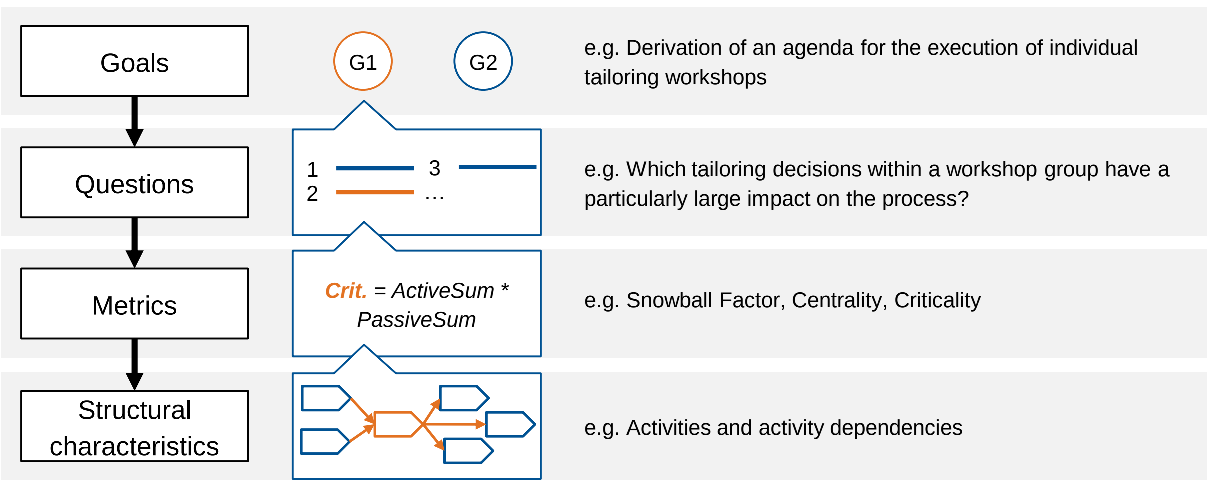


Figure 5-5: Structure of the goal-question-metric approach for a goal-driven organization of metrics and structural characteristics (adapted from Kreimeyer 2010 p. 171)

The **procedure** for the development of the analysis framework is presented in Figure 5-6. First, analysis goals for supporting workshop preparation and application have been defined discursively based on the developed workshop concept, as no similar concepts were available in existing work (1). The defined analysis goals have been detailed by defining corresponding questions (2). In order to assign individual metrics to questions, structural characteristics have been identified and metrics assigned, thereby contextualizing them in order provide meaning in regard to tailoring (3). Since not all analysis goals could be achieved using metrics, further structural analysis methods have also been assigned in this step (stakeholder clustering). Subsequently, a concept for visualization and provision of the analysis results during workshop preparation and application has been conceived (tailoring reports) (4). In parallel to the conceptual development of the analysis framework, intermediate results have been implemented as a software demonstrator in an agile manner, for testing and refinement, triggering iterations as necessary (5). The software implementation is intended to automate the structural analysis in order to reduce effort and demonstrate the feasibility.

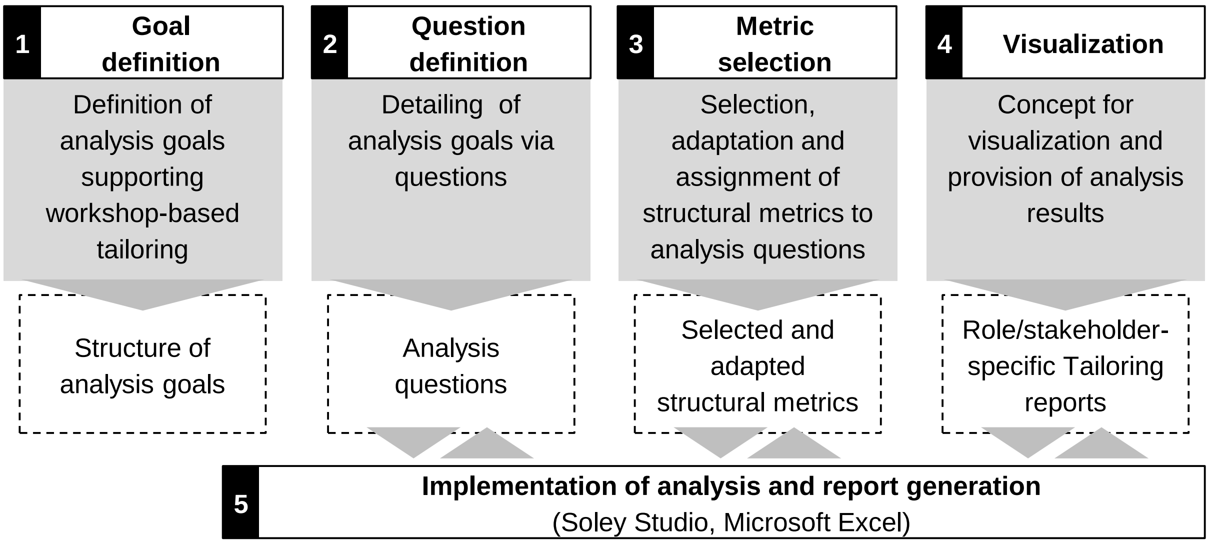


Figure 5-6: Procedure for the development of the analysis framework (adapted from Kreimeyer 2010, p. 139)

Derivation of analysis goals and questions

Based on the overall objective of the tailoring methodology, supporting workshop-based tailoring of complex PDPs, individual analysis goals have been derived and concretized as questions (steps 2 and 3). Due to the absence of approaches and thus pre-defined analysis goals in literature (cf. section 4.3), the analysis goals were defined discursively by deriving the need for analysis results from the intended application within the developed workshop concept and the empirical implications, in particular the importance of activity interfaces and effects of tailoring operations, as well as the importance of communication between tailoring stakeholders (cf. sections 1.1.2 and 3.1). This approach thus follows the following guiding concerns:

- Which information is needed from the TSM to effectively set up and prepare tailoring workshops for a particular project instance?
- Which information is needed from the TSM during tailoring workshops to effectively make tailoring decisions affecting complex PDP RPMs?

The derived analysis goals and corresponding questions are presented in section 7.5.1.

Selection and contextualization of structural metrics

Structural metrics connect the derived analysis goals and questions with the TSM by accessing and quantifying its structural characteristics. As the meaning of structural metrics depends on the domain of application, the metrics need to be contextualized in order to have meaning in regard to the defined analysis goals (Maurer, 2007, pp. 122–133).

A review (cf. section 2.4.3) showed that extensive work regarding the metric-based analysis of structural characteristics has been previously done by Maurer (2007) (analysis of process, organization, and product domain), Kreimeyer (2010) (analysis of PDP models) and Biedermann (2014) (analysis of product architectures). Another approach has been presented by Heimberger (2017), where a combined metric is used to investigate the need for communication between members of a design project induced by product-related dependencies. The metrics presented in these publications have been used as a basis to select a **set of metrics** for the analysis of the TSM (step 3) (cf. Table 5-5). Structural characteristics are difficult to measure in an absolute way. Therefore, structural metrics represent comparative measures to identify structural outliers (Kreimeyer, 2010, pp. 142–143). As such, they need to be considered relatively within the context of the investigated system. Hence, no single metric exists, which offers an objective, quantifiable statement regarding the importance of a process element. Consequently, a set of three overlapping metrics has been selected, which allows to measure the relative **significance of activities** within differently sized scopes (Kreimeyer, 2010, p. 224). Quantifying the significance allows to judge the potential severity of consequences incurred by a tailoring operation. Within the analysis, the calculated metrics of individual activities are subsequently mapped onto the PTR nodes impacting the respective activities, in order to enable the evaluation of the impact and potential complexity of the PTRs.

In order to identify the need for stakeholder communication during tailoring, a modified version of the combined **“alignment”-metric** presented by Heimberger (2017) is used: The alignment characterizes the communication need between two process stakeholders as caused by product and process interfaces within a specific project. This metric is adapted to represent, on the one hand, the need for communication due to **common tailoring decisions (PTR nodes).** On the other hand, as in the original specification, the organizational distance signifies the resistance to and quality of this communication due to the organizational distance between two process stakeholders (Muyun, 2017). The core metrics and their calculation are presented in detail in section 7.5.4.

Table 5-5: Overview of structural metrics and their contextualization within the developed analysis framework

Ref.	**Metric**	**Meaning (Contextualization)**
K	*Criticality (Cr)*	Significance of activity within its direct neighborhood
K	*Snowball Factor (SBF)*	Significance of activity regarding its impact on subsequent elements
K	*Centrality (CB)*	Significance of activity within the overall process/TSM
H	*Alignment*	Designates communication need between two tailoring stakeholders based on the number of common PTR nodes and their organizational distance
K/H	Distance	Organizational distance between two process stakeholders
Key: *K = Kreimeyer 2010; H = Heimberger 2018; Core metrics are printed in italics*		

Stakeholder clustering

Based on the results of the structural analysis, the identified stakeholder communication needs as induced by PTRs are represented and clustered using a matrix-based approach. This allows the derivation of stakeholder groups with common tailoring concerns, which can subsequently be used to set up and conduct focused workshops with a more manageable effort. The clustering approach is applied to a subset of TSM data, namely indirect dependencies between process stakeholders weighted with the alignment metric (Table 5-5). The *Complete Linkage* algorithm has been selected for the clustering approach, based on the rationale outlined by Backhaus et al. (2016).

Visualization concept: Role- and stakeholder-specific reports

The results of the structural analysis are documented in the form of automatically generated **reports**, which essentially represent particular **aggregated model views** (cf. Maurer, 2017, p. 120). The reports have been developed in response to the requirement of providing concise analysis results regarding structural information for the preparation and execution of tailoring workshops. The set of reports addresses the concerns of the individual tailoring roles developed within the scope of the tailoring methodology (cf. section 7.5.6). The tailoring reports, therefore, cover different levels of the TSM: Network level, individual tailoring clusters, and individual nodes/edges (cf. Lindemann et al., 2009, p. 143). In order to visualize the metrics, different representations are used, e.g. histograms (significance of process stakeholders for tailoring) and three-dimensional portfolios (significance of tailoring impacts) (Kreimeyer, 2010, p. 145).

6 Graph-based metamodel for storing and analyzing tailoring knowledge

*The presentation of the developed metamodel for documenting and subsequently analyzing tailoring knowledge is the subject of this chapter and later used within the methodology presented in chapter 7. The model instances created by applying the metamodel are designated the TailoringSystemModel (TSM**)** and represent an integral aspect of the developed tailoring methodology. The TSM enables the documentation and reuse of the tailoring knowledge, as well as the automated structural analysis to support the preparation and application of tailoring workshops.*

6.1 Introduction to the metamodel

This section gives an overview of the metamodel for the object-oriented documentation of tailoring knowledge using graph-/matrix-based representations derived in section 5.3.

Model-based, integrated documentation of the tailoring knowledge is proposed due to the high complexity of the associated knowledge (number of elements, number and variety of relationships between elements) and the depth of this knowledge (description using various attributes). The application of the metamodel during the methodology (phase 3, section 7.4) results in a process- and organization-specific **TailoringSystemModel (TSM)**. The **metamodel** defines the information to be acquired in phase 2 and provides constructs for the documentation of the tailoring knowledge, in particular for formulating tailoring rules. As discussed in section 5.3, the TSM creation is based on the RPM of the PDP to be tailored, extended by the respective application context and recurring tailoring rules. Further, implicit expert knowledge, as well as knowledge derived from the analysis of explicit data sources, can be utilized for creating the TSM (cf. section 7.3). The **TSM** as a concrete metamodel instance provides a central repository for organization- and process-specific tailoring knowledge. It is subject to structural analysis in phase 4 and also stores the generated analysis results.

The TSM metamodel in terms of contained node and edge types represents a **core metamodel**, focusing on the central elements required to model the tailoring system (Kissel, 2014, p. 98) and allowing for case-specific extensions via further node and edge types (section 6.3, c.f. Browning, 2018, 2009; Kreimeyer, 2010).

6.2 Structure of the metamodel

The high-level inheritance hierarchy between element types on M3 and M2 layer[46] is shown in Figure 6-1, with sub-elements inheriting attributes from higher-level element types. A complete depiction of the inheritance tree can be found in Appendix A2.2, Figure A-2. The M3-level indicates the **graph nature** of the metamodel by describing basic graph elements and their

[46] cf. OMG Meta Object Facility for layer specifications (Object Management Group 2016)

dependencies. Each edge type connects either a node to itself or two different nodes. Nodes can be connected by multiple edges. Attributes specify node and edge types. The M2-level defines the node and edge types within the TSM metamodel.

As derived in section 5.3, the metamodel comprises the domains **Context**, **Process**, **Organization**, and **Rules**, specifying which nodes can be modeled and how these elements are linked via edges. The abstract node types representing these domains are **decomposed further** into node and edge types. For each element type within the domains, attributes are defined to facilitate the documentation of expert knowledge and increase traceability as well as understandability. The attributes implemented in the metamodel are categorized into base attributes, tailoring attributes (e.g. tailoring operators and variant designators) and analysis attributes (e.g. structural metrics and auxiliary data). The modeling rules, i.e. edge-wise dependencies between node types, are presented using an MDM notation in Appendix A2.2, Figure A-3. The individual node and edge types and their attributes are described in Appendix A2.2, Table A-33 (node types) and Table A-34 (edge types).

The description of the metamodel in the subsequent sections follows these four domains. First, the context, process, and organizational domain are addressed individually, followed by modeling domain-spanning rules. Analytical edges conclude the description of the metamodel.

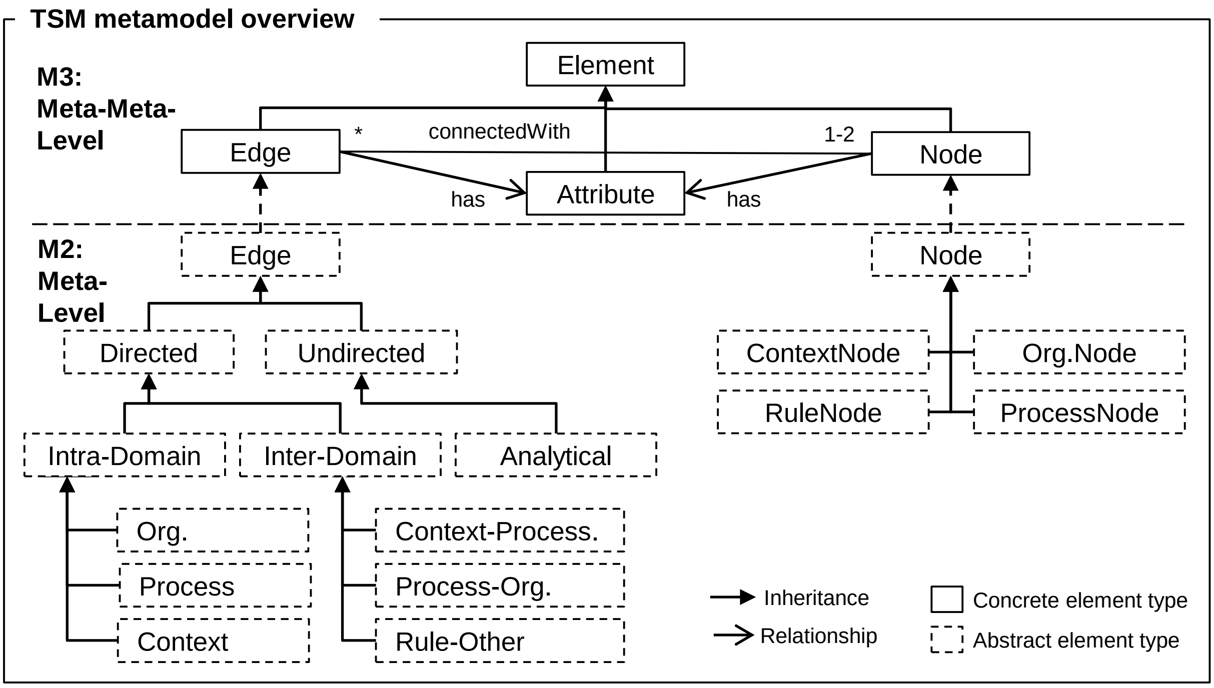


Figure 6-1: TSM metamodel overview (abbreviated, see Appendix A2.2 for detailed descriptions)

Context domain

Figure 6-2 visualizes the node and edge types of the context domain and their exemplary application. The dependencies within the context domain are primarily intended to facilitate navigation between context factors and to create constraints to avoid illegal context configurations.

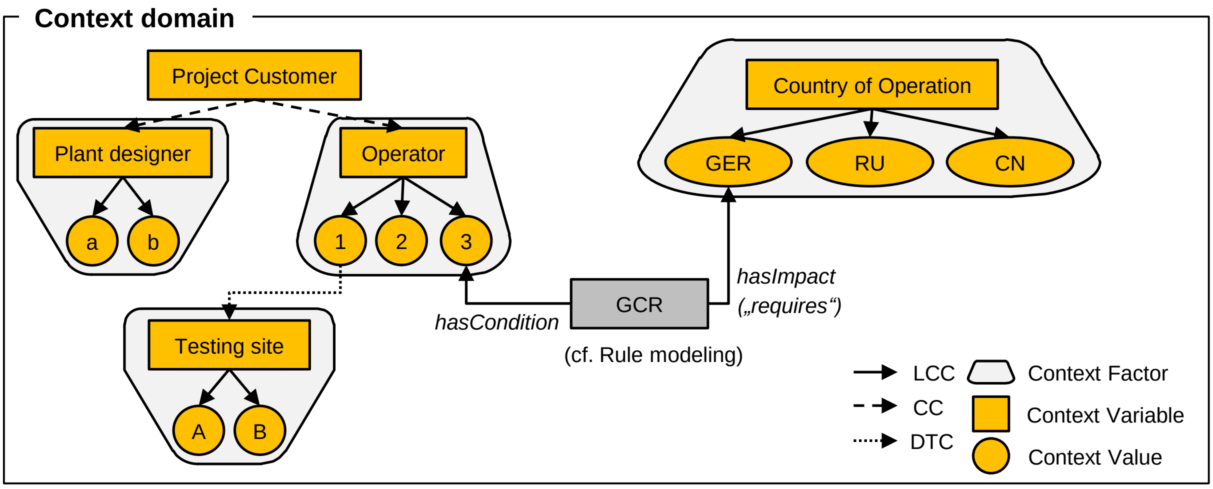


Figure 6-2: Modeling the context domain (example)

The context domain constitutes two node types: *ContextVariable* (CVar) and *ContextValue* (CVal). Context values are associated with their variable by using the edge type *LocalContextConstraint* (LCC) to form a context factor (CF). A context variable specifies via the "operator" attribute, whether one context value is selected exclusively (XOR), context values can be chosen arbitrarily, i.e. one, multiple, all, or none (OR), or context values need to be chosen together (AND). Context variables can, for example, be formulated in a question format (La Rosa et al., 2009). Two further edge types define dependencies between different context factors (cf. Kalus, 2013, p. 119):

- *DecisionTreeConstraints* (DTC) are used to model situations where the selection of a particular context value necessitates the evaluation of another context variable. Contrary to GCRs, the state of the dependent context variable is not predetermined but needs to be evaluated (cf. Kalus, 2013, p. 119).
- *ContextConstraints* (CC) connect two *ContextVariable* nodes. On the one hand, they can be used to represent hierarchical decomposition and detailing of context variables, on the other hand, they can be used for temporary storage, to document generic constraints acquired from phase 2, which are subsequently further concretized during phase 3, e.g. into DTCs or GCRs.

Process domain

The primary node type defined within the scope of this work for the process domain is the *Activity* as illustrated in Figure 6-3. Activities are used as a vehicle to capture occurring process variances in the form of **activity modes**, i.e. variants of a baseline activity which pursue a similar purpose with different characteristics (Lévárdy & Browning, 2009, p. 607).

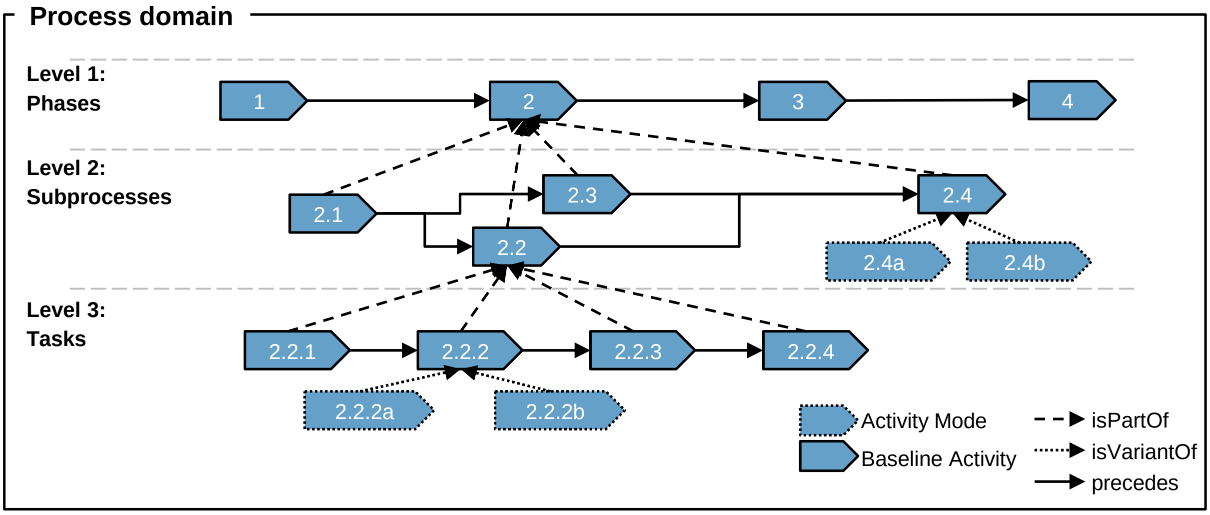


Figure 6-3: Modeling the process domain

Activity modes replace the baseline activity, if selected during tailoring, and can be caused by variations in other process elements and activity attributes, such as:

- Different methods used to perform an activity
- Different IT-systems and tools used
- Different documents used or generated during the activity
- Different roles or organizational units involved
- Different values regarding further activity attributes, such as mean costs or time required

Activity modes are marked as variants using the respective attribute and attached to the respective base activity using the edge type *isVariantOf*. This also allows to model attribute variances, i.e. diverging costs or cycle times for different activity modes (cf. Browning, 2018). In order to satisfy the requirement regarding process interfaces (section 3.3), *precedes* dependencies between activities signify the flow of information and/or artifacts between activities. *Activity* nodes and *precedes* dependencies are vital for the subsequent analysis of the TSM, in order to facilitate the assessment of the impact of tailoring decisions. In regard to the hierarchical decomposition of process models, phases, subprocesses, etc. can all be modeled using *Activity* nodes, realizing the hierarchical structure via *IsPartOf* edges.

Furthermore, the node type *GenericImpact* has been included in order to allow the documentation of impacts acquired during phase 2 of the methodology. Nodes of this type are not further regarded during the analysis but need to be concretized, e.g. via the definition of tailoring rules or through adaptation of the RPM in future reviews. Further node types, such as events, support (methods/tools), and deliverables can be included if necessary.

Organizational domain

The organizational domain is structured using the node types *Role*, *Person*, and *OrganizationalUnit* (cf. Figure 6-4). The resulting nodes are allocated to activities using the intra-domain edge type *executes*. The level of granularity depends on the one hand on the desired analysis results and is on the other hand limited by the available data, e.g. whether specific roles are defined within the organizational structure or the PDP RPM. A mixture of different levels is possible, in case some activities are assigned to particular roles, while others are generically assigned to teams or departments. The nature of the involvement can be specified further using the *RACI* Attribute (Responsible, Accountable, Consulted, Informed) (cf. PMI, 2013, p. 262). *Individuals* are allocated to roles using the edge type *fulfills* and to organizational units using the edge type *isPartOf*. Organizational units (departments, teams, etc.) can be hierarchically decomposed also by using the edge type *isPartOf*. The metamodel of the organizational domain offers further flexibility by enabling to omit organizational units and directly model dependencies between individuals via a *manages* edge type. While both options are possible, they need to be used exclusively and consistently.

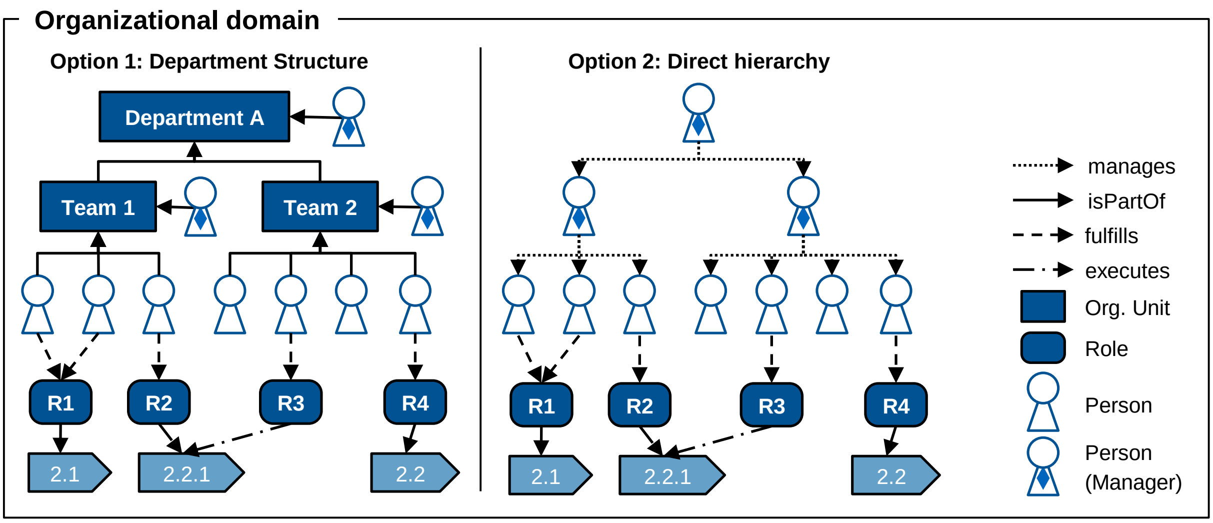


Figure 6-4: Modeling the organizational structure

Intra-/Inter-domain rules and domain-spanning dependencies

The final domain of the metamodel addresses the formulation of complex rules via dedicated rule nodes, as illustrated in Figure 6-5. As indicated by the rule node type, rules can be related exclusively to the context (*GlobalContextConstraintRule*, GCR) or process (*ProcessConstraint Rule*, PCR) domain, or depict contextual influences on the process (*ProcessTailoringRule*, PTR). Rule nodes are connected to the respective rule conditions and impacts via *hasCondition* and *hasImpact* edge types, with their meaning defined by the rule type. The conditions assigned to a rule node represent AND combinations, i.e. all conditions need to be true (e.g. context values selected) in order for the rule to become active.

Situations, where the state (selected or unselected) of one or more context values defines the state of context values associated with other variables, are modeled using a rule pattern with a *GCR* node (cf. section 5.3). The outgoing *hasImpact* edges of a *GCR* node define the state of selection of the dependent variable via “exclusion” or “inclusion” operators (cf. Figure 6-2. In an analog manner, *PCR* nodes document process-side constraints, with *hasCondition* and *hasImpact* edge types connecting the *PCR* node with other process nodes. *PCRs* document when the occurrence of a specific activity in a deployed process requires or excludes other activities.

Lastly, *PTR* nodes (cf. Figure 6-5) map context values to process elements. *PTRs* connect to one or more context values using the *hasCondition* edge types. PTR impact edges (*hasImpact*) describe the applied operators via Boolean variables:

- *Removal* of a process element from the RPM (*topDelete* = true)
- *Selection* of a particular activity mode (*topSelect* = true)
- *Move* a process element to a different position (*topMove* = true)
- *Modify* an activity (*topModify* = true; the *descrMod* attribute describes the modification)

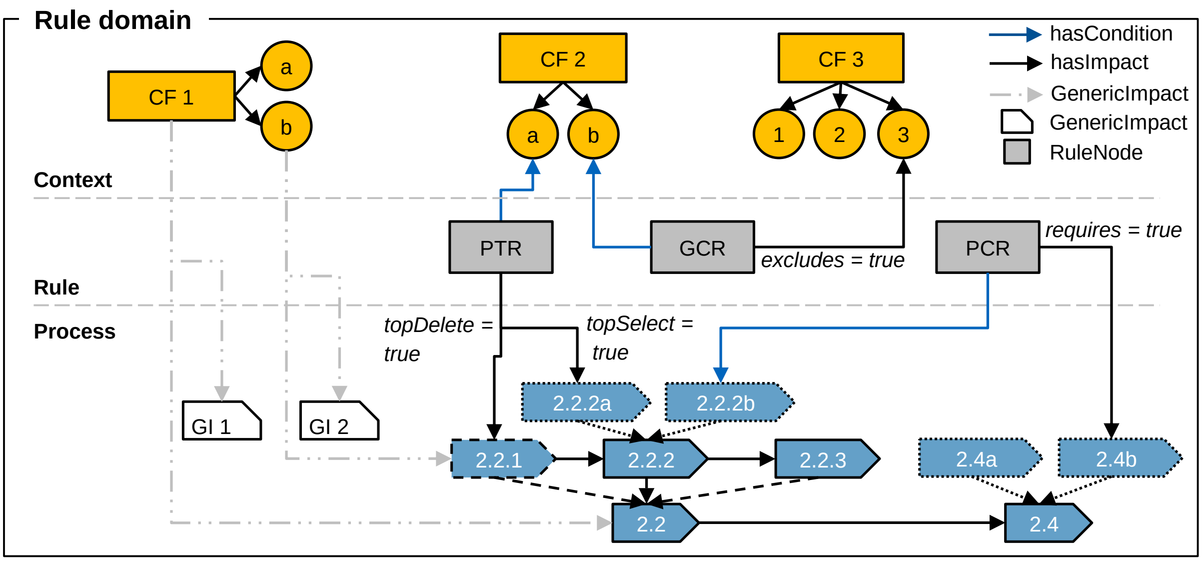


Figure 6-5: Modeling the three types of rules and intra-domain dependencies

Besides the described rule constructs, domain spanning dependencies are defined in the metamodel. These dependencies are for documentation purposes and can be temporary within a TSM instance. These dependencies are:

- *GenericImpact* (GI) between a *ContextVariable* and *ProcessElement*
- *GenericImpact* (GI) between a *ContextValue* and *ProcessElement*

They result from the fact that information acquisition does not always result in clear PTRs, but information often needs to be documented and clarified further. Hence, these dependencies (in combination with the *GenericImpact* node type) can be used to capture unclear dependencies, which are to be clarified in iterations of phase 2 or future reviews. In subsequent steps, these dependencies can be further detailed and resolved into PTRs.

Analytical dependencies

Besides the previously described domains, the metamodel contains four analytical, undirected dependencies (Figure 6-6). These are used as auxiliary elements, generated computationally to calculate and document communication needs between process stakeholders due to common

PTRs (*hasRelationshipWith*), as well as the existence and number of dependencies between two particular PTR nodes due to common context factors, process elements, and stakeholders. The applied structural analysis framework is presented in detail in section 7.5.

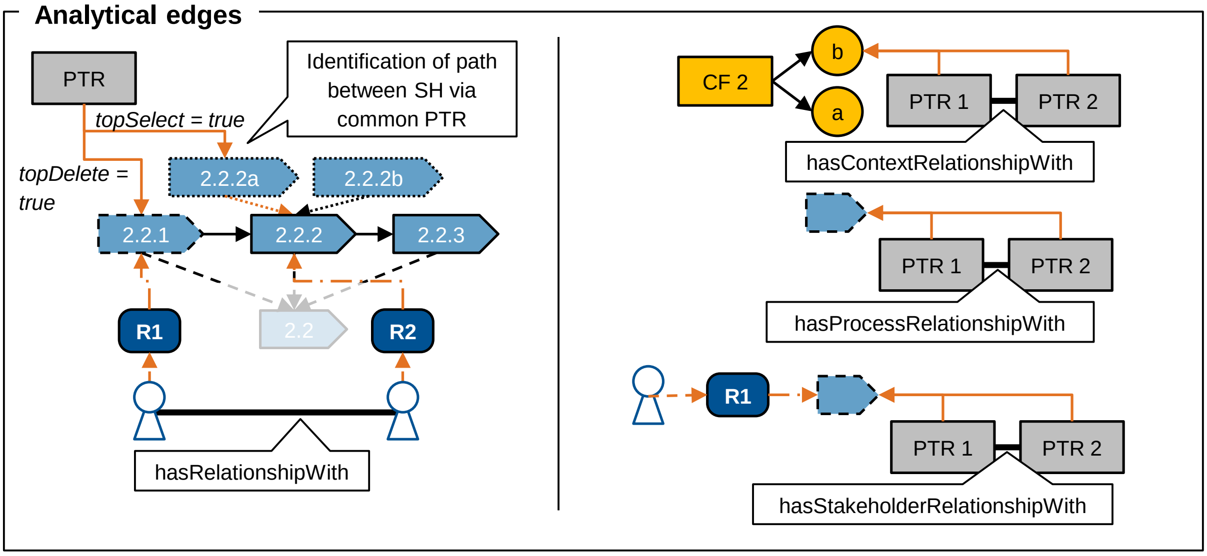


Figure 6-6: Analytical edges of the metamodel and their creation

6.3 Adaptation of the metamodel

As stated in section 6.1, the metamodel represents a **base metamodel** which contains the necessary elements for fulfilling the stated objective of the tailoring methodology. It has been derived from state of the art approaches in combination with empirical studies. It is not intended to provide a universal metamodel suitable for any conceivable situation. However, the provided metamodel can be adapted to different boundary conditions. (cf. Kissel, 2014, p. 98)

This is necessary as process modeling languages and formalisms differ in their elements and dependencies. The process model and organizational structure represent boundary conditions for the tailoring methodology. Therefore, adaptations of the metamodel are to be expected in particular regarding these domains. The provided base metamodel can be extended by

- adding **node types** to capture additional elements within the domains or complex rules,
- adding **edge types** to capture additional dependencies within the process/organization, or
- adding **attributes** to element types in order to capture additional information.

As the context and rule domains are less susceptive to external influences, changes are less expected but equally possible. For example, further attributes to describe context variables and values are possible. Furthermore, the constructs to model rules can be applied to create e.g. more complex local constraints between context variables and values, which requires additional rule nodes (section 5.3). In case the metamodel has been adapted for a specific instance, the implementation of the analysis framework needs to be **reviewed and adapted accordingly**, in particular, the algorithms for import, preparation, and analysis, as well as the visualizations.

7 Methodology to implement and support collaborative workshop-based tailoring

Chapter 7 presents the methodology for implementing and operationalizing workshop-based tailoring, which integrates the constituent elements previously outlined in chapters 5 and 6.

First, the chapter gives a general introduction to the methodology. Subsequently, the methodology is elaborated along its five phases, describing the steps and constituent elements contained within each. The focus of the methodology thereby lies on the analysis framework (phase 4, section 7.5) and tailoring workshop concept (phase 5, section 7.6) as the most novel aspects.

7.1 Introduction to the methodology

This section presents the baseline methodology in section 7.1.1 and possibilities for its adaptation in section 7.1.2. Section 7.1.3 formulates fundamental prerequisites for the application of the methodology, and the tailoring role model is described in section 7.1.4.

7.1.1 Overview of the methodology

The **objective** of the tailoring methodology is to support users (the tailoring team) in **preparing, operationalizing, and eventually applying workshop-based tailoring of complex PDPs**. The developed methodology describes the phases, activities, and corresponding support to achieve this objective.

For ease of presentation, the unadapted baseline methodology is divided into five consecutive phases, as depicted in Figure 7-1, which are presented sequentially in the following sections. As the methodology is designed to be adaptable, possible adaptations due to different organizational circumstances are presented in section 7.1.2. The methodology consists of individual **phases** and **gates** (cf. Cooper, 2001): Phases integrate the constituent elements of the developed tailoring methodology, as well as additional method support. Gates concluding each phase define deliverables and criteria required to proceed with the subsequent phase, providing control questions to support users in assessing the progress made.

Phase 1 addresses the **preparation** of the methodology application, setting up a tailoring team and reflecting the initial situation, e.g. the structure of the existing PDP RPM. In *phase 2*, the **acquisition** of relevant tailoring **information** is carried out. Depending on the availability of explicit and implicit information, the methodology provides different acquisition methods. The acquired information is subsequently **modeled** in *phase 3* via the previously presented metamodel, creating the TailoringSystemModel (TSM). Consequently, necessary process adaptations are derived, and the RPM adapted in order to ensure its tailorability. The thus prepared TSM is **analyzed** in *phase 4* (section 7.5) by applying the developed analysis framework to identify and quantify relevant structural patterns within the TSM. The analysis bridges the TSM and the workshop-based execution of process tailoring by providing condensed analysis results. Based on the derived analysis results, process tailoring for individual project instances is subsequently **operationalized** in *phase 5*, where the PDP RPM is finally tailored within individual project instances using the developed workshop concept. Simultaneously, feedback channels for future TSM reviews are implemented.

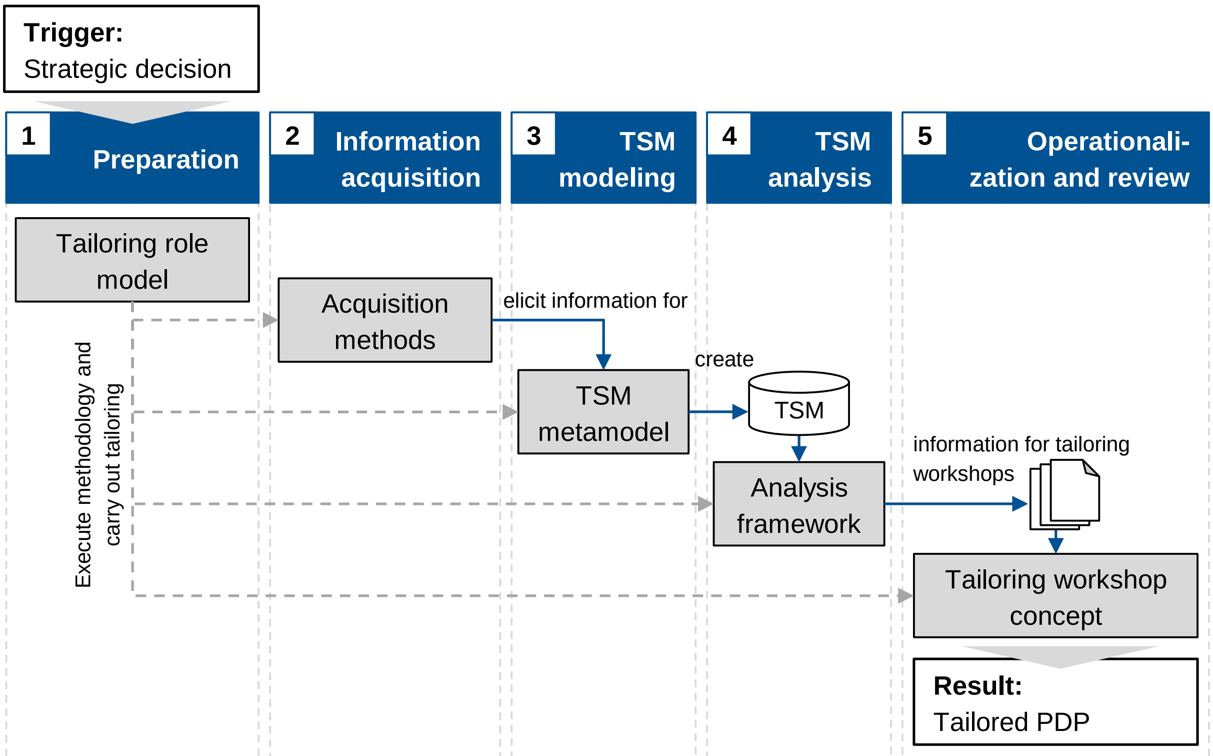


Figure 7-1: Overview of baseline methodology for workshop-based tailoring (see Appendix A3.1 for a more detailed DSM-based depiction)

The representation of the methodology describes its first-time application in an organization and is therefore depicted in a linear manner. The execution of the methodology is **triggered** by a **strategic decision** by one of the relevant functions, i.e. process or project management (PMO). However, it is intended to **be applied iteratively in parallel to PD project execution** in order to extend and updated the tailoring knowledge contained within the TSM (organizational learning cycle, cf. section 2.2). Experiences from the evaluation case studies showed that purposeful **iterations** within and between phases can become necessary during the application, in particular during early phases (information acquisition and modeling). The methodology allows for such iterations within as well as between phases. While they are omitted in Figure 7-1 for clarity, a **characterization of possible iterations** can be found in Appendix A3.2, and they are elaborated where necessary within the phase descriptions.

The description of the methodology in sections 7.2 to 7.6 **follows the most complex case**, the implementation in a large company with a pre-defined, mature PDP RPM. This has been chosen since a) it allows an end-to-end description of the entire methodology with all constituent elements and b) it is the environment that simultaneously presents the highest need for as well as the highest expected benefit of the developed tailoring methodology.

7.1.2 Adaptation of the methodology

A need for adaptation of the baseline methodology can arise due to different boundary conditions, such as: The maturity of the PDP RPM at the begin of the methodology application, the size of the company, and the size of individual PD project teams. Possible ways to adapt the baseline methodology are:

- The selection of methods for information acquisition due to available information;
- The sequence of phases or removal of individual phases (e.g. TSM analysis);
- The executed analysis routines (e.g. omitting stakeholder clustering in case of small project teams where all members can participate in a single workshop);
- Pausing the methodology after initial information acquisition in order to acquire more information via tailoring workshops;
- Frontloading of activities from later phases to earlier phases (e.g. conducting initial tailoring workshops in order to acquire information in case no other information sources are available).

Three adaptation scenarios have been derived from the application case studies and consolidated into three different classes, which illustrate how the tailoring methodology can itself be tailored to different situations (Figure 7-2). However, since adaptation needs to be performed on a case basis and more research is necessary regarding the different dimensions for adaptation, they are exemplary, not exhaustive.

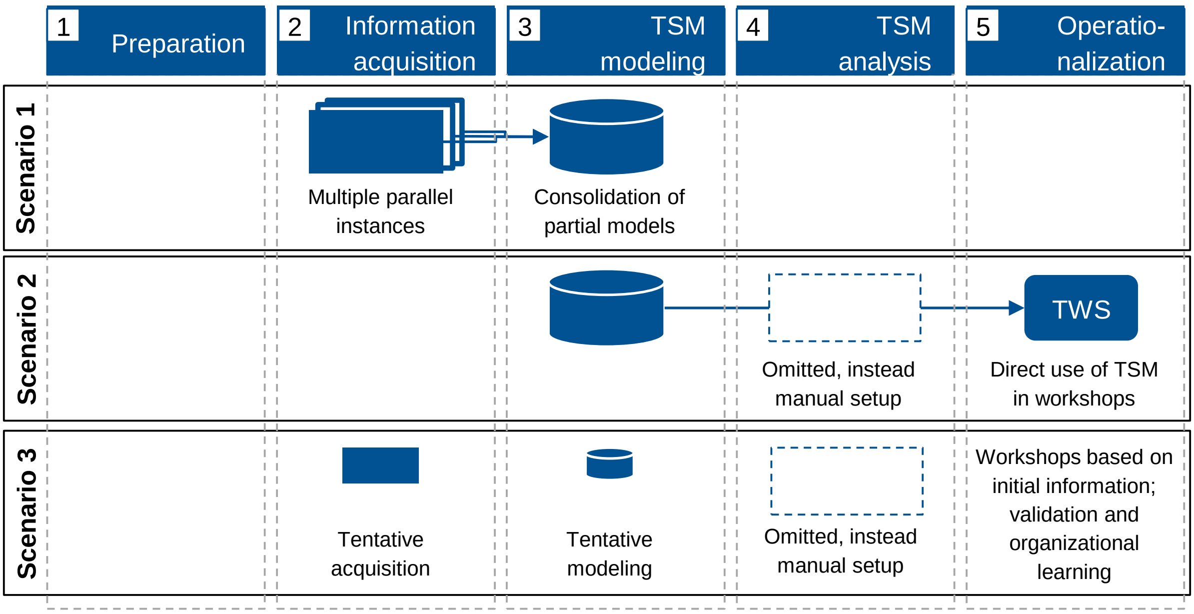


Figure 7-2: Methodology adaptation in practice (empty areas signify application of baseline methodology)

Scenario 1: Large company with mature RPM

Within a large company and a correspondingly extensive process, the tailoring methodology is applied in its entirety. Information acquisition is parallelized in order to decrease the time required (cf. C.1 and C.2). For this, several system boundaries are set up within the first phase of the methodology. The information acquisition is delegated to stakeholders within the different system boundaries by the core team, e.g. subprocess owners. Different methods are then selected, depending on the availability of information within the different system boundaries. The different instances of phase 2 are consolidated into a common TSM by the core team and checked for inconsistencies and RPM adaptation needs, which are resolved discursively with the respective information acquisition teams. The core team guides and advises the different instances concerning adequate method support.

Scenario 2: Small company and/or small project teams with RPM

In small companies, phase 4 is optional, in case the RPM is of lower structural complexity, and project teams are small (5-10 team members), allowing tailoring workshops to incorporate the entire project team. Instead, the information from phase 2 is used to define tailoring rules which are directly used in manually set up workshops. This can also be the case in larger companies, where individual projects may be of smaller scope (e.g. case study C.1). In this case, the analysis phase is only conducted for projects of larger scope, involving more team members, while workshops can be set up manually for smaller teams.

Scenario 3: Small company without RPM

In cases where no or only a preliminary PDP RPM exists, for example in start-up companies, the methodology can be adapted to accompany the RPM development, in order to increase understanding of the PDP to be defined (cf. case studies E and F). While principally feasible, this situation **does not provide ideal circumstances**. A mature PDP RPM, which has been previously applied in several previous project instances is generally preferable and also presents the most urgent need for the tailoring methodology.

In this case, phases 1 to 3 are executed in parallel with the initial design of the PDP RPM, resulting in a tentative RPM and context factors. These are subsequently used to conduct and document manually set-up tailoring workshops for upcoming projects, where the defined RPM is discursively tailored using the tentative context factors, as well as in open discussion. The information gained within the tailoring workshops (and through any additional information acquisition) is then used to review existing and derive additional context factors, as well as to adapt the RPM. Thus, tailoring-relevant information is acquired during the RPM design, enabling to increase its tailorability. A highly dynamic process application context, such as found in start-up companies, increases the effort of information acquisition and limits its reliability. Instead of having one major information acquisition phase, in such cases the methodology also allows to build up tailoring knowledge incrementally in shorter iterations.

7.1.3 Prerequisites for methodology application

In order for the application of the tailoring methodology to be feasible within a particular organization and ensure the desired outcome, certain prerequisites have to be met, which are documented in the form of a checklist in Table 7-1. These represent either basic requirements (R) or facilitators (F) for the application of the tailoring methodology.

Table 7-1: Prerequisites for the execution of the tailoring methodology

	Prerequisite	Description
R	*Understanding regarding tailoring methodology*	A sound understanding of the tailoring methodology and its constituent elements. Prospective applicants first need to familiarize themselves with the tailoring methodology in its entirety.
R	*Availability of resources*	Since the early phases of the methodology are time-intensive, corresponding resources such as time, budget, and personnel need to be made available (e.g. to allow to perform interviews) Because a large amount of information is only implicitly available, access to necessary stakeholders needs to be enabled by management.
R	*Understanding structural modeling and analysis*	A sound understanding regarding the fundamentals of structural modeling and analysis (graph rewriting), in particular, if the metamodel and analysis routines require adaptation or new ones need to be implemented.
F	*Existing baseline PDP RPM*	The tailoring methodology is aimed at macro-level tailoring of detailed, structurally complex PDPs and corresponding RPMs. Therefore, an existing baseline PDP RPM of sufficient detail is required, covering at least the aspects elaborated in the process domain of the TSM metamodel, i.e. activities, activity dependencies, and roles/organizational units.
R	*Profound PDP understanding*	In the absence of a PDP RPM, one needs to be created beforehand or in parallel (cf. adaptation classes in section 7.1.2), which requires a profound understanding of the current, as-is PDP. A benefit of integrating both tasks is the potential realization of synergetic effects for information acquisition, while at the same time an a priori defined RPM has been found to facilitate information acquisition in phase 2 by providing a shared frame of reference. The task of RPM creation is not described in detail. Instead, it is referred to corresponding literature for process modeling (e.g. Browning, 2018).
R	*Project commonality*	While tailoring is based on the variety of project instances due to differing project characteristics, a certain amount of commonality between projects is required for tailoring to be economical (e.g. in series development or within a particular product line).
F	*Previous process deployment*	Previous execution of multiple deployed process instances greatly facilitates the application of the methodology, as it increases the available experience and implicit knowledge for identifying context factors and process variability.
R	*Process/ project management office*	A defined process or project management department and corresponding roles are required in order to embed the methodology within the organization.
R	*Project management methodology*	An established project management approach and project organization are required. Individual projects should be clearly defined in terms of scope.
R	*Defined organizational structure*	The organizational structure should be clearly defined in order to enable the identification of stakeholders (roles, individuals) affected by tailoring decisions.
Key: *R = Requirement; F = Facilitator*		

7.1.4 Tailoring role model

Specific tailoring roles have been defined for two reasons: First, to facilitate the distribution of responsibility for the application of the tailoring methodology within the organization, and second, to enable a generic description of the tailoring methodology in the forthcoming sections. Thus, the methodology is described independently of roles in organizational settings. Tailoring roles are assigned to one or more individuals as needed within a specific application setting. The characteristics of the defined roles are summarized in Table 7-2.

Table 7-2: Overview of tailoring roles and associated characteristics

	Tailoring expert	**Tailoring organizer**	**Tailoring stakeholder**
Project-specific	no	yes	yes
Description	Manages the application of the methodology and project-independent activities related to tailoring implementation, governance, and knowledge management	Manage the application of tailoring for individual project instances5	Project team members who are impacted by tailoring decisions made for a particular project in question.
Possible owners	• Process manager • (Sub-)Process owner	• (Sub-)Project leader • (Sub-)Project manager • Project planner	• Roles defined in the PDP RPM
Responsi-bilities	• Managing tailoring knowledge (consolidation, review, update, etc.) • Application of methodology/delegation of tasks • Modeling TSM/Providing • Modeling support • Training other roles	• Preparing tailoring reports (executing analysis) • Organizing, (co-) facilitating and post-processing of tailoring workshops (consolidation of tailoring decisions) • Returning information (e.g. identified new tailoring rules) to tailoring expert(s)	• Preparation of tailoring decisions, estimating impacts of tailoring decisions for a particular project instance • Participation in tailoring workshops • Collaboration in tailoring decision making
Required skills	• Expert on methodology • Overview of PDP and tailoring rules • In-depth knowledge of structural modeling and analysis (can extend and adapt metamodel and analysis framework)	• Overview of project characteristics and PDP • Basic knowledge of structural modeling and analysis (can apply analysis framework and interpret results)	• In-depth knowledge of responsible process elements • Basic knowledge of structural modeling (can use and interpret analysis results/reports)

The tailoring roles are structured according to the overview/in-depth knowledge required, with **tailoring experts** having the most process overview and **tailoring stakeholders** the most in-depth knowledge regarding individual process elements. **Tailoring organizers** have an overview of individual projects and thus manage the application of tailoring for individual project instances. Tailoring experts are independent of projects and thus manage the persistent aspects of process tailoring, such as the application of the methodology, maintenance, review, and update of the TSM as well as any other governance-related aspects (setting up organizational guidelines, preparing templates, etc.)

The company-specific implementation of the role structure and subsequently required training effort depends on company-specific characteristics, such as the **existing role structure** (identification of roles which are already carrying out process-/project-management activities), the degree of **maturity, size, and decentralization of the process architecture** (more expansive process architectures may require more tailoring experts), and the **number of projects and project leaders** (more projects may require more project leaders and thus tailoring organizers).

7.2 Phase 1: General preparation

The objective of phase 1 of the methodology is to **set up the organization-specific instantiation of the methodology** and **generate a basic understanding** of the initial situation. As the description of the methodology covers the most complex case of a large company (cf. scenario 1, section 7.1.2), the description is focused on ensuring the principal “fitness” of the pre-defined PDP RPM. Therefore, a tailoring team tasked with carrying out the methodology is assembled, and the overall organizational situation is reflected, including the pre-defined PDP RPM. System boundaries are defined to prepare the subsequent information acquisition.

	Step	Result
1	Define tailoring team	*Core and extended team members*
2	Reflect initial situation	*Answered question checklist; initial TSM*
3	Analyze RPM and define system boundaries	*System boundaries for methodology application*
◇	Quality Gate I	

Figure 7-3: Steps and results of phase 1

7.2.1 Define tailoring team

First, a tailoring team needs to be set up, which is tasked with directing the application of the methodology within the organization (cf. Guertler, 2016). This interdisciplinary team should consist of the main leader, core team members, as well as further members to be included on an as-needed basis (extended team). Different viewpoints are necessary in order to create an environment of objectivity and mitigate individual knowledge deficits and biases (Guertler, 2016, p. 103; Kain et al., 2009, p. 194; Varvasovszky & Brugha, 2000, p. 340), in particular bridging the gap between process and project management. In order to leverage synergetic effects and minimize communication overhead, the core team should be comprised of four to eight people (Lindemann, 2009, p. 29). Due to the complexity of the task, different organizational roles should be present within the team, requiring an initial stakeholder analysis during the preparation phase. The core team should comprise the following functions: (1) The leading **“tailoring expert”** (cf. section 7.1.4**)** fulfills the function of the **tailoring project leader**, with in-depth knowledge of the tailoring methodology, its supporting methods, and tools (modeling and analysis). The project leader is responsible for applying the tailoring methodology and gradually operationalizing workshop-based process tailoring. The project leader can carry out the tasks of the methodology himself or delegate these tasks to suitable individuals. (2) One or more internal **process management experts** (PDP RPM designer, owner, or manager) contribute knowledge regarding the content and structure of the PDP RPM and associated process management systems, in order to facilitate tasks such as the initial analysis of the PDP RPM, the identification of relevant stakeholders for the extended team and information acquisition, as well as any adaptations or technical implementations required in the future (e.g. creation of system interfaces). Conversely, (3) One or more internal **project management experts**, such as project managers, planners, or leaders contribute knowledge regarding the project portfolio and individual project instances, such as project characteristics/context factors, process variances between project instances and latent tailoring concerns. Furthermore, they contribute knowledge regarding systems used to manage and document projects. Lastly, these stakeholders represent the eventual “**tailoring organizers**” (cf. section 7.1.4**)** and should thus be included early on. (4) A **member of the top-management** should act as a *power promotor* to ensure strategic management support and resource provision and be informed regularly but is not required to be an operative member of the team (Hauschildt & Kirchmann, 2001).

Particularly in case **multiple instances** of the methodology are executed in parallel (large RPM), the tailoring team needs to be **extended** in order to **delegate** acquisition and modeling-related tasks. Therefore, the respective **sub-process owner(s)** regarding the particular system boundaries, need to be included. Similar to the PDP RPM owner(s) within the core team, these are tasked with applying the methodology or individual tasks thereof within their respective sub-processes, supported by the core team.

Furthermore, tailoring stakeholders with knowledge regarding the detailed process steps as well as the process application context are operatively included on an as-needed basis, such as through interviews, surveys, or workshops, but need to be kept informed on the progress.

7.2.2 Reflect initial situation

In order to further prepare the application of the methodology, the initial situation regarding the status of the RPM and the project organization needs to be reflected. In order to support this step, a checklist containing guiding questions is presented in Appendix A3.3. The guiding questions are related to the PDP application context, the availability of the PDP RPM and its “fitness,” the organizational structure, and the applied project management. Depending on the results, either the methodology or the metamodel need to be adapted accordingly, or the required steps need to be taken before advancing the methodology, e.g. modeling information flow dependencies within the RPM.

In order to proceed with the application of the methodology in the case of a large company with an extensive and complex process, a baseline PDP **RPM** is required, which is mature, detailed, well-structured, and actively applied within the organization. Data regarding the RPM can be found in different repositories and representations (Flowcharts, RACI-Matrices, org. charts, etc.). The baseline PDP RPM needs to provide at minimum the basic process architecture mappings as defined in the process domain of the TSM metamodel (cf. Browning, 2016, p. 15): Hierarchical activity decomposition, information flow dependencies between activities, and assignment of roles/organizational units to activities. This baseline RPM should be decomposed and detailed enough in order to allow for the formulation of meaningful tailoring rules but does not yet have to include activity modes, which are identified in phase 2. Although the tailoring methodology can theoretically accompany the initial creation of a PDP RPM (cf. section 7.1.2, scenario 3), the existence of a PDP RPM which has been communicated, applied, and tested in several project iterations facilitates the information acquisition due to a shared frame of reference (cf. Browning, 2018 for an approach and heuristics regarding PDP RPM creation). **PD projects,** on the other hand, need to be clearly defined in terms of content and organization. A PD project **roadmap** should be acquired or created (e.g. in the form of a Gantt-Chart), detailing which projects are scheduled to begin and when. This facilitates to plan the general methodology application, in particular by identifying possibilities for information acquisition as well as possible application and validation of the acquired information (e.g. via tailoring workshops).

7.2.3 Analyze reference process model and define system boundaries

The baseline RPM is subsequently modeled in TSM notation, thereby unfolding the hierarchical layers of the process architecture (e.g. process, subprocess, activity, task) via *isPartof*-dependencies, in order generate an initial overview of the baseline RPMs structure and to create the basis for the TSM. The organizational structure is modeled in a similar fashion using the provided metamodel, based on the available sources, and both domains are connected by assigning roles and OU to activities. While this forms the basis for the TSM, this tentative model is not intended to remain static is **extended and adapted later**, such as through the addition of activity modes (phase 2) and the adaptation in response to tailoring needs (phase 3).

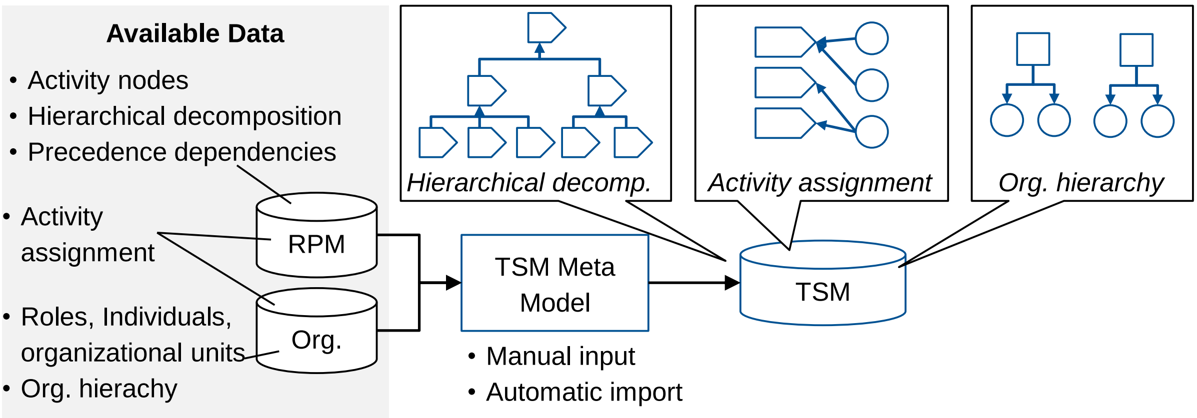


Figure 7-4: Baseline RPM and organizational data as input for initial metamodel; derived views for methodology preparation (based on Heimberger, 2017, p. 98)

Based on this initial TSM, views regarding the hierarchical process decomposition, organizational hierarchy, and activity/role assignment can be derived, which are subsequently used to facilitate the following subsequent tasks:

- **Definition of the system boundary/decomposition:** The hierarchical decomposition aids users in defining system boundaries for the subsequent information acquisition, e.g. based on individual subprocesses or activities.
- **Identification of knowledge carriers:** The activity assignment aids users in identifying roles and individuals as carriers of implicit knowledge for the subsequent information acquisition within particular system boundaries.
- **Identification of recurring activities/subprocesses (Master/Shadow processes):** The analysis for recurring process elements can uncover starting points for the identification of variant (sub-)process.
- **Foundation for the TSM:** The initial TSM sets the basis for further extension with activity modes, tailoring rules, and to derive RPM adaptations (phase 3).

While the main objective is to tailor the entire PDP on project-level, trying to realize this in a single approach can **prove too overwhelming** due to the size and complexity of the PDP. In order to manage this complexity, information acquisition can be **parallelized** by decomposing the process and defining particular system boundaries (cf. section 7.1.2). The selected system boundary restricts the scope of the information acquisition, limiting the information to be acquired and modeled. The respective activities are then **delegated** to process stakeholders with more familiarity and information access regarding the particular system boundary. The definition of system boundaries depends on **organizational factors** such as the organizational structure and the overall process architecture. Therefore, only general strategies can be given, which are described in Table 7-3, indicating consequences for information acquisition. As cross-cutting impacts of context factors are to be expected, the acquired information needs to be subsequently harmonized and integrated into a common TSM (cf. section 7.3.5).

Table 7-3: Possible strategies for selecting system boundaries and consequences for information acquisition

System boundary	Description	Consequence
Entire PDP (top-level)	Initial, top-down acquisition of global context factors on project-level with cross-cutting effects on the entire PDP	Global context factors require subsequent in-depth analysis of impacts on lower hierarchical process levels
Subprocess (sublevel)	Selection of topical (e.g. risk management) or department-specific subprocesses (e.g. engine development)	Focus on local CF with limited scope, which need to be tested for redundancy, relevance, and impacts in other system boundaries
Recurring subprocess	Selection of subprocesses which occurs in several instances (Master/Shadow process, cf. Browning, 2018).	Identification of intra-process context factors and variation due to different positions within the overall process.

7.2.4 Quality gate I

After phase 1, an interdisciplinary tailoring team has been set up, including agents from process and project management, in order to direct the methodology application and carry out core tasks. A general overview of the initial situation has been generated by the core tailoring team, including the structure and content of the RPM, the organizational hierarchy and role assignment, PD project management, and the landscape of scheduled PD projects. The necessary deliverables to proceed to phase 2 as well as reflective questions supporting the execution of the methodology by enabling an assessment of the current progress are presented in Table 7-4.

Table 7-4: Deliverables and reflective questions for conclusion of phase 1

Deliverables	**Tailoring team** (defined core team members)
	Stakeholder map/list of crucial knowledge carriers for extended tailoring team
	Initial TSM (process, organizational domain, and corresponding intradomain dependencies)
	Defined System boundaries for information acquisition
	Plan/schedule for methodology application
	Roadmap describing the landscape of scheduled PD projects
Reflective questions	Does the tailoring team contain all relevant actors?
	Does the tailoring team have the necessary authority and resources to go ahead?
	Has the RPM been sufficiently analyzed and understood?
	Is there enough continuity and consistency between process and project management?
	Are there explicit information sources regarding PD project documentation?
	Have suitable system boundaries been defined?
	Is there a need to adapt the methodology? (Cf. classes in section 7.1.2)
	Is there a need to adapt the metamodel?

7.3 Phase 2: Information acquisition

The second phase of the methodology addresses the systematic acquisition of information necessary for creating the organization- and process-specific TSM. The objective of phase two thus is to analyze and acquire **existing process variability** (activity modes, optional activities) and **contextual process variant drivers** (context factors as variable/value combinations). **Context factors** impact the adaptation of the RPM and are causes for **variances** between **project-specific process instances**. This information can be accessed via different sources, which are often of an implicit nature. The acquired information is documented and subsequently reused for downstream activities. In order to carry out the information acquisition, phase 2 consists of the steps listed in Figure 7-5.

Information acquisition is particularly challenging, partly due to considerable resource demands, and since the reliability and validity of data and assumptions dramatically affects the result and interpretation (Maurer, 2017, p. 129; Lindemann et al., 2009; Bartolomei, 2007).

Information acquisition can also be highly iterative (Lindemann et al., 2009). A systematic procedure for information acquisition is vital to ensure "later accessibility, traceability and extensibility" of the system model, as well as adequate completeness and quality of the acquired information (Maurer, 2017, p. 131). In general, system elements should be acquired first, followed by dependencies (Eppinger, 2001).

	Step	Result
1	Scope information sources within system boundary	*List of sources*
2	Select acquisition methods and plan acquisition strategy	*Selected methods per source; Acquisition tools*
3	Acquire information from explicit sources (optional)	*Extracted information*
4	Acquire information from implicit sources (iteratively)	*Interview minutes; Observation notes*
5	Consolidate and validate information	*Final, documented context factor and process variance information*
◇	Quality Gate II	

Figure 7-5: Steps and results of phase 2

The information acquisition can be executed on two different planning horizons: (1) **Short-Term (Operative),** focusing on the current situation, i.e. only considering context factors relevant for the current project portfolio. (2) **Long-Term (Strategic),** additionally taking changes in the context into account, i.e. prospective future context factors as well as expected changes in existing context factors. In this case, the acquisition is shifted to a planning perspective. The consideration of the strategic perspective can be helpful in case the process application context is highly dynamic, e.g. due to changes in process or corporate strategy, during repeated reviews of the TSM (cf. phase 5), or in case the current process is not mature enough (cf. section 7.1.2, scenario).

7.3.1 Scope information sources

The first step is to scope available information sources and their suitability. Information can be generally acquired from two principal types of sources (Lindemann et al., 2009, p. 82): available documented data sets and implicit information, accessible through, e.g. interviews.

Table 7-5 presents a checklist of possible information sources that should be considered and checked for availability, clustered according to type: Context-related, process-related, and project-related, indicating their most likely origin. At this point in the methodology, it is assumed that there are currently no explicitly documented context factors available within the organization. Accordingly, the information regarding context factors needs to be extracted indirectly from available project documentation or implicit information sources. Furthermore, essential data sources might not necessarily lie within the PD department itself, but with other departments (e.g. controlling, product management, etc.). The result of this first step is a **list** or **map** of available information sources (e.g. systems, documents, databases, stakeholders, etc.).

Table 7-5: Checklist of potential implicit and explicit information sources

ST	Source	Description/Examples
Context information		
E	Literature-based context factor catalogs	Collections of generic context factors (cf. e.g. Langer & Lindemann (2009); Du Preez et al. (2009); Dvir et al. (1998); Gericke et al. (2013))
E	Project classification	Existing project classification schemes
RPM-related information		
E	RPM(s)	Reference process model regarding the process under investigation (EDP, sub-process, etc.)
E	RPM variants	Existing process model variants in response to (implicitly) identified context factors (e.g. for different organizational units, product types, etc.)
E	Historical RPM versions	Changes made to the reference process model in the past (creation of new model versions) due to internal or external influences
I	Process stakeholders (e.g. process owners)	Stakeholders with intimate knowledge regarding the process model, its content and application: Process owners; activity responsibles
Project instance-related information		
E	Project documents	Documents describing the scope of specific projects: Project briefs, requirements documents, Milestone documents, project plans
E	Current and historical project plans	Documented activities for specific projects
E/I	Project planning procedures and practices	Procedures and practices applied by project planners in order to set up development projects (documented or implicit). Assumptions made during project planning
E	Historical tailoring data	Description of historical tailoring decisions with tailored process elements and rationale for tailoring
E	Project lessons learned	Documented activities and retrospectively identified derivations from RPM
I	Project management stakeholders	Stakeholders with intimate knowledge regarding the application and instantiation of the process: Project managers, project planners
Key: *ST = Source Type; E = Explicit; I = Implicit*		

7.3.2 Select acquisition methods and plan acquisition strategy

In order to support the acquisition of tailoring-relevant information, a number of methods have been developed and applied within the individual application case studies (cf. section 5.2 for derivation, Table 8-1, and Appendix A4.1, Figure A-18 for application). Subsequently, first, the methods are presented, followed by considerations on the formulation of an acquisition strategy, and templates and tools to support the documentation of the acquired information.

Information acquisition methods

Figure 7-6 presents an overview of information acquisition methods that have been derived from literature and subsequently concretized within the scope of this thesis, based on the general framework derived in section 5.2. The methods are detailed and described in Table A-37, Appendix A3.4.2.

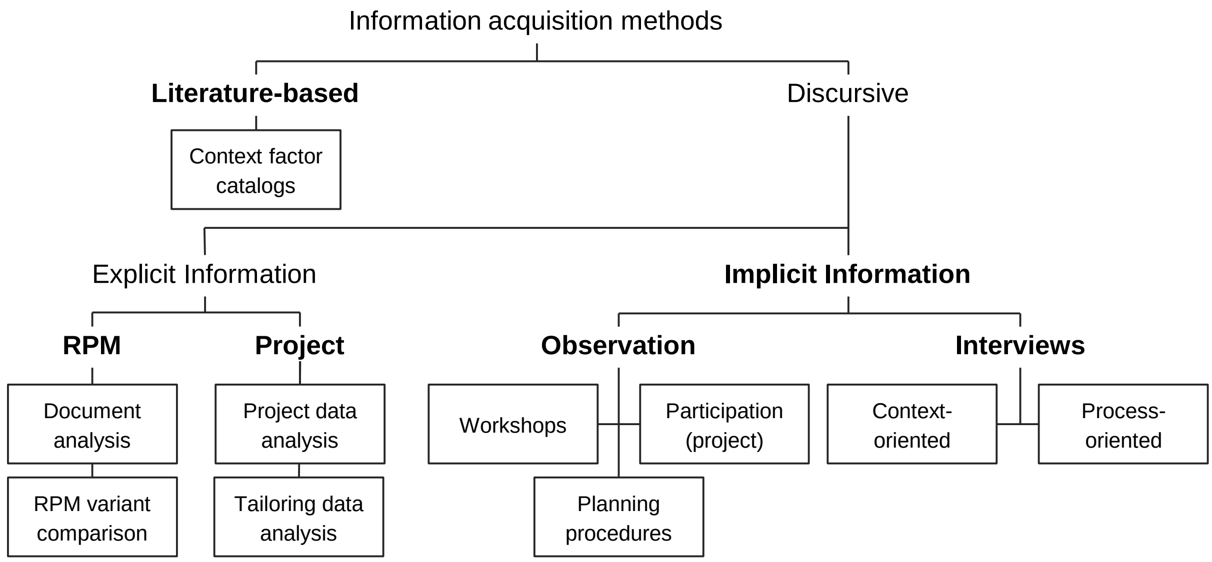


Figure 7-6: Overview of information acquisition methods from information sources

As the PDP and its application context are interdependent, an individual investigation of contextual and process aspects has not been found to be constructive within the empirical studies. Instead, while the methods drive the acquisition from either the context or process domain, the aim is a co-acquisition of information regarding both domains. Due to the specificity of the actual process context and the variance in data availability, developing universally valid acquisition tools is difficult. Therefore, the focus of this section is to describe general approaches and the environment necessary in order to identify relevant context factors.

Regarding **literature-based methods**, catalogs and collections of context factors are available in literature, which are very generic yet suited to give tentative suggestions for possible context factors (cf. section 2.5.3). The first step of any organization-specific information acquisition should be to collect and **analyze existing explicit information** documented in models, databases, or documents (cf. Avnet, 2009, pp. 95–96). Examples are the comparison of (exemplary) existing process variants, the (statistical) analysis of documented project-specific process instances, and the analysis of documented tailoring decisions in order to identify recurring patterns. Statistical analysis can, for example, be used to identify the frequency of occurrence of specific activities in project plans in order to identify the degree of commonality and variability of activities. Besides explicit information, **implicit knowledge** can be accessed using methods such as observations, workshops, and interviews, which can be approached from a process or context perspective (Badke-Schaub & Frankenberger, 2004; Lindemann et al., 2009, pp. 79–80).

While the methods are presented as distinct units, the application of a **combination of methods** as an acquisition strategy is generally preferable, as explained in the subsequent section, e.g. by first analyzing explicit information and using the results as input for subsequent interviews or workshops.

Information acquisition strategy

After the available information sources have been identified by the tailoring team and assigned suitable methods with which to extract the necessary information, the actual acquisition needs to be planned.

In general, **explicit sources should be exploited first**, deriving initial information regarding context factors and process variances, which is later validated and extended using implicit sources (cf. Avnet, 2009, pp. 95–96). Interviews need to be **carefully prepared and planned**, as they are very time and resource consuming, with chances for repetition often limited due to scheduling issues (Lindemann et al., 2009). The case studies conducted within this work have corroborated that information acquisition in interviews is more effective when the interviews can be prepared using previously acquired information. The result of the acquisition from explicit data sources strongly depends on the **quality of the data contained therein**. In the case of suitable information source availability, the combined application of different methods (parallel/sequential) is highly recommended. Redundant or overlapping information acquisition can help to increase the quality of the resultant data set (Lindemann et al., 2009, p. 81).

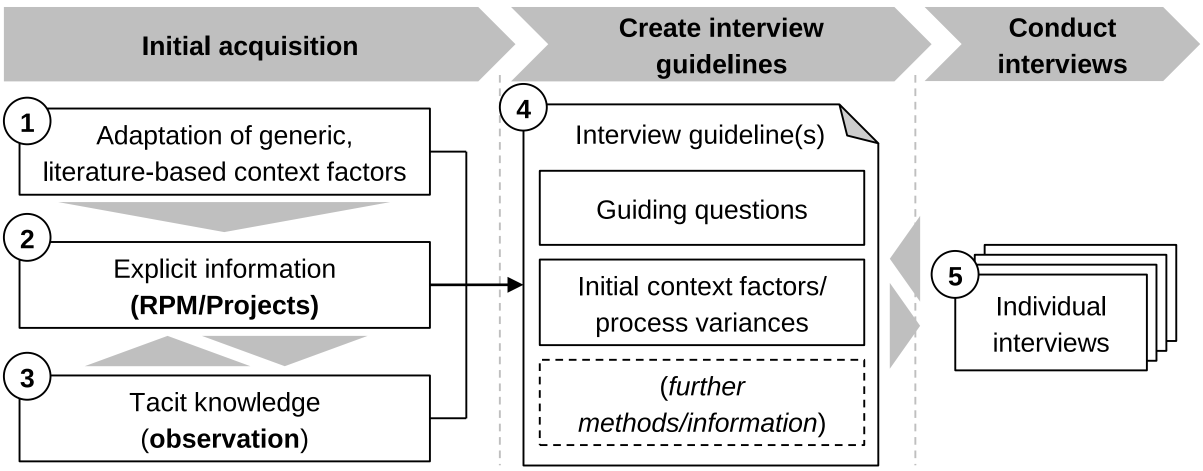


Figure 7-7: General information acquisition strategy

Figure 7-7 presents an example of a **generic information acquisition strategy**: First, possible candidate context factors are selected and adapted from literature, e.g. by the tailoring project leader (1). Subsequently, explicit information is collected and analyzed in order to identify an initial set of concrete, organization-specific context factors as well as process variances using the previously listed methods (2). In parallel, implicit knowledge is acquired using less resource-intensive methods, such as the observation of project kick-off meetings (which are not set up particularly for acquisition and thus would have taken place anyway) and compared with the information from explicit sources (3). Both are subsequently combined and used to create interview guidelines containing a tentative set of context factors and process variances, general guiding questions (cf. Appendix A3.4.5), and further methods as required (e.g. definition of process sub-goals) (4). The interview guidelines are used to conduct individual in-depth interviews (5), validating/falsifying the initial information and potentially uncovering new, relevant tailoring decisions. For example, interview partners can be confronted with different process variants or different previously identified context factors in order to validate their relevance and assess their impact on the respective process elements. New information can then be integrated into subsequent interviews. Based on this general strategy and the information sources presented earlier, **four basic situations** regarding the information availability within an organization can be derived (process and project information), which are illustrated in Appendix A3.4.3.

In order to ensure a structured procedure and establish traceability as well as reproducibility (cf. Kasperek et al., 2015) of the resulting TSM, the planned acquisition strategy, and the individual acquisition activities carried out should be documented in an **information acquisition plan**, as illustrated in Table 7-6. The information acquisition plan should contain the following items: The *information source* and its *type* (explicit/implicit), the applied *method per source*, the expected *contribution* (context factors, process variances, both), the *acquisition date*, and the respective *system boundary* for which the information is valid.

Table 7-6: Exemplary information acquisition plan

				Focus/Contribution	
Method	**Type**	**Date**	**Information source**	**CF**	**PV**
Variant comparison	E	2017-07-06	PDP RPM variants for product lines X and Y	*product line*	X
Observation	I	2017-07-07	Project kick-off meeting		X
Interview	I	2017-07-07	Interview with project planner	X	X
Observation	I	2017-07-08	Project milestone review	X	X
Project plan analysis	I	2017-07-08	Plans of projects running from 2016-01 to 2017-06		X
Key: *E = Explicit; T = Implicit*					

For interviews, the **roles** and **individuals** of interviewees should be listed additionally, in order to enable an initial assessment of the effort involved, and whether individual- or group interviews should be conducted. Additional information can be added to facilitate the information acquisition depending on the individual information sources, such as the **availability** of particular interview partners as well as **schedules** for occurring meetings, such as milestone reviews or project kick-off meetings (cf. project roadmap during phase 1). The information acquisition plan acts as a **checklist**, in order not to forget important sources, and is used to **track** the information acquisition, providing an overview of **progress**.

Documenting the process context

In order to structure the documentation of context factors, an **acquisition grid** can be used to document context variables and corresponding values (cf. section 6.2). Within literature, several existing classifications of context factors are described and can be used (e.g. Langer & Lindemann, 2009; Rosemann et al., 2008; Clarke & O'Connor, 2012). A proposal for a consolidated grid to classify context factors specifically within the context of process tailoring in iPD is presented in Table 7-7[47], consisting of two levels, categories and clusters. IDs are used to number context variables.

Table 7-7: Grid-based scheme for classification of context factors with examples (based on PE-Langner, 2017)

Level 1 – Category	Level 2 – Cluster	Level 3 – Variable	ID	Level 4 (Values)	Description
Environment			1.1.1		
Market	Stakeholder	Suppliers involved?	2.1.1	Yes No	Are external suppliers involved in the project?
	Competition		2.2.1		
Organization	Company		3.1.1		
	Management		3.2.1		
Process			4.1.1		
Project	Project type and properties		5.1.1.		
	Project decisions		5.2.1		
	Development/ Product	Hull geometry change	5.3.1	Yes No	Do component hull geome-tries remain stable?
	Team	Number of team members	5.4.1	1-5; 5-10; >10	
	Time/Pace		5.5.1		
	Budget		5.6.1		
	Other resources		5.7.1		
	Specific process drivers		5.8.1		

Context values are associated with a context variable, similar to feature models (Cf. Thörn & Sandkuhl (2009); Kang & Lee (2013)). The documented context variables and values can be further attributed and described, e.g. by adding the date of identification and the corresponding system boundary in order to designate its currently valid scope. As has been seen in application case studies, context factors can often be classified into different categories simultaneously. Therefore, the scheme is best used as a tool to guide the acquisition rather than

[47] The categorization scheme has been developed as part of PE-Langner (2017) based on a comparison of 22 existing categorization schemes (cf. Appendix A3.4.4).

the retrospective categorization of context factors. Since the initially acquired context factors can be relatively fuzzy at first, they need to be further detailed and concretized, e.g. in additional interviews. Generally, all candidate context factors should be documented for later validation and possible concretization. The context factors need to have certain **characteristics** in order for them to be of relevance for the tailoring methodology at hand, which are:

- **Stability:** A selected context value remains fixed or changes only occasionally from a certain point of the project onwards. Highly fluctuating context factors are difficult to address with the developed tailoring methodology.
- **Simplicity:** The context values need to be formulated as simple as possible to increase understandability and applicability, with the simplest being binary yes/no values. Continuous scales are less suitable (Kalus, 2013, pp. 117–118).
- **Measurability/Observability:** The context factors and corresponding values need to be assessable as objectively as possible, avoiding vagueness and estimations based on personal experiences and subjectivity.
- **Traceability:** The tailoring impacts of the context factor are traceable to process elements as clearly as possible.

Documenting process variability

The documentation of process variability can occur analogously to context factors, in the form of tables documenting process activities, their corresponding attributes, such as the required operator (optional/isVariant) and description of the concrete variance (cf. Table 7-8). Further attributes are possible in order to describe variants more concretely (cf. section 2.4.2 for further possible process activity attributes)

Table 7-8: Documentation of process variance

Process element	Operator	Variant	ID	Description of variance
Activity 1	Optional	-	1	Activity 1 is not required under certain conditions
Activity 2	hasVariant	Activity 2a	2.a	Application of simplified review
Activity 2	hasVariant	Activity 2b	2.b	Application of extensive review
			…	

Tools and continuous information acquisition

In parallel to planning the acquisition strategy, the necessary acquisition and documentation tools need to be **implemented**, such as interview guidelines (cf. section 7.3.4) or documentation templates (cf. Table 7-7 and Table 7-8). Electronic means such as databases or spreadsheet templates are favorable due to their extensibility. In case of subsequent updates or extension of the information acquisition, elements can be added. However, for the initial acquisition, a paper-based approach or even free-form (e.g. using Mind-Maps®/Concept Maps) can be preferable due to the increased flexibility and speed during the acquisition. Therefore, hand-drawn feature models or mind maps can be used to get an initial overview, which can afterward be transferred to an electronic representation.

In order to increase the long-term viability of process tailoring within an organization, means for **continuous collection of tailoring information** need to be implemented, in order to gain feedback from continued application of the process tailoring framework within projects. This aspect will be further addressed in phase 5 of the methodology (cf. section 7.6.5).

7.3.3 Acquire information from explicit sources

The first set of methods described addresses the acquisition of information from explicit data. First, explicitly available information needs to be collected. This extends to **existing reference process models (variants)**, **project documents**, and data **describing project-specific process instances** in order to extract context and process variance information.

Comparison of process variants (Qualitative)

RPM variants can be used in order to analyze differences between, e.g. different project classes or organizational units and their underlying rationale. However, if no further information is available, this method only allows a qualitative comparison of process variants due to a specific context variable. Besides pre-defined RPM variants already existing in the organization, RPM variants can be **exemplarily** modeled as part of the information acquisition in order to capture diverging mental models, e.g. by different stakeholders in different parallel subdepartments, and subsequently compared.

While automated tools for process commonality analysis do exist, they require rigorous process models, using the same notation and comparable level of abstraction (Ocampo et al., 2005). As the necessary quality often is not available in PDP RPMs in practice, this limits the applicability of automated approaches.

Analysis of documented project-specific processes (Quantitative)

Besides existing RPM variants, documented project-specific process instances can be used as a source for identifying process variance. Historical project data records can be used in order to retrospectively identify commonalities and variances between different project instances. Depending on the scope of the documentation, differences in activities, deliverables, documents/templates, or milestones can be identified. This allows the analysis of a potentially large number of instances, depending on the quality and quantity of the documentation.

Due to the expected higher number of instances, this method not only allows a qualitative comparison of RPM variants but also a **quantitative** analysis of how frequently activities are part of different project instances (visualization via histogram). Therefore, the analysis provides further insight, which activities represent commonalities over different project instances, and which ones are specialties. This information can be used to prioritize process elements in subsequent interviews. Furthermore, by analyzing common occurrences of process elements in different projects, conclusions can be drawn regarding **correlations** between process elements that often occur together and thus might underlie the same tailoring rationale. Besides documented project data, documents collected from the individual project instances can be used to draw conclusions regarding the individual project contexts (e.g., requirements lists, project briefs, etc.). Due to the specificity of the documentation, the procedure has to be defined on a case basis. A commonality analysis has for example been conducted in **case study D.1,** as depicted in Figure 7-8 (cf. Table 8-1, p. 189 and Appendix A4.1 for further information).

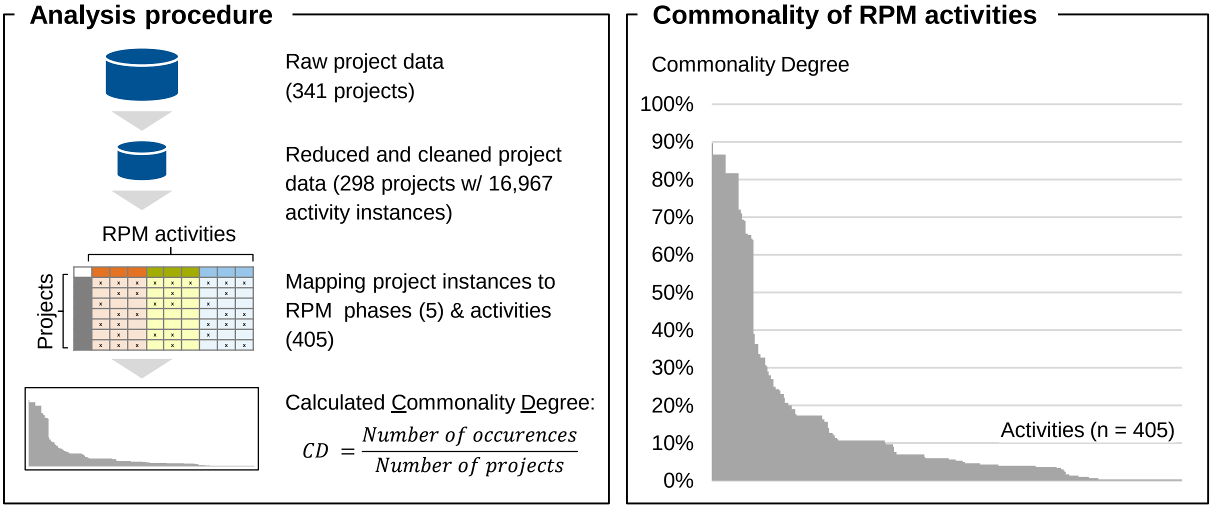


Figure 7-8: Example for project commonality analysis (Case study D.1): Procedure (left) and result (right)

From the project management system, raw data regarding 341 projects and their constituent activity instances has been exported. Activity instances were subsequently filtered due to their documented status, removing activities marked as "not necessary" and identifying "done" or "released" tasks. The results have been further harmonized (editing typos, translating descriptions between languages) and filtered (removing e.g., internal projects or projects created to document individual customer validation measures), resulting in a final set of 16,967 activity instances in 298 projects based on 405 RPM activities. This data has been documented in a matrix to calculate the commonality degree per activity. The resulting commonality analysis shows that no activities exist with 100% commonality over all projects. The commonality distribution indicates that a sizeable amount of activities only occurs in select projects. This data has been used in subsequent interviews to identify the rationale for activity selection.

7.3.4 Acquire information from implicit sources

The acquisition of information from **implicit** sources is vital, regardless of whether 1) information has been previously extracted from explicit sources or 2) implicit sources are the only ones available. Therefore, while the analysis of documented data has been stressed in the previous section, implicit information (cf. section 2.2) is highly relevant, albeit more difficult to access. In particular, information regarding context factors is predominantly acquired from implicit expert knowledge. The analysis of explicit information serves as a facilitating foundation for conducted interviews. Conversely, information acquired from explicit sources needs to be validated and extended with implicit knowledge in interviews and collaborative workshops. This section focuses on the description of **interviews** in order to elicit context factors and activity variances. Further observational methods are described in Table A-37.

Interview types

In general, the acquisition of context and process variance information should be conducted within the same interviews. However, two different strategies are possible for approaching individual interviews (cf. Figure 7-9):

- **Context-oriented interviews** focus on the context of deployed processes, e.g. by identifying discerning aspects of the project portfolio under investigation. Thereby, the interviews start by discussing differences in project characteristics and deducing process variances in the form of activity variants. This type of interview primarily addresses stakeholders with an overview of multiple projects (e.g. project managers and leaders).
- **Process-oriented interviews** focus on identifying possible deviations from the RPM and variances between project instances, subsequently deducing the reasons underlying these deviations. This type of interview is best conducted with stakeholders who have in-depth insights into individual activities, e.g. engineers, designers, etc. The interviews can be structured according to a (prioritized) list of process activities a particular interview partner is responsible for.

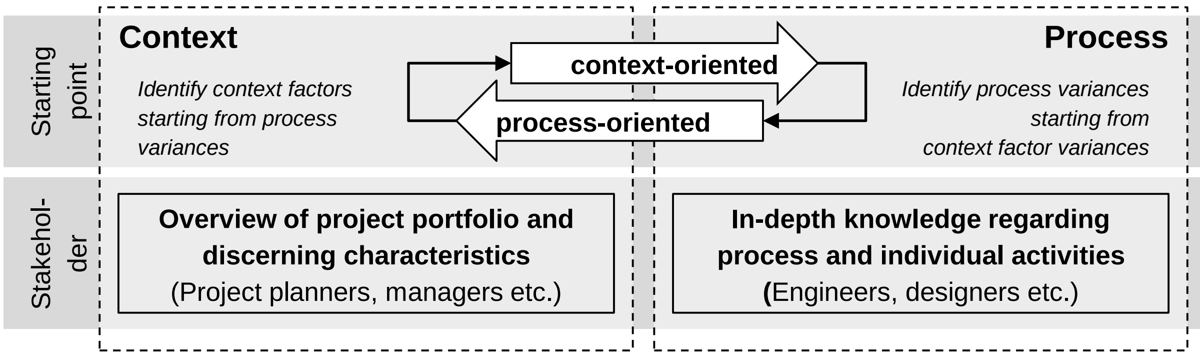


Figure 7-9: Interview types to acquire implicit information

The type of interview will discern the guiding questions and supporting materials used. Both types of interviews can be used iteratively in an alternating manner, identifying and cross-validating context factors and process variances in turns. In order to generate an initial overview, starting with context-oriented interviews is suggested. Further interviews can then scrutinize individual activities. In this section, interviews are assumed to be individual interviews; however, group interviews are also possible. The interviews are **semi-structured,** using a guideline of questions, but leaving enough freedom for discussions of individual context factors and process variances as necessary.

Preparing and conducting interviews

Due to the importance of interviews, a generic interview guideline is presented in Table A-40 (Appendix A3.4.5), containing guiding questions for both types of interviews. The guideline has been consolidated from the guidelines developed for the acquisition interviews within the application case studies[48] and also contains questions adapted from similar approaches. The individual interviews can further be supported by using the following documents, depending on the specific situation at hand:

- **Overview of the TSM metamodel** to explain the required information
- **(Initial) Baseline RPM**, in order to establish a shared frame of reference between interview partners, if necessary, accompanied by a **glossary** of the most essential process terms (cf. PE-Frisch, 2017a)
- **Role descriptions**, e.g. in the form of RACI charts
- Exemplary **historical project plans**, **RPM variants**, or conducted analyses (cf. Figure 7-8)
- **List of described process activities** from the RPM relevant for the specific interview at hand. Extended by previously identified activity variants, if available.
- **Previously acquired context** factors (e.g. from explicit sources or previous interviews) for discussion and concretization within the interviews, especially for process-oriented interviews (cf. the "Design Context Worksheet," Hales & Gooch (2004, p. 45))
- **Modeled project planning procedures** and derived **assumptions/premises**
- **Documentation templates** to document acquired context factors and activity variants and their respective attributes (cf. section 2.4.2), e.g. as spreadsheets or paper templates

After an interview, the acquired information is documented in the format described earlier in this section. For the initial acquisition of context factors, documentation in the form of lists or tables (spreadsheet software) can be beneficial due to an increased speed of documentation. Besides lists, other forms of documentation can be applied during interviews, such as mind maps or paper-based feature models, to support a more detailed investigation of individual context factors. The following chunks of information should be documented during the interviews:

- Relevant **context factors** and their **values,** as mentioned by the interview partners. Further attributes for context factors as necessary (e.g. the frequency of occurrence)
- **Process variances** in terms of **optional** process elements and **activity modes**
- **Relationships** between context factors, between process elements, as well as between both of these domains for the subsequent formulation of context constraints/rules, tailoring rules, and process constraint rules.

7.3.5 Consolidate and validate information

The consolidation of the acquired information is the concluding step of phase 2. The consolidation step is particularly important in case of the following situations:

[48] primarily C.1, C.2, D.1

- Information acquisition has been performed in **different system boundaries** simultaneously, with a potential overlap in context factors relevant for different system boundaries.
- Multiple sequential **iterations** of information acquisition have been performed, uncovering additional information each time (acquisition cycle).
- **Conflicting** information has been identified due to the use of different methods or from different sources (inconsistencies, duplicates).

The consolidation is performed in two steps: First, the information is **harmonized** by the person supervising and/or executing the information acquisition, bringing together documented information from different sources. Second, the consolidated information is **validated** in a concluding workshop, where the acquired, harmonized information is discussed under the eyes of an interdisciplinary team of main stakeholders involved in the acquisition.

7.3.6 Quality gate II

After phase 2, the acquisition of information relevant for building the TSM should be largely concluded. As stated before, iterations between phases 2 and 3 are to be expected, in particular in regard to relationships between context factors and activity variants. The deliverables necessary to advance to phase 3 as well as reflective questions to assess current progress are presented in Table 7-9.

Table 7-9: Deliverables and reflective questions for conclusion of phase 2

Deliverables	**Information acquisition plan**, documenting the steps taken during information acquisition (sources, methods, interview partners, etc.)
	Interview minutes per interview
	Process variability sheet, documenting the relevant process variances and their corresponding attributes as identified from explicit and implicit sources
	Context factor sheet, documenting the relevant context factors, their corresponding values, and attributes for both, as identified from explicit and implicit sources
	Relationships between context and process with varying degrees of maturity, i.e. concrete rules and generic relationships between context variables and process elements
Reflective questions	Have all relevant stakeholders (departments/roles/individuals) been interviewed?
	Has the information acquisition taken a spectrum of different projects into account, broad enough to gain a representative range of context factors and corresponding values?
	Have (initial) relationships between context factor values and process variances been identified?
	Has the acquired information from several independent acquisitions been harmonized and integrated?
	Has the acquired information been validated, e.g. by cross-referencing acquired information with other interviewees?
	Does the acquired information enable at least an initial modeling and analysis of the TSM?

7.4 Phase 3: Modeling the TailoringSystemModel

Within the third phase of the methodology, the previously acquired information is modeled using the metamodel elaborated in chapter 6, resulting in the organization- and process-specific instance of the **TailoringSystemModel (TSM)**, which serves as the central tailoring knowledge repository for knowledge reuse and analysis in phase 4. **Phases 3 and 2 will overlap in practical application**, through iterative acquisition and modeling (cf. Appendix A3.2). The metamodel allows to include tentative information for subsequent concretization in these iterations by attributing information as temporary and modeling generic impacts.

An overview of the steps within phase 3 is presented in Figure 7-10. As indicated, the phase consists of two major activities: **Modeling** the acquired information (section 7.4.1) and **adapting** the RPM if necessary, in case the identified tailoring needs cannot be sufficiently satisfied using the original RPM (section 7.4.2). If phase 2 is carried out in parallel in multiple system boundaries, the information gained from these instances is integrated into a common TSM. The individual modeling steps can be parallelized, although it is recommended to begin with modeling elements and dependencies within the individual domains and subsequently integrating them via modeling the domain-spanning rules.

	Step	Result
1	Modeling the context domain	*Context Model*
2	Modeling the process domain	*Variant-rich process model*
3	Modeling the organizational domain	*Organizational hierarchy*
4	Modeling domain-spanning rules; resolving tentative dependencies and PCRs	*Process tailoring rules*
5	Adapting the reference process model (optional)	*Adapted reference process model*
◇	Quality Gate III	

Figure 7-10: Steps and results of phase 3

Different methods and corresponding **software tool support** can be used, either separately or in combination, to create a TSM corresponding to the requirements (compatibility with graph-based structural analysis/import to graph analysis software). Each has individual benefits and disadvantages:

- **Node lists** (tables) are suitable to capture individual nodes and their corresponding attributes, providing a starting point for the creation of further dependencies
- **Edge lists** (tables) are suitable to capture attributed edges but can become cumbersome to create and maintain manually, with potential for inconsistencies
- **Matrices** (DSM/DMM) are suitable for documenting dependencies such as *LCC*, *precedence*-dependencies or *hasCondition/hasImpact* dependencies of rule nodes

- **Relational databases** require some initial effort for implementation but offer a way to maintain data consistency and facilitate data entry by reuse of previous entries (e.g. for the creation of edges)
- **Graph-based modeling** (using, e.g. the developed software demonstrator or similar graph-based tools), which offers intuitive modeling. As working with graphs in their raw form can become cumbersome once the data increases in volume, additional support is necessary to facilitate data entry.

7.4.1 Guidelines for modeling the TailoringSystemModel

This section addresses the creation of the TSM. Previously created and a priori available models can be reused, such as the hierarchical process model or existing RPM. These serve as a starting point for modeling the process domain. The modeled TSM eventually needs to conform to particular requirements imposed by the subsequent analysis.

1) Modeling the context

The first step is the formalization of the context information. As previously described, the description of the context domain is based on the logic of feature models. Therefore, the following sequence of modeling the context domain is suggested:

1. Define the individual **Context Variables** and create corresponding nodes
2. Define the individual **Context Values** and corresponding **local constraints** (connect Context Values to Context Variables), completing the description of context factors
3. Create **intra-domain cross-tree constraints** as required (cf. Table 5-4 and Table 7-10):

Variables and **values** are described using the attributes listed in Appendix A2.2. While context variables can be defined freely, the use of a question format is suggested (La Rosa et al., 2009). It is also possible to define “empty” context variables without values, to structure the context domain via context constraints. For example, documentation of context factors related to the structure of a product portfolio may require multiple layers of hierarchy, with only the lowest level representing concrete products and thus context values. These context variables are then connected using context constraints (cf. Table 7-10). Modeling of context factors can be prioritized according to the relevance of context factors, e.g. due to the number of times the context factor was mentioned during acquisition interviews or the (estimated) number of impacts on the investigated RPM. Thus, context factors for which concrete tailoring impacts have been identified in interviews should be modeled first.

After the individual context factors have been modeled, **intra-domain cross-tree relationships** are created in order to facilitate the navigation within the context model. The possible relationships have been derived in section 5.3 and presented in chapter 6. Their usage is summarized in Table 7-10, describing possible concerns regarding the relationship between two context elements and indicating the corresponding modeling construct.

Table 7-10: Usage of cross-tree context relationships

Elements	Description	Used Construct
Cvar → Cvar	Hierarchical decomposition of context variables, e.g. in order to add structure and cluster context variables.	ContextConstraint (CC)
Cval → CVar	Selection of a particular context value requires the evaluation of another context factor or excludes another context factor.	DecisionTreeConstraint (DTC)
Cval → Cval	The selection of a particular context value includes or excludes one or multiple specific values of other context factors.	GlobalConstraintRule (GCR)

Figure 7-11 illustrates the modeling of a *Decision Tree Constraint*: Within phase 2, the influence of variant development on PD projects has been identified. First, context factor 1 has been defined, with the corresponding values "yes" and "no." As the impact cannot be sufficiently modeled using a single context factor, a further context factor 2 has been created, describing the number of product variants developed. Both context factors are related, as the selected value of context factor 1 determines whether context variable 2 needs to be evaluated or not. However, context factor 2 needs to be evaluated separately as the relationship cannot be specified further.

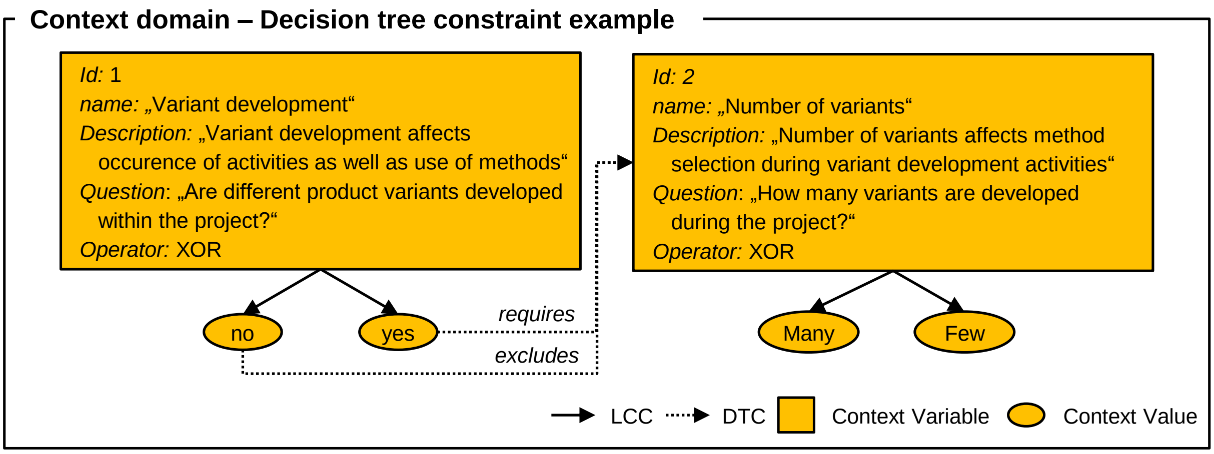


Figure 7-11: Example for Decision Tree Dependencies (Case study C.2)

2) Modeling the process domain

Modeling the process domain in this subsection focuses on extending the initial baseline RPM (cf. phase 1) via the identified activity modes extracted during phase 2. Modeling variant rich processes, therefore, uses regular process modeling as a foundation, extended via the mechanisms for modeling activity variances described in chapter 6. The baseline RPM is imported into the TSM manually or automatically, depending on the initial situation. Therefore, the process domain, in general, contains the most commonly described element types, such as activities, events (e.g. Milestones, support (e.g. Methods, Tools, Systems), and artifacts (e.g. Documents, Product Models).

As stated before, within the scope of this approach, **activities are of particular relevance**, since they provide the foundation for the analysis of the TSM within subsequent phase 4. Other process element types are at this point of auxiliary nature. **Roles** are similarly modeled and of relevance, but within the scope of this approach are part of the **organizational domain**. In order to systematically model the process domain, the following sequence is suggested:

1. Model/import **baseline RPM** to at least the necessary level of decomposition (cf. phase 1)
2. Model the **hierarchical decomposition** of the RPM (cf. phase 1)
3. Mark **optional activities**
4. Add, describe/attribute, and allocate **activity modes**

Steps 3 and 4 are illustrated in Figure 7-12: Optional activities are created by using the *isOptional* attribute. Activity modes are designated by using the *isVariant* attribute and allocated to a base activity via *isVariantOf* edges. During tailoring, optional activities are removed if not required, while a selected activity mode replaces the base activity. Combinations are possible but can result in conflicts (cf. tailoring rule conflicts, section 7.5.4).

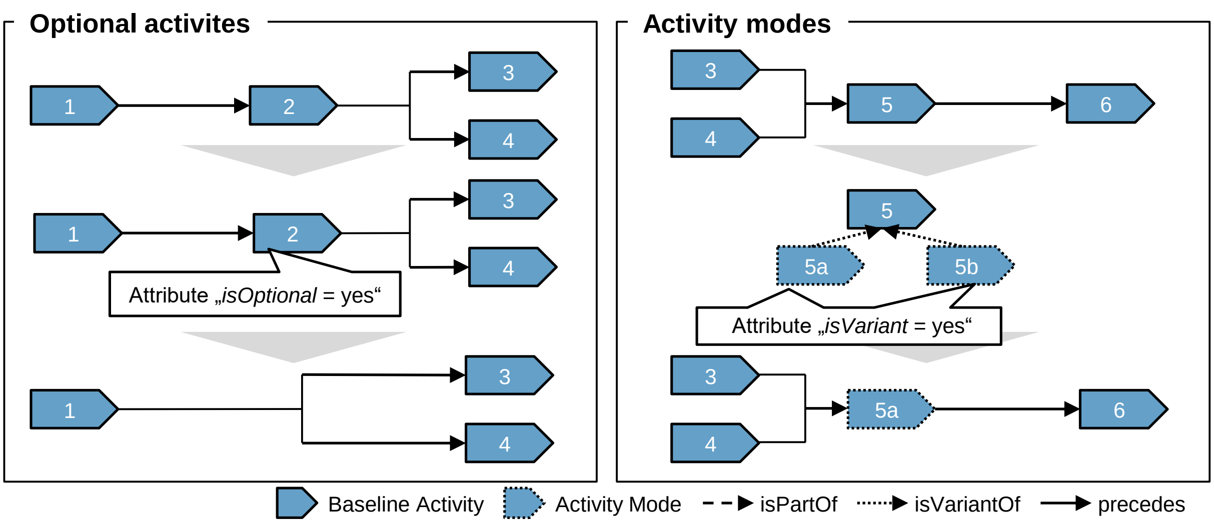


Figure 7-12: Optional activities and activity modes within the TSM

To manage the occurring process variance efficiently, a decomposition-driven approach is encouraged, with a late creation of activity modes (cf. Milani, 2015) in order to avoid duplicate activities. Thereby, activities should be decomposed as far as possible, continually analyzing for commonality and variability (Choi et al., 2016; Ocampo et al., 2005; Washizaki, 2006), adding activity modes for elementary activities on the highest level of decomposition. This needs to be carried out iteratively, as steps 3 and 4 can require an adaptation of the process model in order to achieve the desired tailorability (cf. section 7.4.2).

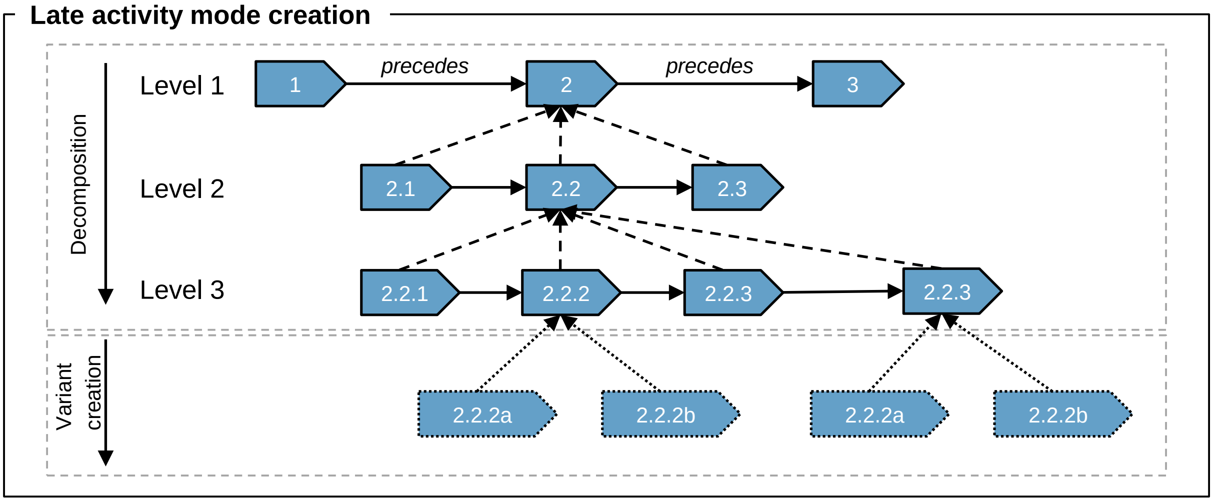


Figure 7-13: Late creation of activity modes to describe process variability

3) Modeling the organizational domain

The developed analysis approach (section 7.5) requires a hierarchical organizational structure within the organization at hand, which is to be expected in larger organizations. Explicit information such as organizational charts or organizational breakdown structures, as well as RACI-Diagrams, can be used to populate the organizational domain of the TSM if the information is not or only insufficiently contained within the RPM. (PMI 2013, pp. 261-262)

The organizational domain is modeled by creating the hierarchy of organizational units, allocating roles and individuals to their respective organizational units. Roles act as interfaces to process elements. Multiple individuals can be assigned to specific roles and vice versa. The assignment between roles/individuals and process elements can be modeled using e.g. a *Responsibility Assignment Matrix* (RAM) (Heimberger, 2017, p. 103; PMI, 2013, p. 262).

The selected level of detail is of relevance for the subsequent analysis, as it limits the possible level of resolution e.g. for the identification of stakeholders with common tailoring decisions. The level of detail is influenced by the amount of information available and the intended resolution of analysis results, representing a trade-off between information acquisition and modeling effort. Three distinct levels of detail are possible and directly related to the defined metamodel (cf. Figure 7-14):

- **Organizational Unit (OU):** Multiple individuals/roles aggregated to the level of organizational units, such as teams or departments. One or more not further specified members of the OU carry out an associated activity.
- **Roles:** Multiple individuals aggregated to task-specific roles. One or more individuals can fulfill a role to carry out an associated activity.
- **Individuals/Persons:** Individual employees, which carry out activities. This level creates the most effort for model creation and maintenance due to employee fluctuation.

A **combination** of these levels is possible if different amounts of information are available or different levels of detail necessary, e.g. in different departments. Therefore, for the scope of the TSM analysis, these nodes will be summarily referred to as “**stakeholders**” in order to capture all possible cases.

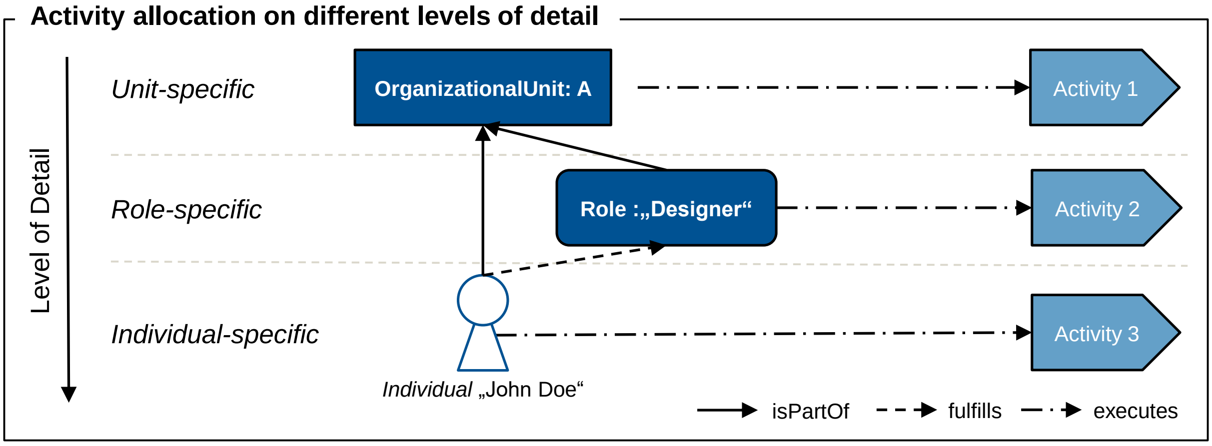


Figure 7-14: Possible levels of detail for assigning activities to organizational nodes

4) Modeling domain-spanning rules

This step links the two initially disconnected process and context domain, requiring a sound understanding between context variability and resulting process variance. Therefore, meaningful results for this step are only possible once enough information regarding context and process variance has been collected. The step can be carried out iteratively with modeling the process and context domain, through the implementation of individual tailoring rules.

In order to link the context and process domains, the modeling construct of **Process Tailoring Rules (PTR)** is used (cf. sections 5.3 and chapter 6). Individual PTRs are modeled using the following procedure (cf. Figure 7-15):

1. Creating a new rule node (node type *PTR*)
2. Connecting one or several context values with a *hasCondition* edge (creating the conditional side of the PTR)
3. Connecting one or several impacted process elements with a *hasImpact* edge
4. Defining the tailoring operator for each impact (*delete* for optional activities, *select* for activity modes, *move*, or *modify*)

This procedure implies that any impacted activities (including modes) are already included in the TSM. If this is not the case, the TSM needs to be adapted accordingly, iteratively adding baseline activities or modes (cf. section 7.4.2). Also, the procedure is only applicable if a concrete, precise relationship can be expressed. If this is not the case, temporal dependencies (*GenericImpact*) can be added and resolved later (see below)

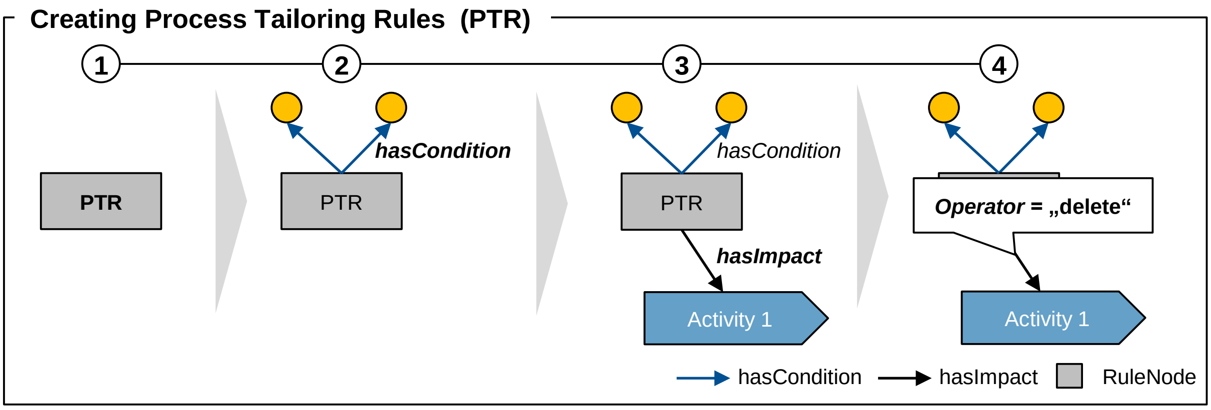


Figure 7-15: Modeling Process Tailoring Rules (PTR)

4a) Modeling and resolving temporary/tentative dependencies

As the information acquisition does not always generate precise relationships between context and process domain, the metamodel offers the capability to document unclear contextual impacts and context-process dependencies on different abstraction levels via the edge type **GenericlImpacts (GI)** (cf. Figure 6-5 and Figure 7-16). The resolution of temporary dependencies can trigger subsequent information acquisition activities for further concretization and potentially result in necessary RPM adaptation. Edges of the GI type can be further described using the *Description* attribute.

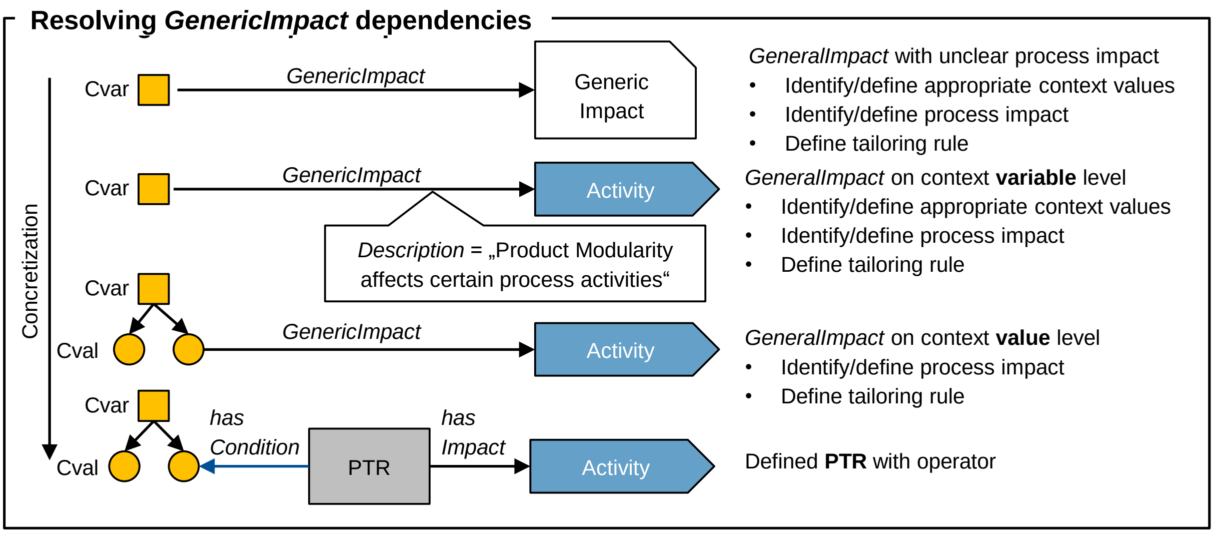


Figure 7-16: Resolving GenericImpact dependencies

4b) Modeling and resolving PCRs to PTRs

Process constraint rules (PCR) are intended to facilitate the capture of process variance information. They enable to capture of information regarding constraint rules between process elements without contextual influences, as sometimes information from explicit sources (e.g. project plans) and implicit sources can point at process elements that need to be part of the project-specific process, depending on the prevalence other process elements.

PCRs can theoretically be used directly in conjunction with PTRs. However, within the scope of this work, resolving PCRs into PTRs is encouraged since PCRs are currently not addressed in the developed analysis framework. The resolution is performed using the following generic sequence (cf. Figure 7-17):

1. Identify PCR
2. Identify conditional process element (via *hasCondition* edge)
3. Identify context factor influencing the process element (General impact or PTR)
4. (optional) Define PTR for the conditional process element
5. Connect process elements impacted by PCR with PTR
6. Remove PCR and associated edges

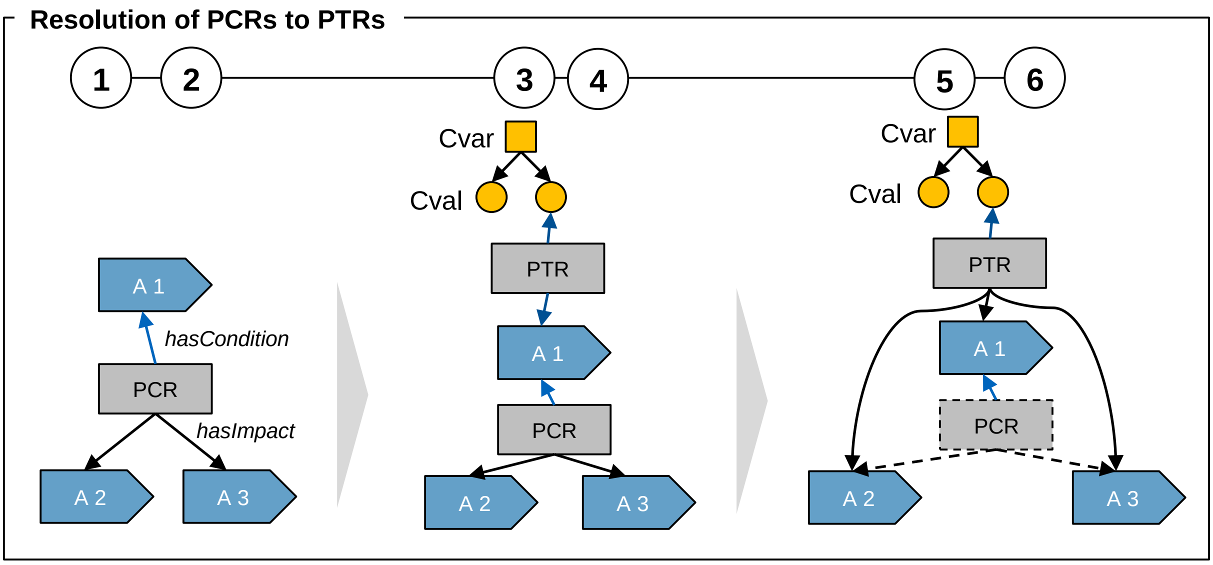


Figure 7-17: Resolving PCRs into PTRs

7.4.2 Adapting the reference process model

As stated previously, several situations can arise during modeling, which require a persistent **adaptation of the RPM** in order to satisfy the context-induced tailoring needs. This is corroborated by the insight that RPMs in practice are often not sufficiently tailorable as they have not been designed with the objective of tailorability in mind. In this case, the identified context factors serve as a starting point for further RPM concretization and detailing. The RPM adaptation activity within the tailoring methodology ensures that the resulting RPM can satisfy all identified tailoring needs. The activity is carried out iteratively within the modeling phase, as the need arises. Possible situations for the use of process adaptation are when tailoring is intended, but…

- … relevant sections of the process are currently not yet defined at all.
- … the process is currently not detailed enough but instead defined on a generic level.
- … impacted activities are not distinct enough to formulate clear tailoring rules.
- … activity modes are not yet defined.

In order to address such inadequacies of the RPM, Table 7-11 presents operators with which the RPM can be altered in order to reflect the tailoring need better. While similar to tailoring operators, these operations reflect persistent changes on the RPM. Further approaches to increase RPM tailorability can be found in literature related to the creation of process lines or families. As this aspect is not within the main focus of this work, further references can be found in section 2.5.4.

Table 7-11: Process adaptation operators to increase process tailorability

Operator	Effect
Add	Insert additional activity/activities
Split	Split composite activities into constituent elements (either on the same hierarchical level or by decomposing and inserting a new hierarchical layer)
Delete	Remove unnecessary activities
Modify/Detail	Detail existing activities and concretize their descriptions
Add activity mode	Define and add required activity mode.

7.4.3 Quality gate III

After phase 3, the TSM should have an adequate degree of maturity to warrant advancing to the next phase, where the TSM is analyzed in order to generate and consolidate information for supporting tailoring workshops. The deliverables and reflective questions to assess the progress made are presented in Table 7-12. This quality gate additionally requires a workshop-based model validation. Furthermore, requirements regarding the model maturity for analyzability are given in Table 7-13.

As a concluding step after all information acquisition and modeling activities (and resulting iterations), the developed TSM needs to be **validated** before it is used for conducting the analyses in phase 4 and applying it for RPM tailoring. This validation should occur in one or several validation workshops, where the developed TSM is presented, discussed, and analyzed for the plausibility of the defined rules and dependencies. For this, initial analyses can be performed on the TSM, e.g. in order to identify conflicts (cf. section 7.5.4).

Table 7-12: Deliverables and reflective questions for conclusion of phase 3

Deliverables	**Consolidated TSM**, conforming to the presented metamodel, modeling guidelines, and requirements described in this section
	Adapted RPM in response to the identified tailoring needs
	Is the TSM mature enough for the subsequent analyses?

Reflective questions	Have the relevant context factors been modeled and validated?
	Has the identified process variance been decomposed into activity modes?
	Have relevant identified activity modes been modeled and adequately attributed?
	Have the temporary dependencies been resolved accordingly, as far as possible?
	Has the RPM been adapted in order to satisfy the context-induced tailoring need?
	Has the TSM been validated by the involved domain experts/stakeholders?
	Are process decomposition levels clearly defined using "isPartOf"-dependencies?
	Have precedence edges been resolved to individual decomposition levels (cf. section 7.5.4)?
	Are the sublevels of composite activities connected using graphs?
	Has the organizational hierarchy been modeled within the TSM?

As the TSM needs to conform to specific requirements in order to be fit for analysis in phase 4, the particular **TSM analysis requirements** are described in Table 7-13.

Table 7-13: Requirements regarding the analyzability of the TSM

C	P	O	R	ID	Description
●				1	Have all relevant context variables been defined and associated with their corresponding context values via local constraints?
●				2	Have relevant intra-domain cross-tree relationships been defined?
	●			3	Are all **hierarchical dependencies** between decomposed process elements modeled?
	●			4	Are *precedes* dependencies between logically/temporally successive activities modeled **on the same hierarchical** level (i.e. between elements sharing the same parent via isPartOf-edges)?
	●			5	Are optional activities defined and attributed with the *isOptional* attribute?
	●			6	Are activity modes defined, attributed (*isVariant*), and associated with their base activity (*isVariantOf*)?
		●		7	Have all roles been defined and associated with the respective organizational units?
		●		8	Has the hierarchical relationship between relevant organizational units been defined?
		●		9	Have relevant individuals been associated with their respective roles?
	●	●			Have activities been allocated to the relevant organizational nodes?
			●	10	Have all PTRs been completely defined (condition, impact, tailoring operator(s))?
			●	11	Have all generic impacts been resolved and concretized as far as possible?
			●	12	Have all PCRs been resolved into PTRs, as far as applicable?

Key: *Domains: C = Context; P = Process; O = Organization; R = Rules*

7.5 Phase 4: Analysis of the TailoringSystemModel

After the organization- and process-specific TSM has been modeled and checked for validity, phase 4 addresses the structural analysis of said TSM in order to derive, export, and visualize information required in order to prepare and execute tailoring workshops, via the generation of **analysis reports**. The derivation of the analysis framework has been described in section 5.4 and was subject to publication in Hollauer et al. (2018b).

7.5.1 GQM framework for TailoringSystemModel analysis

As described in section 5.4, in order to develop the analysis algorithms, first analysis **goals** and corresponding **questions** have been derived discursively as part of the chosen GQM approach. Table 7-14 summarizes the concretization of the two activities supported through the TSM analysis, workshop preparation and execution, via six analysis goals and 26 questions, which form the basis for the development of the analysis algorithms. Goals G1 to G5 mainly address the preparation of tailoring workshops, G6 the execution.

Table 7-14: Derived analysis goals and corresponding questions

Goal	ID	Question
G1: Identification of rule conflicts	Q1.1	Do process elements exist which are impacted by multiple tailoring rules with conflicting tailoring operators?
G2: Identification of outliers and inconsistencies within the TSM	Q2.1	Which tailoring rules influence a high number of process elements (activities)?
	Q2.2	Which tailoring rules influence a high number of stakeholders?
	Q2.3	Which stakeholders are impacted by a high number of tailoring rules?
	Q2.4	Which stakeholders are responsible for a high number of process elements (activities)?
	Q2.5	Which tailoring rules have a high number of dependencies to other tailoring rules?
	Q2.6	Which tailoring rules have a high number of impacts on the process?
G3: Grouping relevant stakeholders into efficient workshop-groups	Q3.1	Which stakeholders have a high need for communication regarding tailoring decisions?
G4: Derivation of individual tailoring workshop agendas	Q4.1	Which tailoring decisions within a workshop group have a high impact on the process?
	Q4.2	Which activities a particular workshop group is responsible for are especially relevant?
	Q4.3	Which stakeholders within a workshop group are impacted by which tailoring rules?
	Q4.4	Which stakeholders are responsible for which process elements (activities)?
	Q4.5	Which stakeholders are dependent on which process elements (activities)?
	Q4.6	Which dependencies exist between individual workshop groups?

Goal	ID	Question
G5: Training of tailoring-affected stakeholders	Q5.1	By which tailoring rules is a stakeholder impacted?
	Q5.2	Which of these (Q5.1) tailoring rules have a particularly large impact on the process?
	Q5.3	Which other stakeholders are also impacted by these tailoring rules (Q5.1)?
	Q5.4	For which process elements (activities) are stakeholders responsible?
	Q5.5	Which of these process elements (activities) have a particular significance within the process?
	Q5.6	Which other stakeholders are also depending on this process element (activity) (Q5.5.)?
	Q5.7	Between which stakeholders does a need for communication exist in regard to tailoring rules?
G6: Provision of a decision basis for making tailoring decisions	Q6.1	On which context factors does a tailoring rule depend?
	Q6.2	Which properties do these (Q6.1) context factors have?
	Q6.3	Which process elements (activities) are impacted by a process tailoring rule?
	Q6.4	Which properties do these process elements (activities) have?
	Q6.5	Which dependencies does an individual process tailoring rule have with other tailoring rules?

7.5.2 Sub-methodology for structural analysis

Phase 4 consists of a 4-step sub-methodology for analyzing the TSM, as illustrated in Figure 7-18. Phase 4 needs to be carried out at least **whenever the TSM is adapted or extended**, e.g. when the tailoring knowledge is updated during reviews or new subprocesses are defined and integrated into the TSM. The aforementioned GQM framework is utilized to formulate the analysis algorithms. The individual steps are outlined briefly and elaborated in the following subsections.

Within the first step of the sub-methodology, the data of the TSM is **imported** into the analysis software. Regarding the actual analysis, first possible **rule conflicts** are identified based on pre-defined graph patterns. Subsequently, **indirect dependencies** between TSM nodes are calculated before the **significance** of activities is **quantified** using the defined set of structural metrics (*Criticality*, *Centrality*, *Snowball Factor*). The metrics are subsequently aggregated onto the respective PTR nodes, via the calculation of mean values per metric. Subsequently, the **communication need** is determined by calculating the communication requirements (via the *alignment* metric). A subset of the TSM is then **exported** for **clustering.** The IDs of the calculated clusters are subsequently **re-imported** into the TSM. The derived analysis results are **exported** separately via .csv-files[49]. These .csv-files are subsequently **re-integrated**, and

[49] Comma-separated values

the final **visualizations** generated in the form of .pdf[50]-based **reports** for printed or digital distribution and use**.** The reports are used in phase 5 to prepare and execute tailoring workshops.

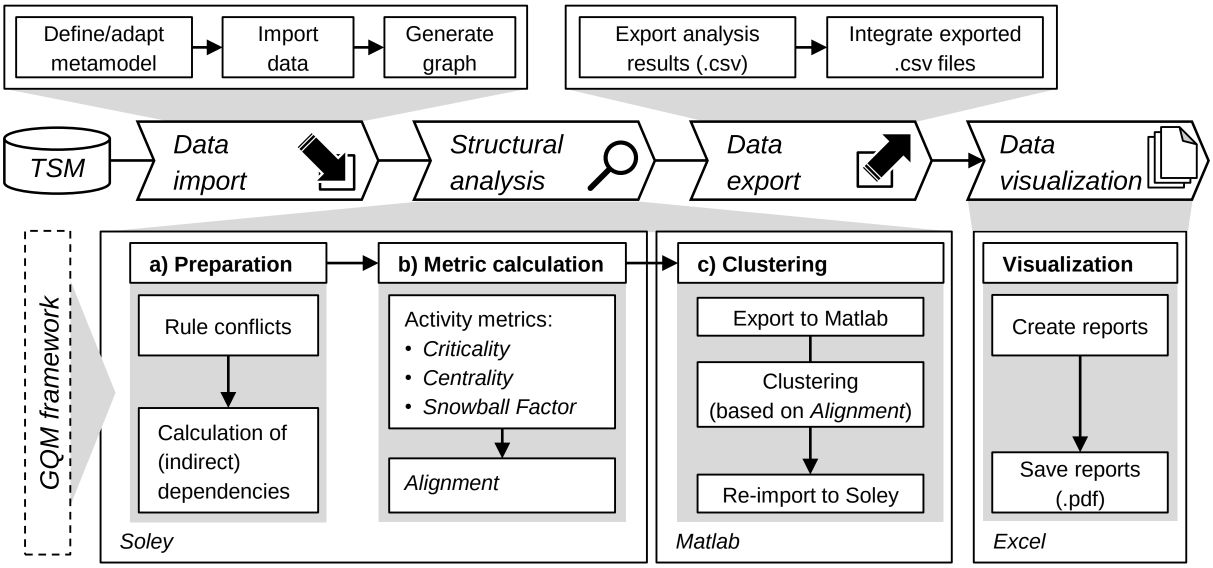


Figure 7-18: Overview of phase 4 – Structural analysis sub-methodology (based on Hollauer et al., 2018b)

Software demonstrator for implementation of the analysis framework

In order to test and increase the applicability of the analysis framework, a software demonstrator based on the TSM metamodel and the analysis sub-methodology has been implemented (cf. PE-Kölsch, 2018): The metric-based complexity analysis has been implemented using the Software ***Soley Studio***, a commercial platform for graph-based data analysis. The demonstrator implements the metamodel as well as graph analysis/rewriting algorithms (Helms, 2013, p. 93) in the form of automated workflows. This allows centralized data storage, calculation of indirect dependencies, structural metrics, as well as the automated intermediate and final import and export of data for clustering and visualization. Stakeholder clustering is implemented using **Matlab** (R2017b) and uses data regarding stakeholder dependencies and alignment metrics generated in *Soley*. The thus generated cluster-ID for each stakeholder is subsequently re-imported into the TSM graph (*Soley*). The final results are exported to an **Excel**-based prototype, which generates the different tailoring reports using VBA macros. The reports are eventually stored in PDF format. The implemented code to calculate the individual metrics and cluster tailoring stakeholders is included in Appendix A3.5.

7.5.3 Data import

As mentioned in section 7.4, the TSM can be modeled via various approaches. If the TSM has been documented using spreadsheet software or a relational database, the model first needs to

[50] Portable Document Format

be imported into the Soley-based analysis tool to generate the analysis graph. This step can be skipped if the TSM has been modeled directly using the software demonstrator. Otherwise, and in particular, if the metamodel has been adapted from the generic metamodel presented in chapter 6, the following preparatory steps need to be checked by the modeling tailoring expert:

1. Definition of node and edge types (in case of adapted metamodel)
2. Definition of the required attributes (in case of adapted metamodel)
3. Creation of templates (e.g. Excel) for preparation of data import (node/edge lists, DSMs to capture dependencies, etc.)
4. Fitting of model information to the template (export of information in case of a relational database)
5. Definition and, if necessary, adaption of the metamodel contained in the analysis software
6. Definition and, if necessary, adaptation of the data import routines in the analysis software
7. Execution of data import routines

7.5.4 Structural analysis of the TailoringSystemModel

Since the goals and questions listed in Table 7-14 address different aspects of the TSM, the structural analyses conducted in the analysis step have been grouped as follows, with the groups being carried out sequentially:

- Identification and resolution of possible tailoring rule conflicts
- Generation of direct and indirect dependencies within the TSM (edge-centric analysis)
- Analysis of the significance of individual TSM elements (node-centric analysis)
- Derivation of communication need (based on the previous calculation of indirect dependencies and the alignment metric)

The individual analyses are implemented in the software demonstrator as analysis workflows using graph rewriting rules facilitated through the use of the *Soley* software platform.

Preparation: Analysis of tailoring rule conflicts

Before calculating structural metrics, an initial plausibility analysis of the TSM should be conducted in order to identify and resolve potential PTR conflicts by adapting the TSM (Q1.1). Rule conflicts are not subject to discussion in tailoring workshops but should be resolved independently by tailoring experts (validation workshops). Three examples of conflict patterns are illustrated in Figure 7-19.

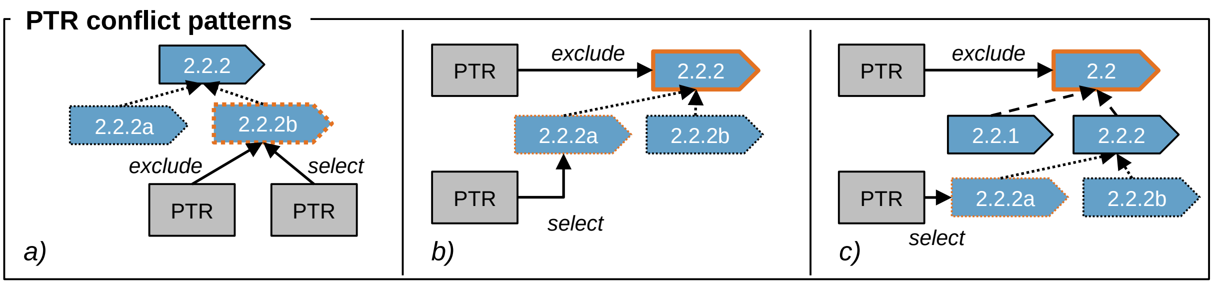


Figure 7-19: Three examples of possible PTR conflict patterns

In case a), two PTRs simultaneously exclude and select the same activity mode. This case represents a modeling error, since exclusion should be applied to the base activity. In case b), a PTR excludes a base activity while another PTR simultaneously selects a specific activity mode. In this case, the PTRs should be checked whether a simultaneous application is possible. GCRs can be inserted in order to avoid the conflicting situation, or if this is not possible, the rules can be assigned different priorities. Conflict c) is similar but further hidden through a level of activity decomposition. The following general strategies are suggested to resolve conflicts:

- **Priority**: Giving precedence or priority to one rule over another via priority levels
- **Conservative tailoring**: Giving preference to element inclusion instead of exclusion
- **Context constraints**: Inserting GCRs in order to avoid conflicting situations

Since the focus of this work is on the subsequent steps regarding the metric-based TSM analysis, this step has been included and exemplarily applied in the form of the presented common rule conflicts, but no exhaustive analysis of potential conflict patterns has been conducted. The presented pattern-based analysis is generalizable and can be adapted and extended in order to identify new rule conflicts or model implausibilities.

Preparation: Calculation of TSM dependencies

The second step of data analysis addresses the analysis questions via the analysis of TSM dependencies. A direct dependency between two nodes represents adjacency. An indirect dependency is a relationship between two nodes via a path of arbitrary length, e.g. two stakeholders working on the same task (Lindemann et al., 2009, p. 99). Within this and the subsequent sections, graph patterns representing (indirect) dependencies are visualized using the following notation:

node type$_a$ *–(edge type)→ [node type$_1$ –(edge type)→ node type$_n$] –(edge type) –* ***node type$_b$***

Thereby, ***node type$_a$*** and ***node type$_b$*** represent the start and end node type whose (indirect) dependency is of interest for a particular analysis. The middle part of the expression represents the path via intermediate node and (directed/undirected) edge types, therefore indicating indirect dependencies between two nodes. For example, if it is of interest whether two process tailoring rules share the same context value via an arbitrary undirected edge (type not further specified here), the pattern and corresponding expression are given in Figure 7-20.

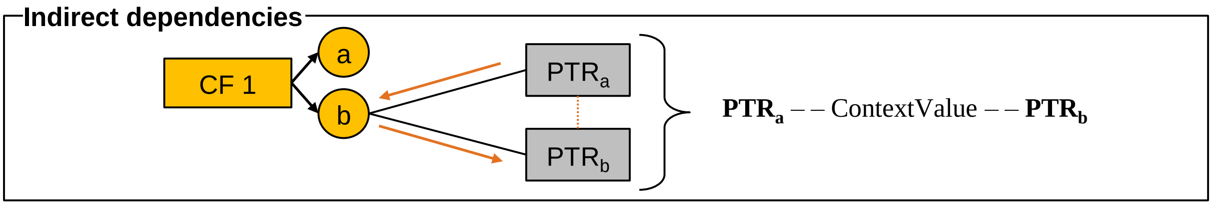


Figure 7-20: Example of an indirect dependency between two PTR nodes via a shared context value

An overview of the analyzed dependencies and calculated basic metrics (e.g. the number of direct or indirect dependencies between two nodes) is presented in Table 7-15.

Table 7-15: Calculated and analyzed dependencies (direct/indirect), attribute the dependency is evaluated to, and associated analysis questions

Dependency	Analytical attribute (element type)	Analysis questions
PTR *– – **Activity***	*numberOfActivities; meanCr, meanSBF, meanCB (PTR)*	Q2.1; Q2.6; Q4.1; Q5.2; Q6.3
PTR *– – Activity – – Role – –* ***Stakeholder***	*numberOfdependent Stakeholders (PTR)*	Q2.2
PTR *– – ContextValue – –* ***ContextVariable***	–	Q6.1
Activity *– – Role – –* ***Stakeholder***	*responsiblePerson (Activity)*	Q6.2
Activity *– –**PTR***	*connectedRules (Activity)*	Q6.4
Stakeholder *– – Role – –* ***Activity***	*responsibleActivities (OrganizationalNode)*	Q2.4; Q4.2; Q4.4; Q5.4; Q.5.5
Stakeholder *– – Role – – Activity – –**PTR***	*numberOfPTRs (OrganizationalNode)*	Q2.3; Q4.3; Q5.1
ContextVariable *– –* ***ContextValue***	–	Q6.2
ContextVariable *– – Context Value – –* ***PTR***	–	Q6.2
PTR *– – ContextValue – – ContextVariable – – ContextValue – –* ***PTR***	*numberOfElements (hasCRSW*-edge*)*	Q2.5; Q6.5
PTR *– – Activity – –* ***PTR***	*numberOfElements (hasPRSW*-edge*)*	Q2.5; Q6.5
PTR *– – Activity – – Role – – Stakeholder – – Role – – Activity – –* ***PTR***	*numberOfElements (hasSHRSW*-edge*)*	Q2.5; Q6.5
Activity *←isVariantOf –* ***Activity***	*numberOfVariants (Activity)*	Q6.4
Activity *–precedes →* ***Activity***	*previousActivitites followingActivities Cr, SBF, CB (Activity)*	Q6.4
Stakeholder *– – Activity – – PTR – – ContextValue – – ContextVariable – –ContextValue – – PTR – – Activity – –* ***Stakeholder***	–	Q4.6
Stakeholder *– – Role – – Activity – – PTR – – Activity – – Role – – Stakeholder*	*CommunicationNeed, Alignment (hasRSw)*	Q3.1; Q5.3; Q4.6; Q5.7
Stakeholder *– – Role – – Activity – – Role – –* ***Stakeholder***	–	Q4.6; Q5.6
Stakeholder *– – Role – – Activity – – Activity – – Role – –* ***Stakeholder***	–	Q4.5
Stakeholder *– – (OrganizationalNode) – –* ***Stakeholder*** (via organizational hierarchy of various length)	*organizationalDistance*	Q3.1; Q5.7
ContextVariable *– – ContextValue – – PTR – – ContextValue – –* ***ContextVariable***	–	Q6.2
ContextVariable *– – Context Value – –* ***ContextVariable***	–	Q6.2

Key: *- = No Attribute, dependency is used directly*

The individual entries represent which dependencies are derived and analyzed (path from start to end node), which analytical attributes are calculated, and with which question an analysis is associated. The analytical attributes are defined in the metamodel in Appendix A2.2. The description of the edge type is omitted if it is unambiguous. To structure the analysis, **inter-** and **intra-domain** dependencies are differentiated: Inter-domain dependencies start and end with two **different** node types, while intra-domain dependencies start and end with a node of the **same** type.

The following subsections focus on the two primary structural analyses: The significance of individual activities and the need for communication between tailoring stakeholders.

Metric calculation: Activity significance metrics

In the next analysis step, the activity metrics are calculated on the TSM graph *G = (V, E)*, in order to quantify the significance of process activities regarding tailoring operations. In the context of this work, a set of three overlapping metrics has been chosen (cf. section 5.4):

- ***Criticality (Cr)***
- ***Snowball Factor (SBF)***
- ***Betweenness Centrality*** (C_B)

The calculation of the metrics only accounts for ***precedes*-dependencies between activities**, hierarchical relationships such as *isVariantOf* and *isPartOf* are **excluded**. This approach has been chosen since the inclusion of hierarchical edges can affect the significance of the metrics (Kreimeyer, 2010, p. 150): For example, an activity with a high amount of associated activity modes would have a high number of incoming edges, although only a single activity mode is eventually selected. A similar situation arises for activities which are decomposed into smaller activities. The exclusion of the hierarchical edges has **two consequences**, depicted in Figure 7-21.

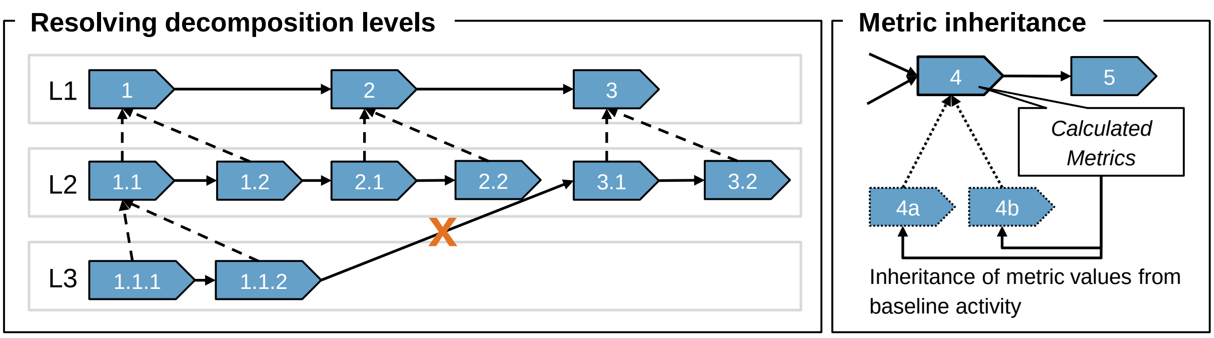


Figure 7-21: Treatment of hierarchical dependencies for the calculation and interpretation of activity metrics

First, the **decomposition** level of activities has to be considered during the metric interpretation, as a comparison of the same metric on different levels is not meaningful. Therefore, the hierarchical decomposition level needs to be included in the activity descriptions, either manually or calculated from the hierarchical decomposition, which is indicated via *isPartOf*-edges (cf. the *Height of hierarchy* metric, Kreimeyer (2010, p. 342)). This is further influenced by how the RPM is originally modeled, e.g. whether precedence-dependencies cross different levels of hierarchy or are limited to the same level of decomposition and whether decomposed activities are connected on all decomposition levels or only the highest one. For the calculation of meaningful activity metrics, precedence dependencies are therefore required to be **limited to a single level of decomposition,** and decomposed activities are **connected on all levels** (cf. Figure 7-21). Second, metrics for activity modes are **inherited** from the metric of the base activity they are replacing.

The ***Criticality*** *(Cr)* is calculated as the product of the sums of incoming (*passive sum*) and outgoing (*active sum*) edges of a particular node (Lindemann et al., 2009, pp. 127–130). Hence, the metric represents the significance of an activity node within its direct neighborhood. The calculation is described in equation 7-1. The metric is visualized within the final reports as individual metrics per node as well as a portfolio. The algorithm and software implementation for the criticality can be found in Appendix A3.5.3.

$$Cr(v) = AS(v) \cdot PS(v) \tag{7-1}$$

With: *v:* *Node of node set V*
AS: *Active Sum (sum of all outgoing edges of node v)*
PS: *Passive Sum (sum of all incoming edges of node v)*

The ***Snowball Factor*** *(SBF)* is used to analyze activities for downstream effects of a tailoring decision. The snowball factor takes all nodes subsequent to a particular starting node into account, regarding the height as well as width of the network. The snowball factor is calculated as the sum of the products of the width of each level with the height of the hierarchy, weighted by the current hierarchical level (cf. equation 7-2). Within the analysis reports, the snowball factor is given as individual numbers per activity as well as an overview in the form of a portfolio, where the bubble size indicates the size of the Snowball factor. The stepwise calculation of the snowball factor and its visualization is depicted in Appendix A3.5.4.

$$SBF(v) = \sum_{i=1}^{h} \frac{w(i) \cdot h}{i} \tag{7-2}$$

With: *v:* *Node of node set V*
w: *Width of the current level*
h: *Height of the hierarchy*
i: *Current hierarchical level*

As the *Snowball factor* only takes subsequent activities into account, the last activity metric, the ***Betweenness Centrality*** *(C_B)*, allows assessing the significance of an activity on a global level. The *Betweenness Centrality* represents the sum of the ratios between the number of shortest paths of a node pair, which contain the investigated node and the overall number of shortest paths between the node pair (Freeman, 1977, p. 37). The calculation of the *Betweenness Centrality* is described in formula 7-3 (Brandes, 2001, p. 3).

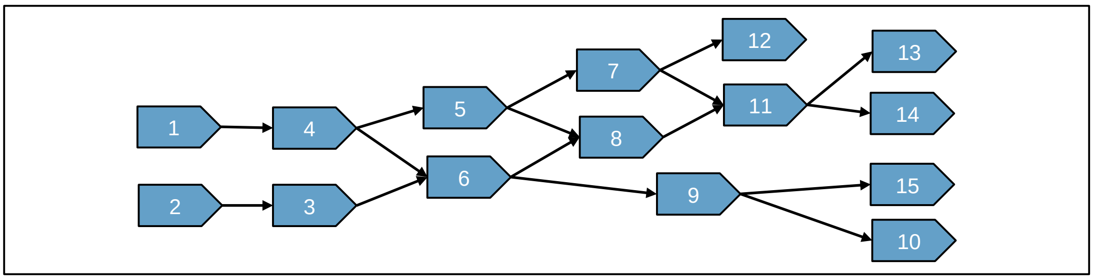
$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}} \qquad (7\text{-}3)$$

With: s, t, v: *Nodes of node set V*
σ_{st}: *Number of shortest paths between s and t*
$\sigma_{st}(v)$: *Number of shortest paths between s and t, containing v*

When calculating C_B for a particular node, the shortest distance between each possible node pair them is calculated. Subsequently, the selected node is analyzed for occurrence in each shortest path. The more central the position of a node within the overall activity network, the higher is its centrality. More detailed information regarding the conceptual algorithm and its implementation can be found in Appendix A3.5.5.

To summarize the activity metrics, an example is given in Figure 7-22, illustrating the calculation of the individual metrics via a simplified activity network. Possible visualizations of the resulting metrics are presented, as they are used within the analysis reports: Portfolios (*Cr*, *SBF*) and a bar chart/histogram (C_B).

Exemplary activity metric calculation and visualization



Node ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Active Sum	1	1	1	2	2	2	2	1	2	0	2	0	0	0	0
Passive Sum	0	0	1	1	1	2	1	2	1	1	2	1	1	1	1
Cr	0	0	1	2	2	4	2	2	2	0	4	0	0	0	0
Height	5	5	4	4	3	3	2	2	1	0	1	0	0	0	0
Width	5	4	4	5	3	4	3	2	2	0	2	0	0	0	0
SBF	20	13	12	19	9	10	4	2	0	0	0	0	0	0	0
C_B	0	0	8	15	18.5	36	12.5	31.5	10	0	20	0	0	0	0

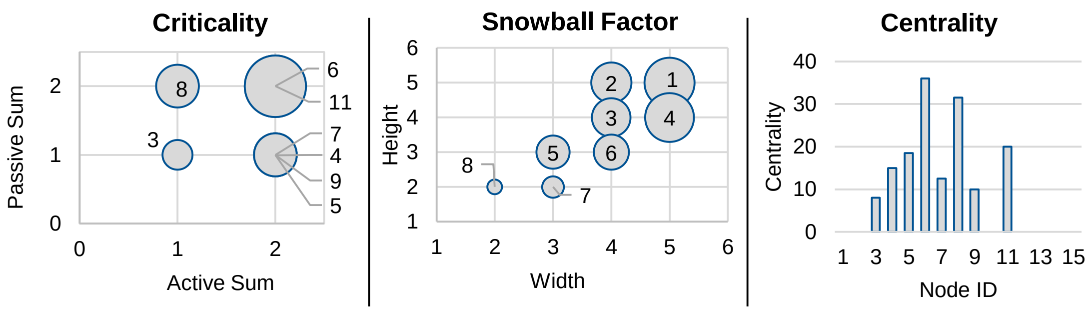
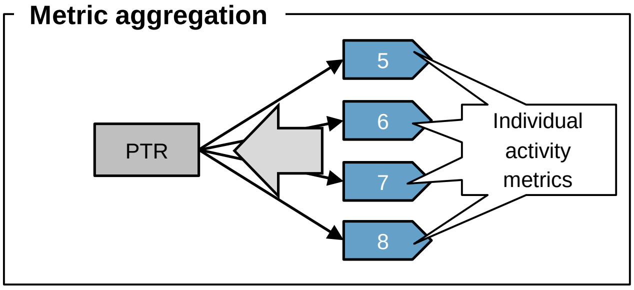


Figure 7-22: Illustrative example of activity metric calculation and visualization (calculated using the Soley demonstrator)

Metric calculation: Average structural metrics per process tailoring nodes

Using the presented activity metrics, a quantified assessment of activity elements in regard to their significance for tailoring decisions is possible. In order to further facilitate the assessment of the impact and associated complexity of a tailoring decision, the metrics of the individual activities related to a particular **PTR** node need to be considered. Besides the calculated individual activity metrics, average (mean) values for each metric can be calculated, in order to aggregate the information for each PTR node (Figure 7-23). The means of the individual metrics are standardized to the number of activity impacts of the particular PTR node.



Node ID	Cr	SBF	C_B
5	2	9	18.5
6	4	10	36
7	2	4	12.5
8	2	2	31.5
PTR	**2,5**	**6.3**	**13.6**

Figure 7-23: Average metrics for a PTR (example)

Metric calculation: Alignment to analyze communication need

The results generated through the metric-based analyses as described above are used to characterize the individual process activities and, consequently, the process tailoring rules. In order to further support workshop-based tailoring, the need for communication between tailoring stakeholders[51] is analyzed via the combined **alignment** metric (*A*), as described by Heimberger (2017) (cf. section 5.4). The metric (7-4) describes the need to coordinate communication between two process stakeholders, by taking their process-induced communication needs and the organizational distance (OD) into account (cf. Figure 7-24). The former is calculated based on their common tailoring decisions, while the latter indicates the resistance to this communication due to their potential unfamiliarity based on the organizational structure (Heimberger, 2017, p. 109; Muyun, 2017, p. 173).

$$A(s,t) = [num\_of\_CN(s,t)] \cdot [OD(s,t)]^2 \qquad (7\text{-}4)$$

With:	*s, t:*	*Organizational nodes of node set V (s ≠ t)*
	num_of_CN:	*(Weighted) number of common PTR between s and t*
	OD(s,t):	*Organizational distance between s and t)*

[51] As laid out in section 7.4.1, this particular analysis depends on the way the organizational domain is modeled. Therefore, in order to enable different levels of detail (or the combination of different levels), the analysis is described using the generic "stakeholder"-term, which extends to all possible organizational nodes to which activities are assigned, i.e. roles, units, or individuals.

Within this work, the **communication need** is determined by the number of indirect dependencies between two organizational nodes (*hasRelationshipWith*) via their common PTRs, which impact both via their respective activities (7-5). Besides the unweighted dependencies, the calculated activity metrics can be utilized to characterize the importance of the communication need further: Under the assumption that PTRs with higher average *Cr*, *SBF* and C_B have a more significant impact on the process and thus need to be evaluated more carefully, the communication need is weighted using the values of these metrics (7-5). Thus, the importance of the need for communication increases with the significance of the tailoring impacts. Since the significance of a metric value cannot be evaluated in an absolute way but depends on the maximum value within the investigated network, the values are standardized according to the maximum of the metric averages for the PTR nodes between two stakeholders.

$$num\_of\_CN(s,t) = (\alpha + \beta + \gamma) \cdot (\|P_{st}\|) \quad (7\text{-}5)$$

With: *s, t:* *Organizational node of node set V (s ≠ t)*

$P_{st} \subseteq G$: *Subgraph of derived indirect dependencies (hasRSw) between s and t via roles and activities*

Weighting: $\alpha = \sum \frac{\emptyset Cr(P_{st})}{max\ (\emptyset Cr(P_{st}))}$; $\beta = \sum \frac{\emptyset SBF(P_{st})}{max(\emptyset SBF(P_{st}))}$; $\gamma = \sum \frac{\emptyset C_B(P_{st})}{max\ (\emptyset C_B(P_{st}))}$

In case no weighting is applied: $\alpha + \beta + \gamma = 1$

The OD is the shortest path between two organizational nodes (units or individuals) via the organizational domain of the metamodel (cf. Figure 7-24) and squared for the calculation of the alignment metric. As the organizational domain can be modeled in various ways (cf. section 6.2, Figure 6-4), only a generic description of the calculation is given, requiring further case-specific adaptation of the analysis algorithms. In the example in Figure 7-24, roles are defined as interfaces between organizational nodes and activities.

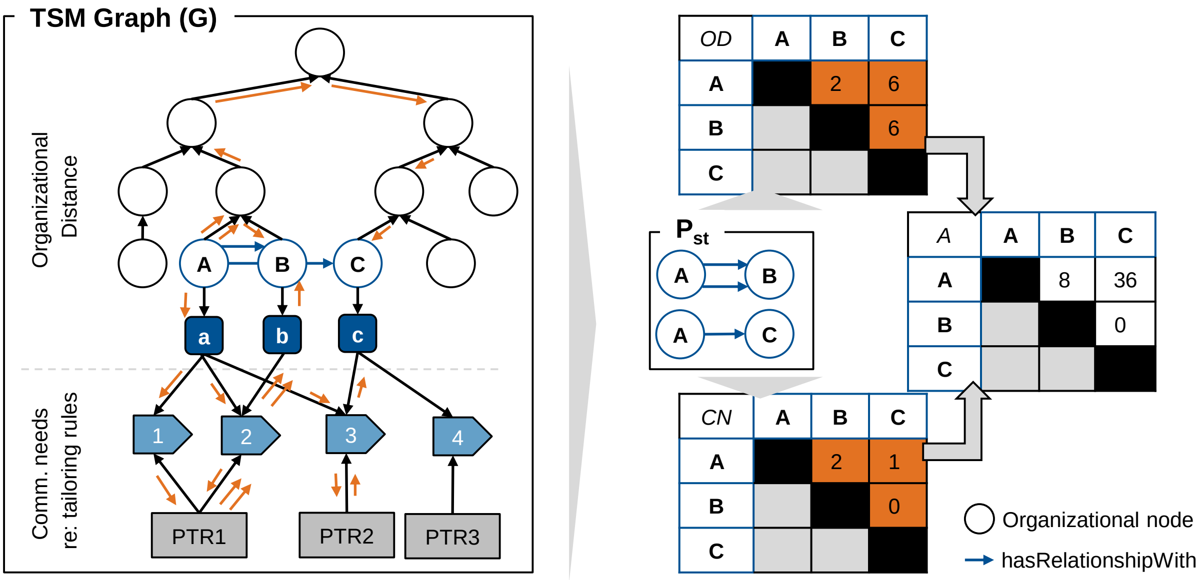


Figure 7-24: Illustration of calculation of communication needs (CN), organizational distance (OD), and Alignment (A)

As the calculated alignment metrics characterize the symmetric pairwise communication dependencies between tailoring stakeholders, they are visualized as the symmetric **alignment matrix** (AM) in DSM notation. The AM can be used to visually identify stakeholder dyads with a high bilateral need for communication, e.g. through added coloring (Heimberger, 2017, p. 114). In order to further structure the need for communication, stakeholders with high communication needs can be grouped by applying common clustering algorithms. This requires a transformation of the alignment matrix into a Distance Matrix. Formula 7-6 describes the calculation of a distance value in regard to the global maximum of all alignment values within the given dataset, which is exemplarily visualized in Figure 7-25. The figure also shows an exemplary AM as derived from the metric calculation (left), the thereupon calculated Distance Matrix for clustering (middle), and the AM after clustering (right).

$$D_{(Cl)}(s,t) = max(A) - A(s,t) \qquad (7\text{-}6)$$

With: *$D_{(Cl)}$* *Distance for clustering algorithm (not to be confused with OD)*
A(s,t): *Alignment metric for stakeholder dyad s,t*
max(A): *Global maximum of alignment within data set*

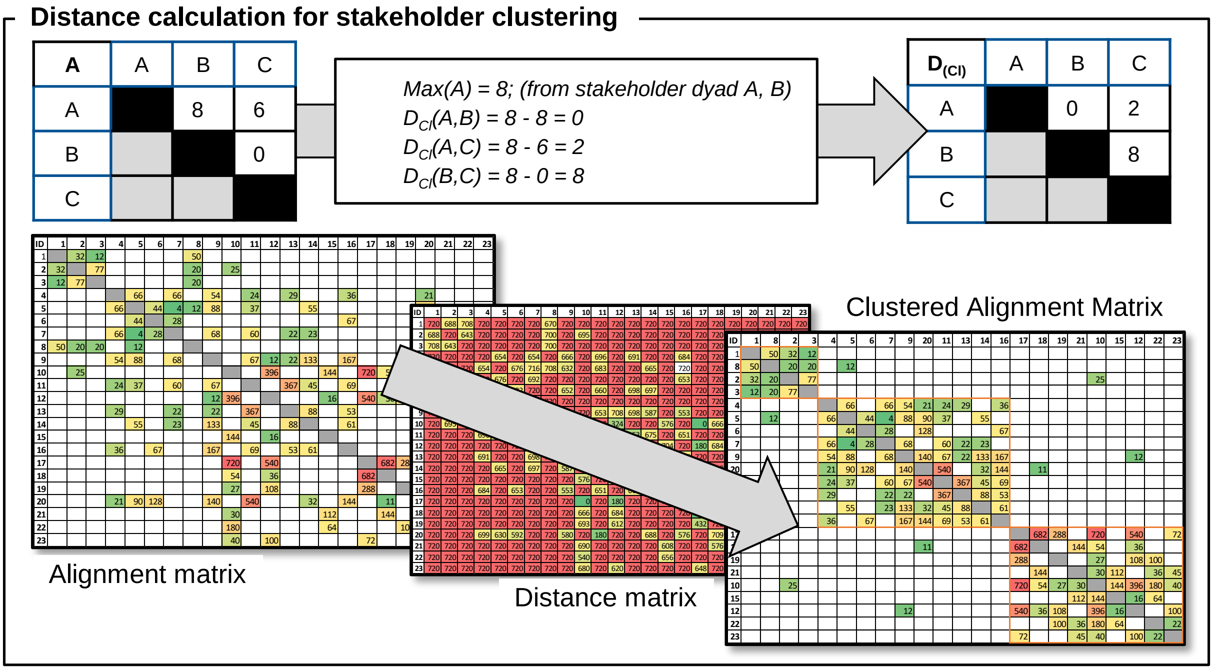


Figure 7-25: Example of distance calculation for stakeholder clustering

The clustering algorithm has been implemented using Matlab (R2017b) (cf. Appendix A3.5.7). The required data set is first exported from the graph-based model. The alignment matrix is then created and converted into the distance matrix. The *complete linkage* approach has been selected as a clustering algorithm, which is subsequently applied in Matlab (Backhaus et al., 2016, pp. 483–484). After clustering, a cluster-ID is assigned to each tailoring stakeholder. The derived cluster-IDs are re-imported into Soley via the auxiliary node type *Help* for the subsequent report generation (section 7.5.6).

7.5.5 Data export

In order to increase the usability of the analysis results, the final results are exported from the graph-based model for stakeholder-specific utilization in the form of reports. The data export is realized using seven export sequences implemented in the Soley-based demonstrator, which write the data in a table format to .csv-files. In order to facilitate the subsequent generation of analysis reports, the export sequences are divided according to node types, separately exporting data required to assess the individual elements within each domain.

Independent of the respective domain, the data export consists of two parts (Figure 7-26): The export of all nodes of a certain type with their respective attributes (*id*, *name*, *description*, and *metrics*) (Figure 7-26, upper left orange section), and the export of all dependencies related to the individual nodes of this type (lower right, green and yellow sections). Hence, dependencies are exported together with the other node attributes; for example, the *Criticalities* of activities impacted by a specific rule in order to limit the number of generated export files. Duplicate information is exported as required for the report generation.

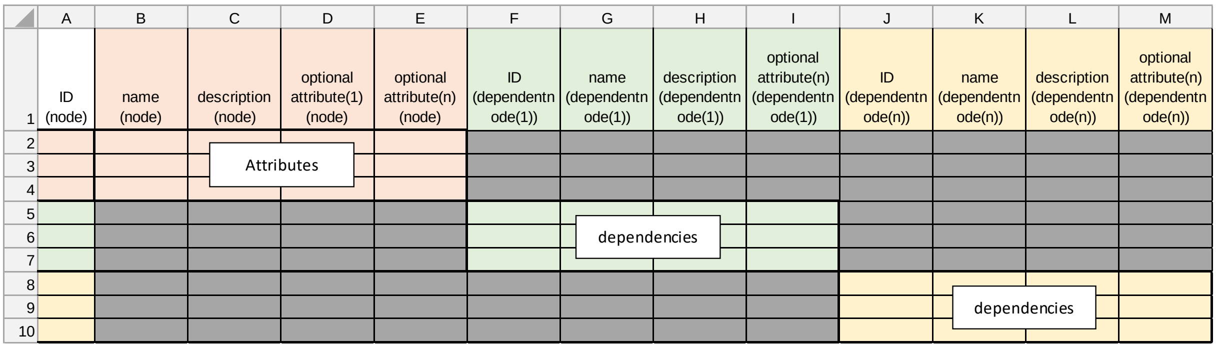


Figure 7-26: Structure of export files

The analysis results are exported in the following order: Context, Rules, Process, Organization[52]. Individual export files are generated for organizational nodes, PTRs, activities, context elements, stakeholder clusters, PTR dependencies, and Alignment. The exported information content is listed in Appendix A3.6.1.

[52] In the software demonstrator, the export has only been realized for the node type *Individual*. Depending on the level of detail of the organizational domain, the export can be adapted for other organizational node types.

7.5.6 Data visualization: Tailoring analysis reports

As stated previously the analysis results are visualized in the form of **reports**. These reports aid the individual tailoring roles in answering the questions associated with the individual analysis goals. The reports provide information relevant for the respective tailoring roles and are thus themselves “tailored” to the level of overview/detail required for the particular role (cf. section 7.6.2 for report usage). For example, **tailoring experts** require a more **global** perspective, with the option to drill down into details. Their primary concern is to manage the information contained within the TSM and the general outline of the tailoring process (e.g. significant communication needs between two different departments) as well as the design of the PDP itself and major tailoring impacts. In contrast, **tailoring stakeholders** require more detailed information regarding their immediate tailoring impacts as well as communication needs, motivating **local** views on the TSM. This motivates the use of different views on the overall TSM in order to **avoid information overload** and achieve a **targeted information provision** fit for the needs of different stakeholder groups (cf. Task-Technology-Fit-Theory, Goodhue & Thompson (1995)). The reports are structured according to the level of detail the specific analyses address: **Network**, **cluster**, and **node level** (Müller-Prothmann, 2007, p. 225; Zhu et al., 2007, p. 296). Templates have been created using Microsoft Word for visualization (cf. Figure 7-27), with the report instances created automatically via Microsoft Excel-based VBA macros, resulting in static .pdf-files for print or digital use. Full-size reproductions of the templates, descriptions of the reports, their structure, and content can be found in Appendix A3.6.2 and A3.6.3.

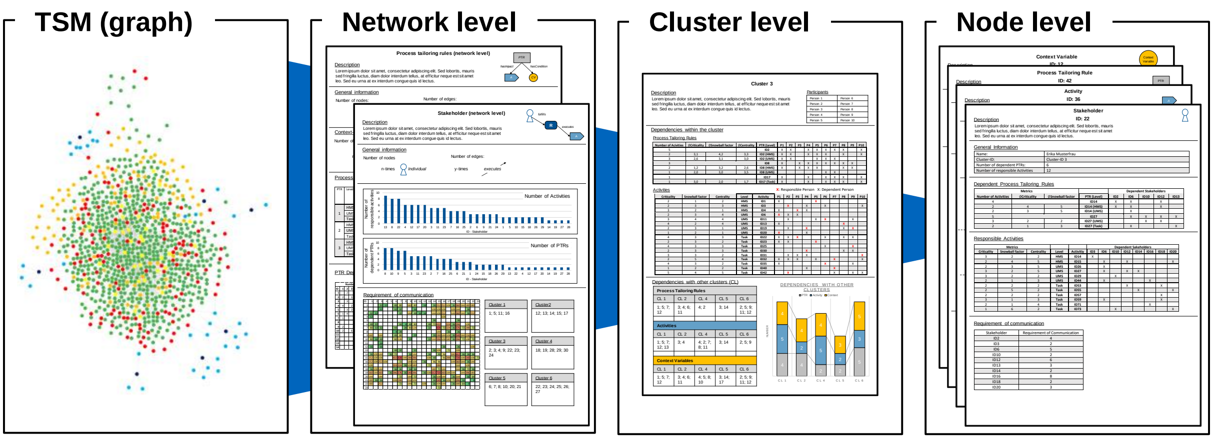


Figure 7-27: Overview of tailoring analysis reports (based on Hollauer et al., 2018b, see Appendix A3.6.3 for detailed report templates)

In total, seven types of reports are generated. The reports are listed and described in Table 7-16. The individual reports address concerns of the respective tailoring roles, with their use described in section 7.6.2. The analysis framework can be adapted and extended by specifying further report types if the need arises, e.g. to create an activity overview on network level in order to facilitate the identification of tailoring-critical activities, e.g. for a PDP redesign. Each report contains the general elements described in Table 7-17.

Table 7-16: Generated analysis report types per level of detail

Level	Report type	Description	Instance
Network	Process tailoring rules	General overview of all PTR nodes within the TSM, their average metrics, and dependencies between PTRs.	Once, per network
	Tailoring stakeholders	General overview of all tailoring stakeholders, their involvement within the PDP, the severity with which they are affected by tailoring, and the Alignment matrix.	Once, per network
Cluster	Workshop group	Aggregate information per workshop group, indicating the relevant rules, stakeholders, and activities (workshop agenda), and dependencies between workshop groups	Per cluster
Node	Context factor	Aggregate information per context factor, e.g. the values and associated PTRs, and dependencies between context variables via common PTRs	For each *ContextVariable* node
	Process tailoring rule	Conditions and impacts per PTR, listing and visualizing all impacts and corresponding activity metrics; dependencies with other PTRs via common context variables, activities, and stakeholders.	For each *PTR* node
	Activity	List metrics per activity, number of variants, position within the process and impacting PTRs	For each *Activity* node
	Tailoring stakeholder	Provide condensed information for each tailoring stakeholder regarding PTRs, responsible activities, and dependent stakeholders (communication needs).	For each *Org.Node* with an activity assignment

Table 7-17: General structure of tailoring analysis reports

Element	Description
Title	The title contains the name of the particular node type (network level), cluster-ID (cluster level), or node id (node-level) for unambiguous identification.
Description	The description contains information regarding the subject of the report. For instance, on node level, the description of the report can correspond to the attribute *description* of the respective node (e.g. activity description).
General Information	The general information can be designed individually per report and offer additional content for the analysis results, e.g. how to interpret structural metrics.
Analytical attributes/ Structural metrics	The visualization of the analytical attributes contains information for answering the analysis questions, i.e. the calculated structural metrics.
Dependencies	The reports conclude with visualizations of identified relevant dependencies, depending on the particular report type, e.g. dependencies between PTR nodes due to common context variables, or communication needs between stakeholders.

7.5.7 Quality gate IV

After phase 4, the TSM has been analyzed using graph-based analyses, through the calculation of structural metrics. Individual reports have been generated which are used in phase 5 to prepare and execute tailoring workshops. The deliverable and reflective questions to assess the progress are presented in Table 7-18.

Table 7-18: Deliverables and reflective questions for conclusion of phase 4

Deliverables	**Analysis results** in TSM graph (calculated dependencies and metrics)
	Exported analysis results (.csv files and integrated Excel-Sheet)
	Automatically created **analysis reports** (.pdf files)
Reflective questions	Has the organizational structure been appropriately modeled?
	Have the analysis rules regarding the organizational structure been checked and adapted a) in order to correspond with the way the organizational hierarchy is modeled and b) in order to address the intended level of detail?
	Have the analysis reports generated based on the most current version of the TSM?
	Have the identified rule conflicts been resolved with affected stakeholders?
	Have the network-level reports been checked for plausibility by tailoring experts?

7.6 Phase 5: Operationalization & review

The previous phases have addressed the acquisition, modeling, and structural analysis of the TSM. Phase 5 addresses the application of the thus collated knowledge (ruleset in TSM) and the derived analysis results (rule impacts and stakeholder communication requirements) **in tailoring workshops for individual project instances**. Furthermore, strategies and feedback channels are identified for continuous future **review and maintenance** of the TSM, as the knowledge therein does not remain static over time, but the RPM and corresponding context change. The steps within this phase are illustrated in Figure 7-28 and subsequently elaborated.

Phase 5 needs to be applied for every project where workshop-based tailoring is required, thereby ensuring that the most current TSM is used (update of tailoring reports). Tailoring decisions are then made collaboratively in the workshops in order to ensure the satisfaction of the identified communication requirements. In order to address the **adaptability** requirement of the tailoring methodology, phase 5 is supported through a combination of the following means:

- The TSM **analysis results and reports** generated in phase 4, which support several activities during the preparation and execution of tailoring workshops. The analysis reports are particularly relevant in organizations with mature PDP RPMs and corresponding structural RPM complexity.
- A **generic workshop concept** (cf. section 7.6.3) for carrying out the individual workshops, supported through a procedure and a checklist of guiding questions and heuristics (cf. Appendix A3.7.2) (cf. PE-Rast (2018); Hollauer et al. (2018d)). This workshop concept can in principle also be applied independently of the previously generated analysis reports, e.g. when tailoring workshops are conducted as a means of information acquisition (cf. phase 2) or when the current RPM complexity does not yet require the use of the analysis framework (cf. section 7.1.2, scenario 3).

	Step	Result
1	General preparation for operationalization	*Implemented tailoring activity*
2	Setup and preparation of project-specific workshops	*Workshop set-up for specific project*
3	Conduct individual tailoring workshops	*Documented tailoring decisions per workshop*
4	Workshop Postprocessing: Collation & Harmonization (Optional)	*Final tailoring deicions*
5	Communication of results	*Tailored RPM*
6	TSM review and update	*Updated TSM*
	Quality Gate V	

Figure 7-28: Steps and results of phase 5

7.6.1 General preparation for operationalization

Before any project-specific tailoring is applied, general preparation is required in order to implement and anchor the tailoring activity within the organization. Based on the analysis results, any **rule conflicts** or **outliers** (e.g. particularly large and complex PTRs) should be addressed and resolved as necessary via iterations of phases 3 and 4.

Subsequently, one or several **tailoring points** within the PDP need to be defined and integrated into the RPM via corresponding activities. Discrete tailoring points are defined in order to keep the effort for tailoring manageable. In general, tailoring should be conducted as late as possible before the affected activities, in order to ensure that the respective context variables can be evaluated and to allow reaction time (Lévárdy & Browning, 2009, p. 615). However, this is not always feasible in reality. One convenient tailoring point is at project kick-off meetings, which often take place in any case. Further tailoring points can then be aligned with select project milestones, depending on when the identified tailoring decisions can be made, and owing to the fact that the composition of the project team can change over the project's lead time. Therefore, tailoring decisions need to be aligned with the milestone/phase when the corresponding information required to evaluate the particular context variables is available. Subsequently, the newly defined tailoring activity needs to be **communicated,** and the role owners, e.g. tailoring organizers and key tailoring stakeholders as identified via the network-level stakeholder report need to be **informed** and **trained** accordingly.

7.6.2 Setup and preparation of project-specific tailoring workshops

Setup of project-specific workshop instances

For each of the aforementioned tailoring points in the PDP where workshop-based tailoring will be applied, workshops first need to be set up by the tailoring organizer, which can take considerable effort. However, sound preparation is vital for an effective workshop (Ruedel, 2008, p. 100). Preparatory **guiding questions** are documented in a **checklist** (cf. Appendix A3.7.2), starting with the **reflection of the current project situation** and the corresponding clarification of the workshop goals (Hamilton, 2016, p. 11), e.g. the selection of the current tailoring point, the relevant process phases, and critical tailoring decisions from the TSM/analysis reports. This aids in clarifying how tailoring can contribute to the project goals. Furthermore, the prospective **participants** (tailoring stakeholders) need to be **selected** based on the composition and hierarchical levels of the project organization. Therefore, tailoring stakeholders with in-depth knowledge regarding individual activities and tailoring effects need to be selected. In case an organizational unit is responsible for an activity, a representative delegate needs to be selected. Besides tailoring stakeholders, further facilitating roles are:

- A **moderator** (mandatory), experienced and impartial, e.g. from the project management office or an independent department, with sufficient process overview
- A **co-moderator** (optional) to facilitate and support the workshop (e.g. documentation)
- The workshop initiator (optional[53]) (e.g. the product management)

Based on the participant selection, a central decision is whether to conduct one **single** or **multiple workshops** (cf. Figure 7-29).

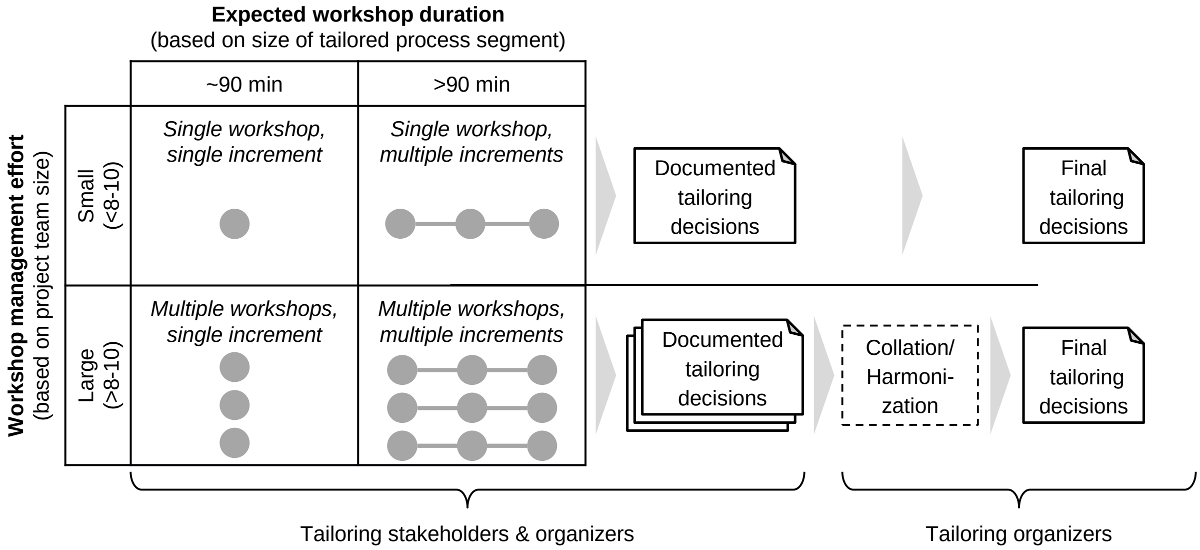


Figure 7-29: Workshop setup: Single vs. multiple workshop instances and increments

[53] In case of multiple workshops, the attendance of the initiator in all workshops can prove time-consuming; the attendance of a project leader or manager can be detrimental to the flow of discussions within the workshops

For **small projects** with teams of manageable sizes, conducting a single workshop can be sufficient (~8-10 people). In the case of **larger, more complex projects** with a higher number of team members, which cannot effectively communicate and collaborate within a single workshop, **multiple** workshop groups need to be set up. In order to partition project stakeholders into different workshop groups, different strategies are possible:

- Cross-functional workshops based on the calculated *Alignment* metrics
- Department-specific (functional) workshops, discussing department-specific tailoring decisions with a concluding workshop to validate cross-functional decisions
- Sequential workshops based on the tailoring rule prioritization

Generally, the last strategy will be easier to implement but can prove inefficient in case individual stakeholders are affected by many and dispersed tailoring decisions, as they need to remain engaged and participate in the workshops for a longer time. Therefore, the calculated **Alignment** is used to group workshop participants according to common tailoring decisions. That way, the likelihood is increased for workshop participants to have only to participate in relevant discussions. In case of multiple workshops, if there is overlap between groups in terms of relevant PTRs, the documented outcomes of the individual workshops need to be collated and harmonized by the tailoring organizer(s) (cf. dependencies between clusters in cluster reports).

In case the RPM segment to be tailored is very large, these workshops can be further **split into 60- to 90-minute increments** using the following strategies:

- Structuring according to the sequence of process elements
- Structuring PTRs into increments according to their prioritization
- Structuring PTRs according to impacts on common process elements (and thus, stakeholders), followed by ranking them according to prioritization (activity metrics). Thereby, smaller workshops are still structured according to thematic groups.

After the workshop structure for a project instance has been decided and documented in a **workshop plan**, the individual workshop instances can be scheduled either **sequentially** or in **parallel**. A sequential execution allows to build-up knowledge over the workshop instances, as participants can attend multiple workshops and documents can be reused, reducing the final postprocessing effort. Conversely, parallel execution saves time, but requires more intensive postprocessing and potentially causes duplications within discussions and decision making.

Preparation of workshop instances

To ensure a comparable level of knowledge of all workshop participants and increase the efficiency of discussions within the workshops, the tailoring stakeholders first need to **prepare individually.** Participants need to be informed in advance about the project situation and objective for which the RPM will be tailored. Using primarily the **node-level stakeholder report**, the tailoring stakeholders can familiarize themselves with:

- Their responsible activities as defined in the RPM and their significance (activity metrics)
- The PTRs impacting them and their significance
- Necessary communication partners per PTR (Alignment)

Department-specific pre-workshops can be used as an additional stage (e.g. for particularly large RPMs or critical projects) in order to prepare for interdepartmental decision-making workshops, discussing and making department-specific tailoring decisions (i.e. rules that are not affecting or affected by other departments) and impacts from department-spanning rules. The communication needs (alignment) can be used to identify decision partners in order to enable the preparation of tailoring decisions in pre-workshops or bilateral discussions.

Further aspects of workshop preparation cover **organizational aspects**, such as available **time** and **budget**, or a suitable **venue** for the workshop. For each workshop, the agenda needs to be adapted to the goals defined (see above) and the corresponding tailoring rules to be discussed (using e.g. the cluster reports, cf. Table 7-19). Furthermore, the use of **methods and materials** required for the individual workshop groups need to be planned and prepared, e.g.:

- Large-scale (printed) overviews of the process/sub-process to be tailored (cf. phase 3)
- Tailoring rules per workshop group (cf. phase 3)
- Tailoring analysis reports for the respective project and cluster (cf. phase 4)
- Input-output dependencies (in process overview, as dependency graph or matrix)

Use of analysis reports for workshop preparation

As mentioned before, the analysis reports and their content support certain activities during the preparation of tailoring workshops. The supported activities, along with the respective reports used, are listed and summarized in Table 7-19.

Table 7-19: Project-specific preparatory tasks for individual workshops supported by tailoring analysis reports

Task	Reports	Description	Result	Role
Identification of key stakeholders	Stakeholder (Network)	Identification of stakeholders which are particularly affected by PTRs	List of key stakeholders who receive training and can act as multipliers/which have a high priority for participation in tailoring workshops	Tailoring Expert/ Organizer
Training/ Preparation of individual participants	Stakeholder/ PTR/ Activity/ Context Variable (Node)	Individual preparation of tailoring decisions according to the responsibilities of the individual stakeholders	All participants have the same level of knowledge and are familiar with their respective tailoring decisions, impacts, and communication needs	Tailoring Stakeholder
Workshop group definition	PTR/ Stakeholder (Network Level)	Grouping of project stakeholders into workshop groups	Workshop groups with high internal communication need and low degree of dependencies to other workshop groups	Tailoring Expert/ Organizer
Workshop agenda definition	Cluster	Structuring and prioritizing tailoring decisions to be made during a workshop	Agenda structuring the execution of individual workshops	Tailoring Organizer

7.6.3 Conducting individual tailoring workshops

After the workshops for a project instance have been planned and prepared, the individual workshop increments need to be carried out.

Generic workshop procedure

The workshop procedure is split into three phases: Introduction (~25% of total time), Working Phase (~65%), and Conclusion (~10%) (Lienhart, 2015, p. 79), as shown in Figure 7-30. Guiding questions supporting the execution of individual workshops are also documented in Appendix A3.7.2.

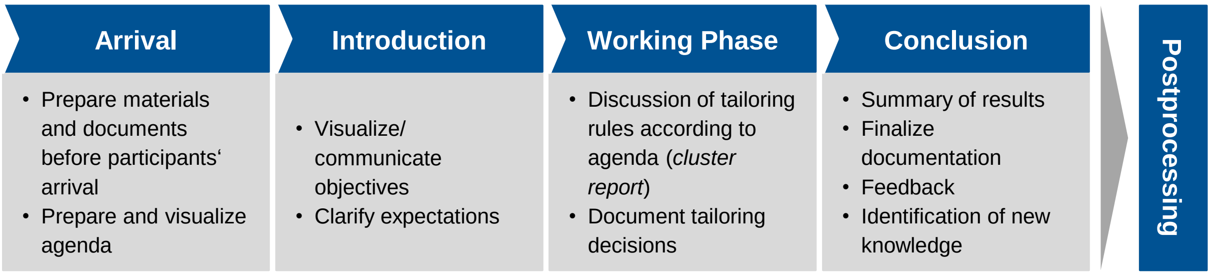


Figure 7-30: Overview of the generic workshop procedure

During the **Preparation-phase**, the workshop venue and materials are prepared, and the workshop **agenda is visualized** (flipchart, hand-outs, or similar) (Beermann et al., 2015, p. 63; Oberholzer et al., 2015, p. 12). A large printout of the RPM scope to be tailored should be well visible to the workshop participants. After welcoming the participants, the **objective**, **context,** and **agenda** of the workshop are explained in the **Introduction**-phase. The current situation of the project is briefly reflected together with the participants, clarifying the current tailoring point and the scope of the process to be tailored within the workshop.

The **Working-phase** takes up the majority of the workshop, where collaborative tailoring is performed. The agenda of the Working-phase is structured by the documented PTRs, prioritized by the activity metrics, which are sequentially discussed (cf. Cluster-report or network-level PTR report). The cluster report, which lists the relevant stakeholders per PTR to be consulted for a specific tailoring decision, can be used as a checklist to ensure all relevant stakeholders have contributed to a particular decision. For each PTR, a collaborative decision needs to be made, whether:

- The PTR is **applied as documented** in the TSM.
- The PTR is **rejected**, and the RPM is not tailored.
- The RPM is **tailored differently** than documented in the TSM due to specific needs within the project at hand

In case **a decision is postponed**, e.g. because key stakeholders are missing, or not enough information is currently available, this is documented along with the defined next actions. These decisions need to be clarified in follow-up meetings/workshops or bilateral discussions. Each of the tailoring decisions is visibly **documented** on the **pinboard** or in list form in order to track the overall workshop progress. This decision list is the primary deliverable for each workshop, used to a) secure commitment from all participants for the decisions made and b) in subsequent postprocessing steps.

While the agenda of each tailoring report is defined by the tailoring organizer based on the PTRs described in the analysis reports, **open discussions** should be permitted and encouraged to a certain degree. The PTRs document recurring patterns, but due to the unique and complex nature of PD projects, tailoring needs to be investigated on a case-basis. Open discussions can lead to the generation of new tailoring-relevant knowledge, by identifying additional context factors, tailoring operations, as well as potential activities to be added for individual projects, as the PTRs only cover reductive tailoring. Therefore, the guiding questions within the workshop checklist also cover the aspect of open discussions, e.g. through the initial reflection of the project situation and guiding questions related to the documentation of individual tailoring decisions. For each decision, the following **information** should be documented:

- **Referenced PTR** (in case a PTR is the basis for the tailoring decision)
- **Decision result** (tailored/rejected/postponed; Tailoring operator per process element: removed, selected, added, etc.)
- **Rationale** for the tailoring decision (Context factor or description of rationale in case of a new decision)
- **ID/Name** of affected process element(s)
- If discovered: Additional, so far **undocumented impacts**
- Responsible **stakeholders**
- **Next actions** and responsible stakeholder (e.g. further tailoring stakeholders need to be informed/consulted, decisions need to be harmonized with another cluster, or additional information needs to be added to the TSM)
- Free-form **comment**

During the **Conclusion-phase,** the achieved results are summarized, and the documentation finalized. In order to generate commitment, the attendance of tailoring stakeholders should be noted. Finally, feedback is gathered from the participants, especially in light of new knowledge generation and for improvement of the workshops. In order to gather feedback, parts of the evaluation questionnaire used within this work can be used (Appendix A4.2).

Analysis reports for workshop execution

Similar to the workshop preparation, the execution of the individual workshops via the previously presented phases and activities is supported through the tailoring analysis reports, as summarized in Table 7-20.

Table 7-20: Tasks during workshop execution supported by tailoring analysis reports

Task	Reports	Description	Result	Role
Structure/ Adapt workshop agenda	Cluster, PTR (network level)	Adapt pre-defined workshop agenda based on the current situation	Agenda structuring the execution of individual workshops	Tailoring Organizer
Discuss individual PTRs	PTR/ Stakeholder/ Activity/ Context (node level)	Conduct group discussion per PTR and create decision outcome	Decision recommendation per PTR	Tailoring stakeholder
Document stakeholder contributions/ decisions	PTR (network)/ Cluster	Document whether all relevant stakeholders have given their input for a particular tailoring decision	Documented input/contribution	Tailoring Organizer
Support workshop execution	PTR/ Activity/ Context (node level)	Support workshop participants in particular questions regarding individual TSM elements	(individual)	Tailoring Expert/Organizer

7.6.4 Workshop postprocessing

Post-processing of individual workshops

During post-processing, the moderator sends a workshop report (documentation template) to all participants and the tailoring organizer(s) (as the workshop initiators) for review. The report contains the following aspects (Beermann et al., 2015, p. 124):

- Topic and goal of the workshop
- Tasks of participants
- Results and decisions
- Important points of discussion
- A plan to address defined measures and open items

Post-processing is of high importance for process tailoring, as the decisions made within the tailoring workshops need to be put into action in order to create the project-specific process (i.e. project plan). Clear and comprehensive documentation is necessary to establish traceability, a central requirement from practice (PE-Rast, 2018). Only when the rationale for a tailoring decision is documented, further PTRs can be derived and transferred to future projects. The documentation can lead to the identification of new context factors, as well as validate or revoke existing ones. Therefore, the tailoring knowledge should continuously grow with each workshop instance.

Collation and harmonization of multiple workshop instances

In case multiple workshop groups are carried out, the tailoring decisions made in individual workshop groups have to be collated and harmonized by the tailoring organizer(s). This involves the comparison of different outcomes of a decision in different groups. The **cluster-level** reports can be used to identify PTRs, which are common to different clusters and therefore require particular attention. After the collation, final decisions are made. This can require further, more focused workshops or bilateral discussions with tailoring stakeholders, in case there is need for further clarification. The final decisions are documented and then **communicated** to the relevant tailoring stakeholders as well as project management as input for further project planning activities in order to create the project plan, which is subsequently used as a basis for scheduling, budgeting, and further optimization.

7.6.5 TailoringSystemModel review and feedback channels

As the RPM subject to tailoring and process context do not remain static over time, the knowledge documented within the TSM needs to be **reviewed and updated periodically** for tailoring to be viable in the long term. As new knowledge is expected to be generated, e.g. during tailoring workshops (socialization) and needs to be documented (externalization, combination) and distributed (internalization). The presented methodology can serve as a way to start this particular **organizational learning cycle**, as shown in Figure 2-2 (p. 21).

Within this section, possible **feedback channels** for the integration of new knowledge are illustrated. However, these aspects need to be **addressed and detailed in further work** by applying the tailoring methodology within an organization in multiple iterations. The individual channels partly overlap with and reuse **methods for information acquisition** presented in section 7.3, as also, in this case, e.g. interviews will be necessary to validate new knowledge. **Two categories** of reviews are carried out by **tailoring experts**:

- **Reactive reviews**, which are caused by an external factor, such as the identification of new knowledge, e.g. from a particular workshop instance, which needs addressing and is subsequently integrated into the TSM and RPM, triggering an iteration of phases 2 to 4. A reactive review can also become necessary in case the RPM is changed, e.g. due to the integration of new subprocesses or process improvement initiatives.
- **Proactive reviews** are triggered by tailoring experts, e.g. on a schedule, and can take two forms: Examining the TSM regarding expected future changes, e.g. by identifying new context factors due to new project characteristics (prospective). The second type is the regular analysis of the generated tailoring documentation (decisions and final project plans) to identify patterns over multiple project instances (retrospective). Proactive reviews can be aligned with reviews of the RPM, which may already be carried out.

The analysis results generated in phase 4 provide inputs for reviews, in particular, to estimate the effort related to TSM changes. For example, as the node-level context variable reports contain information which PTRs the context variables values are part of, the reports indicate the complexity associated with adapting individual context factors. The network-level PTR report can be used to identify complex rules, with large numbers of affected activities and stakeholders, which also require more change effort.

The feedback channels identified throughout this work are outlined in Table 7-21. The entries indicate the name and type of the feedback channel, and whether none, a single, or multiple tailoring applications are required beforehand. Feedback gathered from the feedback channels can be used to add new TSM/RPM elements, restructure existing RPM elements (moving/parallelization), remove obsolete elements, and adapt existing TSM elements.

Table 7-21: Tailoring knowledge feedback channels

Name	C	I	Description
RPM change	R	-	• Change of TSM in reaction to changes in RPM • Adaptation of PTRs, integration of new PTRs
Direct Workshop Feedback	R	S	• Through the recombination of the involved stakeholders' implicit knowledge, individual tailoring workshops act as nuclei for the generation of new tailoring knowledge. • Activities added for individual project instances should be reported to tailoring experts to evaluate permanent additions to the RPM • Newly identified tailoring decisions and context factors should be reported to tailoring experts to evaluate TSM additions
Comparison of tailored with actual process	R	S	• At tailoring points and project conclusion • The actual project plan is compared retrospectively with the tailored project plan and the documented tailoring decisions (e.g. within the scope of a lessons learned workshop) • Deviations from the tailored project plan are identified and analyzed whether they represent additional tailoring rules
TSM analysis	R	S	• Identification and resolution of outliers/rule conflicts identified through TSM analysis
Analysis of tailoring workshop documentation	P	M	• Tailoring decisions collected from multiple project instances are compared • Analysis of the frequency of decision outcomes per PTR (apply/reject) in order to rate the validity of rules/identify rules with high variation in application and rejection • Identify recurring tailoring decisions not yet formalized • Identify recurring added activities
Analysis of project plans	P	M	• The final project plans and documented contexts from multiple project instances are compared (cf. phase 2, analysis of project plans) • Identification of communal and variant process elements • Comparison with communal and variant context values
Periodic strategic review of the TSM	P	-	• Expert-based TSM review TSM in analogy to RPM reviews • Identify and validate new potential context factors e.g. due to expected changes in the project portfolio • Identify and define new activity modes
Key: *C = Category; P = Proactive, R = Reactive; I = Instance, M = Multiple, S = Single*			

7.6.6 Quality Gate V

At the conclusion of phase 5, workshop-based tailoring is integrated as a new activity within the organizations' project management and PDP RPM and has been initially applied and tested. It can henceforth be applied for subsequent project instances. Furthermore, feedback channels and a review schedule for the TSM have been developed and implemented. The deliverables and reflective questions to assess the progress are presented in Table 7-22. However, it has to be noted that aspects of phase 5 are tied to every project instance where workshop-based tailoring is to be applied, as workshops need to be prepared and set up on a per-case basis. These aspects represent an ongoing effort within the organization.

Table 7-22: Deliverables and reflective questions after phase 5

Deliverables	Defined and integrated **tailoring activity** (project management and PDP RPM)
	Implemented **review channels and schedule**
	Workshop plan and schedule for project instance (per instance)
	Tailoring decision documentation for project instance (per instance)
Reflective questions	Have the owners of the respective tailoring roles been informed and trained?
	Have the key tailoring stakeholders been informed and trained, e.g. in the usage of the tailoring reports?
	Has the tailoring activity been integrated into project management as well as the PDP RPM?
	Have review channels been defined and implemented within the organization?
	Have regular reviews been scheduled?
	Has a roadmap of further steps (e.g. integration with technical process/project management system, development of a process configurator, etc.) been defined?

7.7 Directions for further extension of the tailoring methodology

Within this section, two directions for further extension of the tailoring methodology are presented. While several limitations and potential for further research remain and are discussed separately (cf. sections 8.5.1 and 9.3), the two herein presented approaches focus on further usage of the TSM in order to increase RPM tailorability: The **modularization** of the PDP RPM via a matrix-based clustering approach and the derivation of frequently used **process variants** as starting points for tailoring workshops. While the approaches are tentatively elaborated and partially evaluated, they require further work for testing and improvement and are outside the main scope of this thesis. Therefore, they are not subject to evaluation in chapter 8.

Process modularization

In order to further increase the tailorability of the RPM, an approach for a context-oriented process modularization has been developed, by adapting similar product modularization approaches, such as modular function deployment (cf. PE-Thomas (2018) and Hollauer et al. (2018e) for more details). The approach aims at deriving context-induced process modules, defining modules of activities similarly influenced by the process application context, which are consequently tailored in a similar manner.

The approach (Figure 7-31) uses a MIM (Module Indication Matrix) extracted from the TSM to directly map context factors to influenced activities (DMM structure). The MIM is used to calculate an activity similarity matrix (Proximity DSM) is calculated, describing the similarity of process elements. This DSM is subsequently clustered. The cluster structure is subsequently transferred to a DSM containing activity interfaces (*precedes* dependencies). Clustering quality metrics are finally applied to the clustered process interface DSM to calculate the modularization quality and decide between different modularization variants.

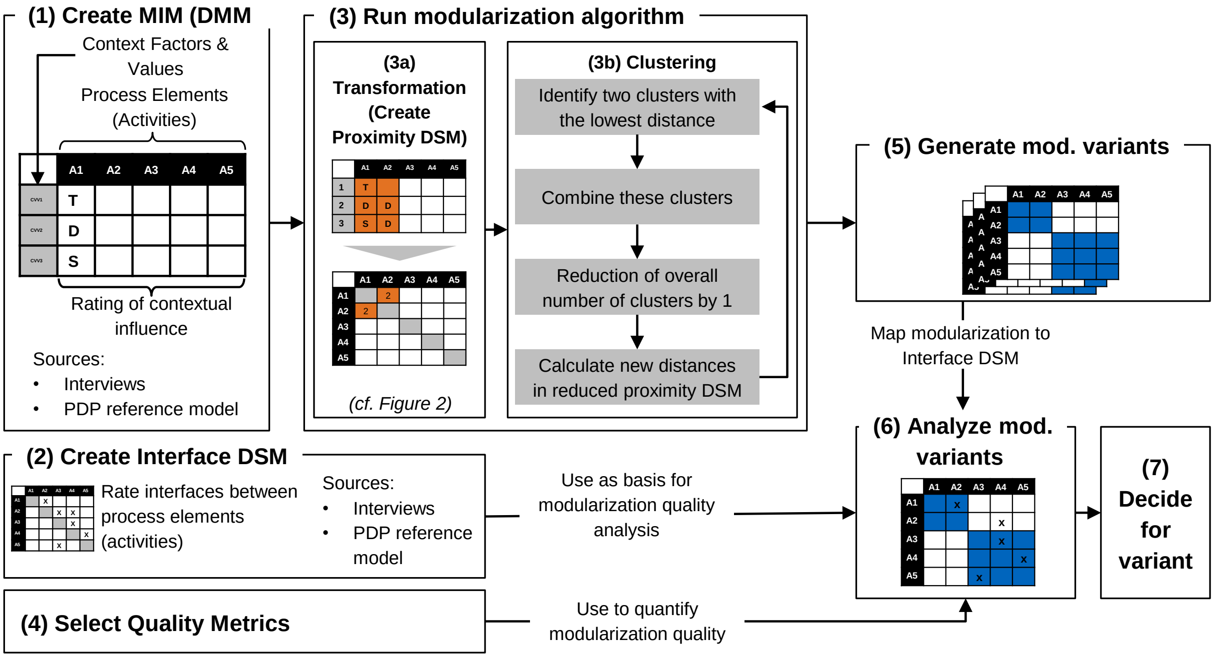


Figure 7-31: Context-oriented process modularization method (Hollauer et al., 2018e)

The approach has been applied on two datasets, one academic, and one acquired from case study F.1, and subsequently discussed with the user of the tailoring methodology in this case study. The user confirmed the usefulness of the approach and pointed out the importance of selecting the right quality metrics within a specific context. Different clustering algorithms can be used, with single linkage, complete linkage, and a combination of both being tested within this work (Backhaus et al., 2016), but further research is necessary to identify the best clustering strategy.

Analysis of TSM for context configurations and process variants

In order to increase the efficiency of tailoring workshops, the data contained within the TSM can be used to derive frequently occurring context configurations, and thus pre-tailored process variants as starting points for tailoring workshops (cf. "templates," González et al. (2014)) (PE-Sapundziev, 2018). The approach requires adaptations of the base metamodel not included in its current description, by adding nodes for individual context configurations and attributing context values with the frequency with which they occur in different projects (as an absolute number or a relative percentage).

Using graph rewriting, a “variability tree” is generated from the TSM in order to derive the most common context configuration and thus process variants (Figure 7-32). In order to facilitate the handling of large sets of context data, the context data set is first reduced to the context factors with the highest number of tailoring impacts, omitting context factors below a defined threshold. The variability tree is generated, sorting context values according to their frequency of occurrence. Illegal configurations violating GCRs are subsequently removed from the tree. The context configurations are then derived by walking through the tree branches according to the frequency of occurrence of the individual context values, documenting context configurations within the respective nodes. Using PTRs, pre-tailored process variants can then be derived from the context configurations.

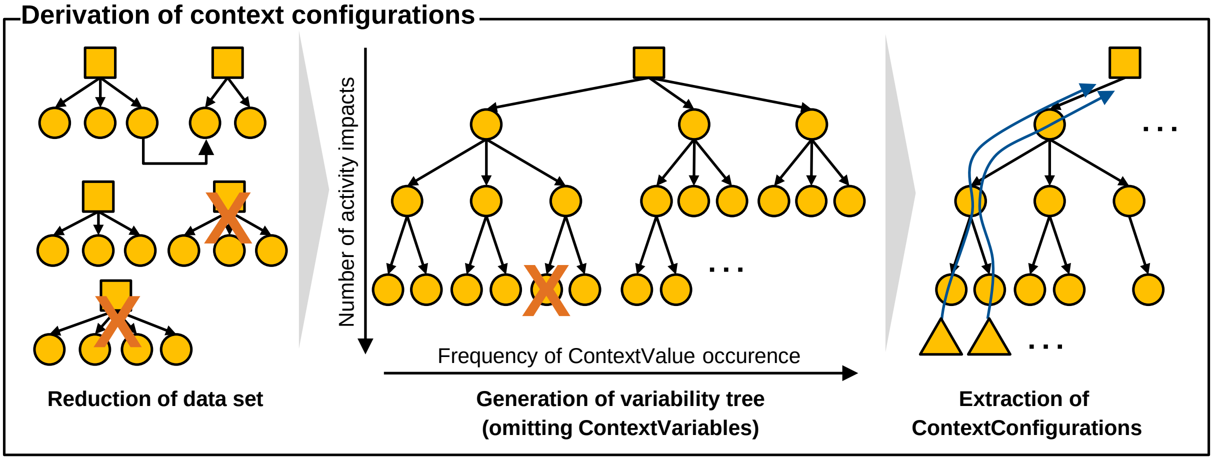


Figure 7-32: Derivation of context configurations from TSM via variability tree (based on PE-Sapundziev ,2018)

The approach has been exemplarily applied to the data set from case study D.1 to create a reduced variability tree with 64 context configurations. Further advancement of the configuration analysis should focus on the development of more efficient algorithms for identifying context configurations from the full variability space, under consideration of GCRs and PCRs.

7.8 Summary of workshop-based tailoring methodology

The presented tailoring methodology aims at **supporting the implementation of workshop-based tailoring**, which in turn enables **collaborative tailoring decision-making for structurally complex PDP RPMs**. Decision making itself is supported by documenting process tailoring rules and subsequently calculating, condensing, and visualizing the associated structural complexity and emerging tailoring-related communication needs via metric-based structural analyses and the generation of tailoring reports. Thereby, a basis for decision-making and to support efficient and effective communication between stakeholders during tailoring is provided. The methodology is deliberately open for further extension and adaptation, with avenues for advancement outlined in sections 7.7 and 9.3.

The overall **procedure** provides a phase structure of activities to be carried out. While the **base** methodology is designed to support the initial implementation of workshop-based tailoring in mature organizations with complex PDPs, it can be adapted for specific organizational contexts and is intended to start an organizational learning cycle. Three **classes** for an adapted base methodology are provided. Further steps, e.g. integration into the existing system landscape for process- and project management, or governance aspects are not addressed, due to the existence of related approaches and the strong dependence on organizational boundary conditions.

The **role model** structures the responsibilities for methodology application, as well as for carrying out the tailoring activity for specific project instances. The role model aims at facilitating the integration of the tailoring methodology into pre-existing company-specific role models.

Within the methodology, a set of empirically derived **information acquisition methods** provides starting points to facilitate information acquisition. The individual methods can be selected and adapted depending on the need and data availability.

The **metamodel** describes how to store tailoring knowledge in an object-oriented, graph-based manner, resulting in the TSM, which is persistent over individual project instances. The metamodel has been derived from related approaches in literature and adapted to enable the metric-based structural analysis. The corresponding **analysis framework** provides a sub-methodology and a selection of structural metrics that enable the automated graph-based analysis and visualization of tailoring rule complexity and communication needs for tailoring workshops. This is intended to contribute to increasing process transparency and decision-making ability within tailoring workshops.

The generated reports are utilized in collaborative tailoring workshops, for which a **workshop concept** has been developed. This workshop concept provides a procedure for executing tailoring workshops, describing essential aspects of workshop preparation and postprocessing in the form of a checklist.

The application and initial evaluation of the tailoring methodology in terms of applicability and success is the subject of the subsequent chapter 8.

8 Application and evaluation of the tailoring methodology

Chapter 8 presents the evaluation of the developed tailoring methodology using a mixed-method approach. Data for the evaluation has been gained from the observation of the application as well as from accompanying interviews in ten industrial application case studies, as well as a concluding interview study. Two of the conducted case studies are presented in detail in sections 8.2 and 8.3 to illustrate the application. Both focus on the evaluation of the tailoring workshop concept. The analysis framework has been evaluated separately by investigating its applicability using a software demonstrator. This demonstrator has been subsequently presented and discussed in a series of expert interviews for an initial success evaluation (section 8.4).

Overall, the evaluation has a predominantly formative and initial summative character, focusing on the applicability and initial success evaluation of workshop-based process tailoring supported by metric-based structural analysis. The developed tailoring approach is reflected against the postulated requirements and discussed in section 8.5.1. The chapter concludes with a discussion of the research methodology in section 8.5.2.

8.1 Overview of evaluation concept

The DRM project type selected for this research (type 5, cf. section 1.3.1) stipulates to perform an **initial DS II**. Blessing & Chakrabarti (2009, p. 184) define support, application, and success evaluation as the three forms of evaluation for any development of design support. The **support evaluation** aims to ensure testability of the developed support and has accompanied the PS, by formulating requirements and regularly discussing and reflecting the tailoring methodology. The **application evaluation** focuses on the applicability of the tailoring methodology and whether it addresses the objectives and requirements postulated in sections 3.2 and 3.3. The **initial success evaluation** assesses the general usefulness of the tailoring methodology. (Blessing & Chakrabarti, 2009, pp. 181–186).

Outline and rationale of the evaluation approach

A **mixed-method approach** has been chosen for the evaluation, combining different methods and data sources as illustrated in Figure 8-1 (Collis & Hussey, 2014, p. 71): The procedure, acquisition methods, metamodel, and tailoring workshop concept have been applied in industrial **case studies**, which combine aspects of application and success evaluation (cf. Yin, 2014). The **analysis framework is evaluated separately** due to two considerations: First, since resource constraints prevented its application in one of the case studies, and second, to put a specific focus on its evaluation due to its high importance as well as novelty within the overall tailoring methodology. The applicability is tested based on an implemented software demonstrator together with data from case study D.1 (test case) and its usefulness in an interview study involving experts from different companies.

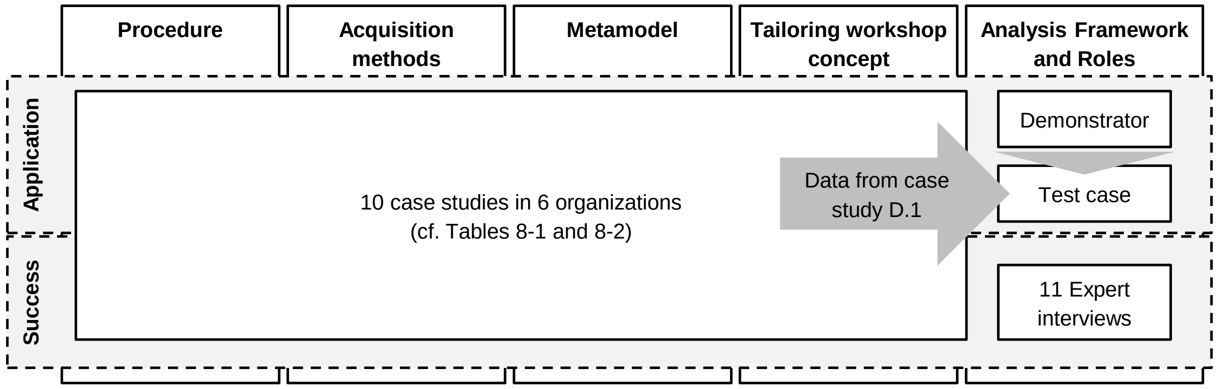


Figure 8-1: Outline of the evaluation concept

Due to factors such as long duration of PD projects, long lead times required for application and continued implementation of the methodology, as well as learning effects associated with the application, no assessment of long-term effects of the developed tailoring methodology was possible, e.g. improved project performance (cf. Blessing & Chakrabarti, 2009, p. 183). Therefore, the focus lies on assessing **short-term effects and benefits** realized by the tailoring methodology, as illustrated by the following questions:

- Can the required information be acquired and modeled with the developed support?
- Does the tailoring workshop concept find acceptance and is seen as useful?
- Does the analysis framework generate the intended and beneficial results?

The evaluation was carried out **iteratively** with the development of the tailoring methodology. Feedback and lessons learned gained from formative application case studies have iteratively informed its refinement (Blessing & Chakrabarti, 2009, p. 191). Chapters 6 and 7 present the **final state** of the developed tailoring methodology, where lessons learned from the evaluation studies are already incorporated.

Characteristics of the application case studies

A multiple case design was chosen due to the following reasons: First, due to limitations such as **organizational and resource constraints** such as access to rich data, confidentiality concerns, and the high effort for information acquisition, the tailoring methodology could not be evaluated end-to-end within the scope of a single case study. Instead, individual elements of the tailoring methodology were evaluated in different case studies. Second, the multiple case design allowed to test the tailoring methodology **under different conditions**. This design allows to draw conclusions regarding the reproducibility of results from the application of the tailoring methodology (cf. Yin, 2014, p. 57), increasing the reliability as well as the validity of the evaluation.

Table 8-1 presents an overview of the application case studies conducted within the DS II, during which an aspect of the developed tailoring methodology has been applied (cf. Appendix A4.1 for more details on the individual case studies). For each case study, details regarding the company and particular units of analysis (UoA) are given, as multiple case studies have been conducted in some companies. Companies are classified regarding size, industry, and market. Per unit of analysis, the respective process level (PDP or subprocess), a priori availability of a reference process model, and the existence of previous tailoring experience are indicated. The case studies are numbered using the following format:

- Case studies are clustered according to the **organization** where they have been conducted, as indicated by a **capital letter**[54] (A, B, C, etc.).
- Different units of analysis (UoA) within an organization (e.g. different processes) are indicated by an appended number (A.1, A.2, C.1, etc.).
- Case study C.1 represents a **multiple embedded case study**, with the tailoring methodology applied by different users (Yin, 2014, p. 51).

Table 8-1: Characteristics of evaluation case studies[55] (cf. Appendix A4.1 for associated publications)

Case	Size	Industry	Market	UoA	Process Level	RPM	Tailoring Experience
A	L	Automotive	B2C (OEM)	1	PDP*	Yes	No
				2	SP (Configuration release)	Yes	No
				3	SP (Lessons learned)	No	No
				4	SP (Sensor integration)	No	No
B	L	Automotive	B2C (OEM)	1	SP (Styling design)	Yes	No
C	L	Commercial Vehicle	B2B/B2C (OEM)	1	SP (P&L)	Yes	Limited
				2	PDP	Yes	Limited
D	M	Plant engineering	B2B (Supplier)	1	PDP	Yes	No
E	S	Medical lab devices	B2B (OEM)	1	PDP	No	No
F	M	Production plant	B2B (OEM)	1	PDP	No	No

Key: *S = Small; M = Medium; L = Large* — *PDP* = PDP of a specific product department*
B2B/B2B = Business-to-Business/Customer — *SP = PD sub-process*
UoA = Unit of Analysis — *P&L = Development of Production & Logistics concepts*

The case studies were selected based on two primary considerations: First, they should represent the **principal intended applicants** of the tailoring methodology, i.e., medium-sized to large iPD organizations with mature and sophisticated RPMs, which carry out multiple PD projects simultaneously. Second, they should represent a **broad spectrum of organizations with diverse boundary conditions** to increase the reliability of the evaluation. Case study E.1

[54] Letters only indicate a rough chronological order. For a chronological overview, see Appendix A4.1.

[55] Company names are omitted in order to protect confidentiality.

intentionally contrasts the other case studies with the selection of a small start-up company to investigate the scalability of the tailoring methodology regarding applicability and usefulness.

The case studies were carried out in the form of **master theses** for two reasons (cf. Appendix A4.1): First, to enable **immersion** in the organizational contexts and increase access to implicit and explicit data, otherwise often limited by confidentiality concerns. Second, due to **resource constraints**, proxies enabled the execution of multiple parallel case studies. The students as tailoring methodology applicants where closely instructed, supervised, and regularly reported back their findings. Regular meetings with the industry partners provided further feedback

Application of tailoring methodology elements and evaluation focus

Table 8-2 maps the tailoring methodology elements to the corresponding evaluation studies. As described earlier, procedure, acquisition methods, tailoring workshop concept, and metamodel have been applied and evaluated in industrial case studies. The analysis framework has been evaluated based on a software demonstrator, applied to data generated from case study D.1 (test case), and interview study with process and project managers from different companies.

Table 8-2: Mapping between tailoring methodology elements and corresponding evaluation methods (Focus of subsequent description highlighted in grey)

Tailoring Methodology Element	Case Studies										Demonstrator	Test Case	Interviews
	A.1	A.2	A.3	A.4	B.1	C.1	C.2	D.1	E.1	F.1			
Procedure	◑	◑	◑	◑	◑	●	●	◑	◑	●	◑	◑	◑
Acquisition methods	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	-	-	-
Metamodel	-	◑	●	●	◑	●	●	●	◑	◑	◑	◑	◑
Tailoring workshop	-	-	-	-	-	●	-	-	●	-	-	-	◑
Analysis FW	-	-	-	-	-	-	-	-	-	-	●	●	●
Tailoring roles	-	-	-	-	-	-	-	-	-	-	◑	◑	◑

Key: *● = Focus; ◑ = Applied, - = Not evaluated;* **bold** *= Focus of DS II description*

The individual elements of the tailoring methodology have been applied in the following ways:

- The **procedure** has guided the application to a varying extent in all case studies (cf. Appendix A4.1, Figure A-18). Phases 1 and 2 have been applied in all case studies. The particulars of phase 3 were dependent on the maturity of the TSM metamodel under development. The analysis phase has not been executed in the case studies, due to insufficient maturity of the developed analysis framework at the time. Phase 5 has been applied in case studies C.1 and E.1, focusing on the developed tailoring workshop concept.

- **Information acquisition** methods have been designed and applied in all case studies, based on the framework derived in section 5.2, with methods design and applied as demanded by the information available within the particular cases (cf. Appendix A4.1, Figure A-18).
- The **metamodel** has been iteratively applied and refined within case studies at different degrees of maturity (cf. section 5.3). While the metamodel specified the documentation for all case studies, graph-based representations were not exclusively used. For example, case study F.1 used matrix-based documentation, as no complex PTRs were identified.
- The **workshop concept** has been applied and evaluated in case studies E.1 and C.1 (in chronological order, cf. sections 8.2 and 8.3). Feedback has been gathered from discussions and observations during and after the workshop, as well as via a questionnaire filled out by all respective participants.
- The **analysis framework** (cf. section 8.4) is implemented as a software demonstrator and applied to a test case, using the TSM from case study D.1, extended with synthetic data, in order to test its feasibility and applicability. Subsequently, an expert interview study has been conducted to evaluate its applicability as well as the resulting benefits further. The expert interviews focused primarily on the metric-based analysis and corresponding visualizations.
- **Tailoring roles** have been evaluated not explicitly but as part of the expert interviews due to their implementation within the test case.

Extended overviews of the individual case studies, their chronology, focus, derived implications for improvement, and the applied tailoring methodology elements can be found in Appendix A4.1. As highlighted in Table 8-2, the subsequent sections **focus on selected case studies** (C.1, C.2, and E.1), emphasizing, in particular, **the evaluation of the tailoring workshop concept and the analysis framework** due to their novelty. A critical discussion of the overall tailoring methodology based on all case studies is found in section 8.5.1.

8.2 Case study C: Commercial vehicle OEM

Case study C has been selected for presentation as it represents the most extensive case study conducted, containing multiple embedded UoA which extended over multiple master theses. All constituent elements of the tailoring methodology have been applied, except the analysis framework. The case study description, therefore, focuses on the acquisition and documentation of tailoring knowledge and the subsequent application in a tailoring workshop.

8.2.1 Objective and initial situation

The case study was conducted on-site at a large, global Commercial Vehicle OEM catering to multiple market segments. The company has a variant-rich product portfolio, for example short- and long-haul passenger and cargo transportation in different weight categories, as well as purpose-built construction and military vehicles. The OEM is itself a subsidiary of a larger corporate group. Projects address the development of new vehicles and variants with customer-specific adaptations, as well as individual modules, for example engines, gears, and axles. Furthermore, the company offers mobility-related services. The company has 15 production sites in 10 different countries. The PDP RPM contains around 150 subprocesses assigned to 12 departments. Around 100 projects per year are conducted in parallel.

Within this organizational setting, the case study investigated two units of analysis as depicted in Figure 8-2: C.1 focused on one department-specific subprocess of the overall PDP[56], the development of production & logistics concepts (P&L), while C.2 investigated tailoring on an overall PDP-level (embedded in the department for central process & project management). C.1 was conducted from 2016-11-01 to 2018-03-15, spanning four master theses, with C.2. carried out in parallel between 2017-05-01 and 2017-11-01 in one master thesis.

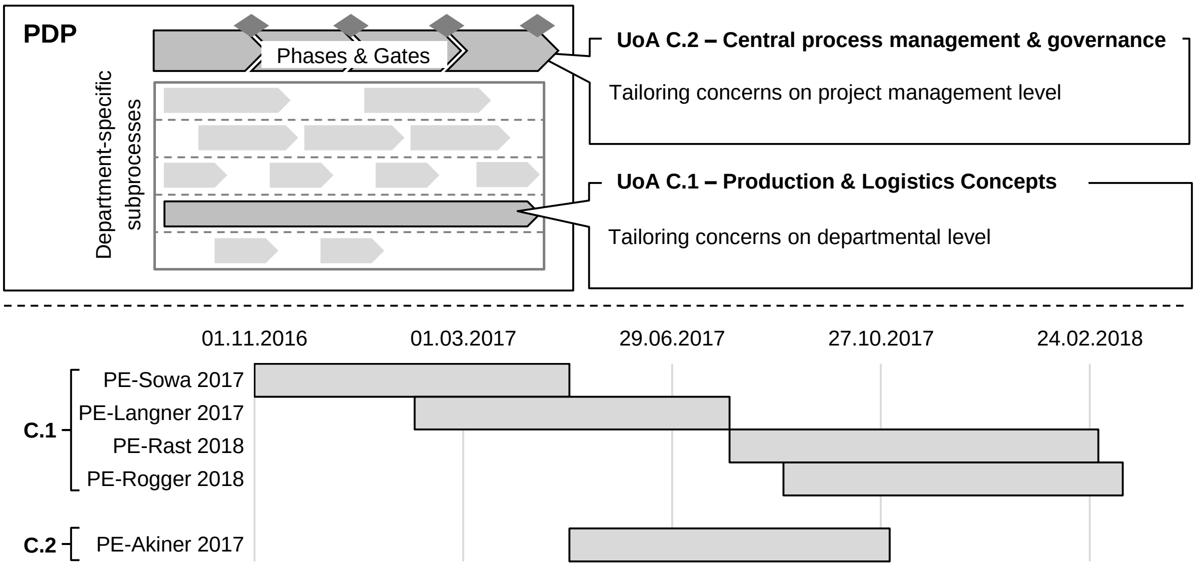


Figure 8-2: Case study C. Illustration of PDP layout and integration of Units of Analysis (top); Chronological sequence of units of analysis (bottom)

Objectives and procedure

The case study was initiated by a P&L subproject leader (C.1) and the PDP process owner of the central process management (C.2), respectively. The objective was to extend the company's process tailoring capabilities in light of current efforts to further systematize overall PD project management, as evidenced, e.g. by the introduction of a new project management system.

As case study C was conducted in parallel to the development of the tailoring methodology, it has a strong **formative** character, particularly regarding the applied **procedure** and **metamodel**. As the analysis framework had not been developed at this point, the procedure focused on **information acquisition, modeling, subsequent operationalization, and planning of future reviews**. The **tailoring workshop concept** has been applied in its **final**

[56] Due to confidentiality concerns, all information related to the RPM – and consequently to tailoring rule impacts - had to be omitted or abstracted. This also relates to the description of context factors in case it enables traceability.

design. Evaluation interviews have been carried out at the conclusion of each of the conducted master theses in order to assess applicability and success.

Initial situation regarding process tailoring at the industry partner

In order to facilitate assessing the tailoring methodology's impact, the initial situation, as found by the industry partner, is laid out subsequently. The initial situation regarding tailoring has been analyzed by performing initial, descriptive interviews in both units of analysis, indicating differences in the respective tailoring approaches.

Due to the size of the company as well as the high amount of variance between projects, for example in size and objectives, the company, in general, has recognized the need for tailoring the generic PDP RPM and had some previous experience. Tailoring is integrated as an activity within the PDP RPM and has been conducted within workshops at project initiation, with subsequent workshops in projects only conducted if the project scope changed significantly. Workshops are not conducted for every project, and according to the analysis, no standardized procedure is defined or applied. During the workshops, the PDP RPM elements are discussed sequentially and tailored based on the respective project briefs and experiences of workshop participants. Specific guidance during workshops is limited, but the results have to be documented in a gate-checklist, defining which gates and activities need to be performed or can be removed, which is the only applicable tailoring operator. However, subsequent analysis indicated that the documentation is incomplete and tailoring rationale often unclear.

Workshop participants extend to the project core team, which is constituted by overall project leaders and department-specific subproject leaders. Acquisition of input from further project stakeholders such as leaders of simultaneous engineering teams is at the discretion of the individual workshop participants, with final tailoring decisions made by the core team. However, as the interviews also showed, the PDP RPM in its current state does not include sufficient details to enable well-informed tailoring decisions without implicit knowledge from project stakeholders familiar with the individual activities.

The analysis of the initial situation further indicated that tailoring a priori (i.e. as part of project planning) is primarily conducted on an overall project management level. Conversely, tailoring on department level is conducted in an a-posteriori manner: Tailoring decisions made previously are justified at subsequent gate reviews. Tailoring decisions have not been explicitly documented and reused as rules in future workshops. Both levels seem mostly unconnected.

As the initial situation shows, the company and its employees had previous experience with process tailoring in general and are therefore well suited to evaluate the applicability and success of the developed tailoring methodology.

8.2.2 Application of the tailoring methodology and results

Based on the organizational context and initial situation of the case study, the application of the tailoring methodology is subsequently described in order of the applied phases of the procedure. The following subsection elaborates on the results of the evaluation.

Preparation

In both cases, the PDP RPM was initially analyzed in order to **identify hierarchical levels**, which were found to be well-defined. The RPM spans three hierarchical levels with increasing element decomposition: Process phases/gates and departments form *swimlanes* for the integration of specific subprocesses; swimlanes are further decomposed into discrete subprocesses, each concluding with subgates; subprocesses are further decomposed into activities and criteria for gate fulfillment. The definition and elaboration of these levels are mandatory for all departments and thus identical for both units of analysis. Further detailing is at the discretion of individual departments.

Early in C.1 (PE-Sowa, 2017), the PDP RPM was enhanced to **depict information (input-output) dependencies on subprocess-level** in a graph-based representation, using the information contained in the individual subprocess descriptions. Furthermore, **stakeholders** were identified which served as sources for phase 2 of the procedure. Due to the nature of the case studies, no extensive teams were formed to carry out the tailoring approach.

Information acquisition

Table 8-3 lists the information acquisition methods defined and applied within each unit of analysis.

Table 8-3: Defined and applied information acquisition methods in case study C

C.1	C.2	Method	Scope	Source
●	●	Gate checklists	Current/concluded Projects	Explicit
●		Interviews (Context/process variability)	Current/concluded projects	Implicit
	●	Comparison of pre-defined PDP variants	Future projects	Explicit
	●	Workshop observations combined with interviews	Newly initiated projects	Implicit

In **C.1**, **gate checklists** from 12 different projects were analyzed, documenting ca. 6900 tailored process elements, around 40% of which had a documented tailoring rationale. The projects in question have been selected since they used the current version of the OEMs PDP. The data was analyzed twofold: Tailoring rationale was analyzed **qualitatively** to formulate context factors, and a descriptive **quantitative** analysis investigated the frequency of tailored process elements, calculating the number of times a particular process element has been tailored with respect to the number of projects analyzed (cf. Figure 7-8, 144). The results were used in subsequent interviews, to validate and identify further context factors as well as process variabilities. However, since most projects had not been completed at the time of analysis, the results are only valid for early gates and subprocesses of the RPM. Nonetheless, the conducted analyses led to conclusions regarding the most-tailored RPM elements. The interviews further corroborated insights gained through the quantitative analysis: Most tailoring efforts are related to testing activities and prototyping. Only one subprocess with associated subgates was not subject to tailoring, since the subprocess's objective is to ensure readiness for the start of production. In total, 88 candidate context factors and generic impacts on the process were identified from gate checklists and interviews. In a second step, these context factors were examined and **filtered to identify context factors with tangible impacts for tailoring rule formulation**. Context factors were removed due to the following reasons: Unclear impact, no valid reason for tailoring (e.g., related to capacity, scheduling, budget, or organizational reasons), the context factor addresses process redesign instead of tailoring (e.g., “gate unknown”), or context factor addresses only logistics department[57]. Conversely, context factors were decomposed in case a more concise specification was necessary, e.g. the location where a pre-series release vehicle is built or where assembly worker training is required. In total, **31 final context factors** were used to specify tailoring rules, which were documented using a questionnaire format (cf. Appendix A4.3.1).

Throughout **C.2**, three **tailoring workshops** have been observed, one current project has been analyzed using the documented **gate checklist**, and the PDP RPM has been **compared** to a newly defined PDP concerning group-wide PD projects (e.g. for crosscutting modularization initiatives). The comparison resulted in an extension of the scope of the OEMs PDP, caused by a pre-defined context factor (group projects), which triggers whether the additional process elements need to be included in a project instance. As this was a new development within the corporate group without precedence, no further analysis could be made at the time being. The analysis of the current project was performed in four steps: Searching for a relevant project, checking the documentation for availability and completeness, identifying tailoring rationale and operations, and validating results with a process expert. **Workshop observations** were combined with **interviews** (cf. Badke-Schaub & Frankenberger, 2004, p. 50): Within the workshops emerging discussions related to tailoring operations and corresponding rationale could be directly observed and documented. The workshop documentation was subsequently discussed and validated with the responsible project managers as well as the PDP owner. Documented insights were furthermore cross-validated in subsequent workshops. In order to identify further corresponding tailorable process elements, candidate elements were identified within the PDP RPM documentation using a keyword-based search (phases/gates, subprocesses/subgates, and activities/gate criteria). Tailoring impacts were identified on the lowest level of detail possible, e.g. individual activities within subprocesses or entire subprocesses to be removed.

In total, the information acquisition in C.2 focused on the identification of relevant context factors and initial formulation of tailoring rules, resulting in **20 context factors** (cf. Appendix A4.3.2) based on which **18 tailoring rules** have been defined, one of which represents a complex rule dependent on three context factors. The context factors “amount of carry-over parts” and “product modularity” were documented as **indirect** context factors (General impacts) since no direct tailoring rules could be formulated, but they do have indirect impacts on the processes according to the experts involved.

In both UoA, tailoring rules were identified, which are applied in individual as well as multiple instances, i.e. depending on different assessment bases (cf. component classification in C.2, material change in C.1.

[57] In order to reduce effort, the focus was set on production-related aspects in agreement with the industry partner.

Modeling and documentation

The documentation of tailoring rules was implemented by different means in order to evaluate the feasibility and applicability of the initial metamodel. In the case of C.2, context factors and impacts were described using presentation software in order to create managerial overviews for reuse during workshops and further discussions among process experts (validation, further decomposition). The presentation slides include the context variable, respective values, description, and impacts. In C.1, spreadsheet software was used for list-based documentation and in order to create questionnaires for each defined tailoring point (i.e. project initiation and concept decision) (cf. Appendix A4.3.1). Additionally, graphical feature models were created, depicting context factors as well as context and decision-tree constraints (cf. Appendix A4.3.1). CCs were used to represent context factor groupings. DTCs were necessary since, for example, context factors 1.3.2 to 1.3.6 are conditional to the production concept being changed. The identified context factors were subsequently used to refine further the content of the P&L-specific RPM, by permanently adding, removing, splitting, and modifying RPM elements.

The refined RPM was documented as a two-dimensional process model, grouping the tailorable process elements according to the identified context factors, as illustrated in Figure 8-3.

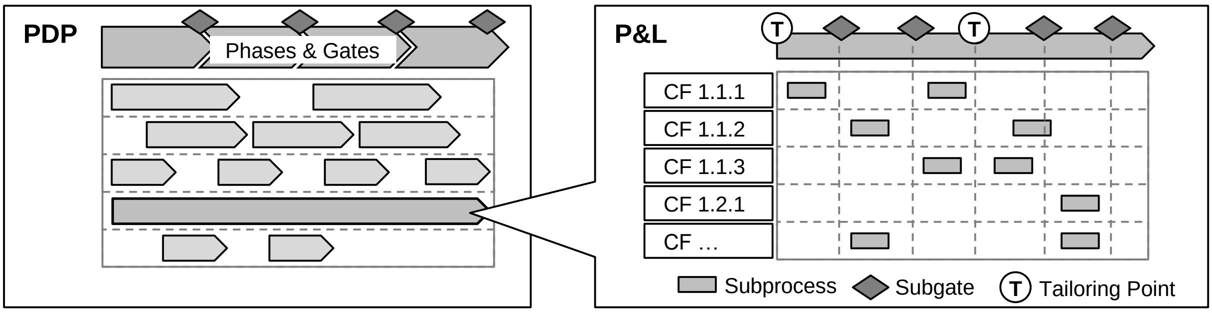


Figure 8-3: Swimlane representation of the P&L-specific RPM integrating identified context factors

Tailoring workshop

In order to evaluate the final tailoring workshop concept, a tailoring workshop was conducted within a selected project at the industry partner towards the end of C.1 (PE-Rast (2018); Hollauer et al. (2018d)). The workshop was applied on a **small project** tasked with increasing the range of applicability of an unpowered front axle in order to extend the company's product portfolio. The project started in July 2017, with start of production planned for late 2018. The most significant challenge for the project was a shortened development time of about 18 months, with concept release delayed by about five months due to missing calculations and analyses. The project is handled by a single simultaneous engineering team. Seven employees from different departments participated in the workshop, which was carried out based on the specifications described in section 7.6. Due to confidentiality concerns, the workshop was carried out by the respective master student, supported by the leader of the responsible simultaneous engineering team. The workshop was carried out in one session of 2 hours duration, including the presentation of the workshop concept. The P&L department was tasked with preparing tailoring decisions using the previously identified tailoring rules. Further aids used during the workshop included a presentation of input-output dependencies for subprocesses, PDP printout, and poster wall for documenting tailoring decisions.

The workshop was conducted by first presenting the initial situation of the project and objective of the workshop (15 minutes), followed by two subsequent working phases. The first working phase was used to present the previously defined 24 P&L tailoring rules and discussing and documenting the prepared decisions (25 minutes). The second working phase proceeded to tailor the PDP for the remaining departments. Since no context factors had been prepared, the workshop proceeded to discuss the PDP chronologically. For each decision, it was specified whether an element is removed or modified and documented accordingly. This phase turned out to be very time-intensive (100 minutes). Regarding P&L tailoring decisions, only the impact on subsequent subprocesses was discussed. The results of the tailoring decisions were documented in parallel, and at the end of the workshop participants gave feedback via a questionnaire.

8.2.3 Evaluation results and discussion

The following evaluation results and discussion focuses on the information acquisition, documentation, and the applied tailoring workshop.

Information acquisition

The methodology offered enough flexibility to acquire information in both UoA, as in both the same (gate checklists) as well as different (workshops vs. in-depth interviews of process role holders) types of information sources were available. In both UoA, the applied acquisition methods allowed to acquire sufficient information to formulate multiple tailoring rules. The documented context factors and formulated tailoring rules could be validated by using multiple information sources, e.g. multiple tailoring workshops.

However, not all context factors could be used to formulate rules (e.g. modularity, amount of carry-over parts). In these cases, the context factors were documented nonetheless, in order to enable reuse and facilitate their possible concretization in the future. While the identification of context factors in both UoA was comparatively easy, as evidenced by their numbers, formulating causal relationships to process impacts poses a greater difficulty, as evidenced by the reduction in context factors in C.1. This also indicates, as corroborated by concluding interviews, that information acquisition should be an ongoing process.

A comparison of the sets of context factors acquired in both UoA reveals similarities as well as differences: The context factors acquired in C.2 are mostly related to project objectives and general characteristics, while the context factors in C.1 are more directly related to particular activities and closer to the product under development. This can be traced back to the different perspectives in both UoA and the difference in process overview vs. more profound insights due to the different stakeholders involved in information acquisition (management vs. roles carrying out the activities in question). However, overlaps in general tailoring concerns can also be seen: For example, aspects regarding virtual and physical validation are important on both levels, as is the location of production sites, albeit on different levels of detail. Thus, as can be expected, the rationale of the derived tailoring rules is mainly dependent on the concerns of the stakeholders regarding the investigated (sub-)process. In both cases, tailoring rules of different cardinalities were formulated, to be carried out once (e.g. the number of variants developed), or multiple times (e.g. classification or hull geometry alteration per component).

In C.2., no further detailed analysis of tailoring impacts was possible, since no project stakeholders on detailed process levels were available for interviews. Therefore, no additional need for adaptation of the RPM could be derived.

Modeling and documentation

Tailoring rules were found by the process experts to be a beneficial[58] form of documentation in order to eventually make tailoring workshops more efficient (C.2). A particular, rare constellation of context values (project time below benchmark, no variant development, and small lot size) results in the possibility to remove a considerable number of gates, which was not possible to depict with the original metamodel since the rule constructs were not yet developed. This was subsequently addressed through the integration of additional node and edge types within the metamodel, which were used in the final documentation of context factors in C.1 (cf. section 5.3 and Appendix A4.3). The hierarchical levels defined within the RPM limited the possibilities for defining tailoring operations in C.2, to the removal of entire gates and phases, subprocesses, and activities.

However, the process management expert responsible for the overall PDP interviewed at the conclusion of C.2 found the formulated context factors and tailoring rules to be an improvement over the initial situation. While well aware that a complete identification of all relevant context factors is not feasible in the initial acquisition, an “80%-solution” (process expert) was nonetheless found to be an improvement. Furthermore, the documented context factors are seen as a way to concretize the documentation of tailoring rationale in the documentation checklists. As the department-specific process in C.1 has been detailed by the applicants of the tailoring methodology, more concrete relationships and thus, tailoring rules could be defined.

In interviews (cf. PE-Langner, 2017), stakeholders in C.1 evaluated the identification of context factors and tailoring rules to support systematic tailoring, facilitate decision making, and increase transparency regarding tailoring decision making. However, the necessary and considerable effort for information acquisition was repeatedly mentioned as a limitation.

Since several process elements were not suitable to address the identified context factors, this corroborates the importance of adapting the RPM in phase 3. The refined department-specific RPM (C.1) has further been found by stakeholders to facilitate tailoring since it contains a higher level of detail, and elements commonly tailored together are visually grouped into swimlanes (PE-Rogger, 2018).

Tailoring Workshop

During the tailoring workshop, participants, also from departments other than P&L, described the context factor approach as **understandable and usable**. However, the presented P&L

[58] Intermediate evaluation, 2017-07-25

context factors themselves were too specific to be transferable to other departments. Since not all relevant stakeholders did attend the workshop, not all tailoring decisions could be made on a well-informed basis, corroborating the importance of implicit knowledge and the respective knowledge carriers.

The workshop was evaluated by all participants (N=7) at its conclusion, using a questionnaire with 5-step Likert scales. Results are visualized in Figure 8-4. The question items and detailed results can be found in Appendix A4.3. Overall, the **quality** of the workshop has been evaluated as positive (Q1-Q6). Regarding workshop **materials**, the poster wall, presentation (input-output dependencies), and PDP printout were very well received by the participants. Although the workshop was intensive, the allotted time was perceived by participants to be adequate. The results indicate that the workshop participants found the workshop to be meaningful for large organizations in general (Q10; mean=1,1) as well as the OEM in question (Q7; 1,3). They see tailoring workshops as appropriate to create a more agile and flexible development process (Q8; 1,6) and to generate a shared vision of the project-specific process (Q12; 1,4). Further, they agreed that the tailoring workshop aids in designing interfaces and distributing responsibilities between team members (Q9; 1,4) and creating an efficient process (Q15; 1,7). Furthermore, tailoring workshops were seen to provide benefits for future projects by utilizing the documentation in retrospectives (Q16; 1,9). Tailoring workshops were seen to support project leaders in their work (Q19; 1,3) and participants are generally inclined to participate in future workshops (Q18; 2,3). However, as the application indicated, the workshop was time- and work-intensive, requiring extensive preparation and process understanding.

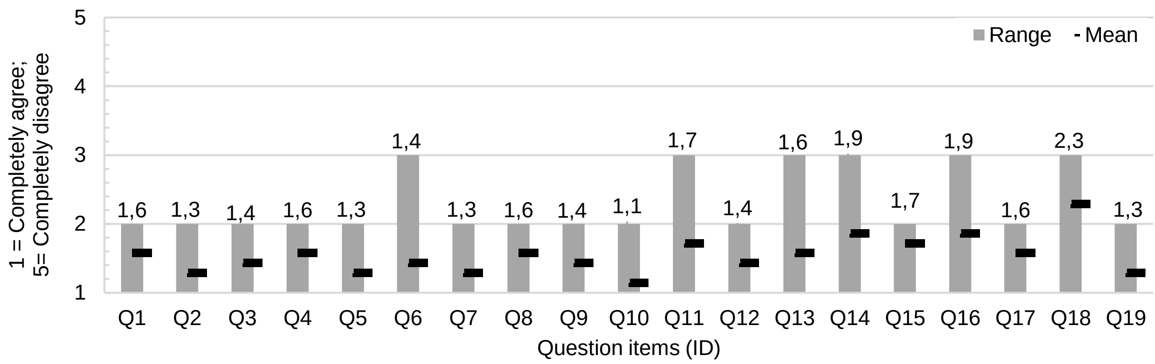


Figure 8-4: Tailoring workshop evaluation results (Case study C.1)

8.2.4 Conclusion and lessons learned

Within C.2, context factors were identified, which only address a single, as well as multiple departments, indicating that they require different degrees of communication. At least some require communication between different departments. This led to the **formulation** of an initial, heuristic approach to deal with different tailoring rules (inter-/intra-departmental), forming an early precursor to the subsequent development of the analysis framework.

The inability to model complex context dependencies during C.2 resulted in the further elaboration of the constructs to model PTRs, which was carried out and validated within D.1, eventually resulting in the rule domain of the metamodel (cf. section 5.3).

Additionally, throughout the case study, **workshops** were identified as a candidate solution to address the social aspects of tailoring (via C.2). Workshops were already applied at the industry partner, but, as shown in the analysis of the initial situation, unstructured and not based on the reuse of tailoring knowledge. The idea of tailoring workshops was subsequently further investigated, identifying a research gap in this area (cf. section 4.4). Due to the resulting shift towards workshop-based tailoring over the course of the case study, several activities initially included in the tailoring procedure were removed and altered, such as the integration of tailoring into process management systems. Instead, a structured workshop concept was developed and initially tested in E.1. The developed initial tailoring workshop concept, which uses documented tailoring rules, was then fed back into the case study (C.1.), further detailed and applied in its final design.

The workshop-based approach proved to be both applicable as well as beneficial (cf. also section 8.3) for addressing the communication-intensiveness of tailoring. Therefore, the tentative procedure developed and applied at the beginning of the case study was adapted to include the workshop concept in phase 5. Simultaneously, C.1 illustrated the importance of dependencies for assessing tailoring decisions and the difficulty of tailoring a structurally complex RPM in practice without further aid, prompting the development of the structural analysis framework in order to further facilitate the handling of complex information during the workshops. This was further corroborated since context factors identified in C.2 rarely impacted single departments but had wide-ranging impacts over the PDP.

8.3 Case study E: Laboratory device startup

This case study focuses on the evaluation of the **tailoring workshop concept within a small startup**. It is based on the work documented in PE-Saad (2018).

8.3.1 Objective and initial situation

Case study E has been conducted within a start-up company developing laboratory devices. The product under development aims at supporting pathology departments in hospitals and independent laboratories by automating the analysis process of tissue samples for cancer diagnosis. The process involves many steps, which are currently executed manually, resulting in an error-prone process causing false positives as well as negatives. This may result in false diagnoses for patients as well as lawsuits for laboratories.

The company is in an early phase, currently developing a working prototype of its product, with no mature product ready for sale when the case study was conducted. The product consists of different modules, such as the actual automation unit, carriers for tissue samples as well as management software. The company currently works in an agile manner, with a low degree of organizational or process structure. No project organization is currently set up. Due to the increasing growth as well as high employee turnover (many employees are working students or students working on their theses), the need for a more structured process as well as a documented process model has been stated by the founders of the startup, initiating the case study. The RPM needs to be flexible and introduced gradually within the organization.

Due to these circumstances, the case study focused on the initial design and implementation of an RPM. The methodology is applied in a supportive manner in order to identify and document the process application context as well as possible process variances early on. The focus of the evaluation lies on the application of a process tailoring workshop. The case study highlights the potential benefit of tailoring workshops for applicants with limited previous experience.

8.3.2 Application of the tailoring methodology and results

This section briefly illustrates the main aspects of the application of the tailoring methodology. The case study focused on the acquisition of tailoring-relevant information and the initial development and implementation of the tailoring workshop concept. The analysis framework has not been applied.

Preparation

The primary requirement within the preparation phase was the development of an initial RPM, which did not exist before the start of the case study. The development of the RPM overlapped with phase 2 of the methodology, combining interviews regarding the acquisition of information for the RPM with the acquisition of context factors and process variability. As the process was considered manageable due to the number of people involved in the company, the system boundary encompassed the entire PDP.

Information acquisition

Within phase 2 of the methodology, context factors and process variances were identified. The following methods were used: Literature-based context factor catalogs, document analysis (e.g. the business plan), observation of meetings, as well as individual interviews.

While initially, 85 context factors have been identified, concrete values and definable process impacts could not be identified for all of these, thus reducing this initial set. The resulting set of 15 context factors identified within the case study and used as input for the tailoring workshop is presented in Appendix A4.4.

Several **challenges** hindered the acquisition of context factors: Understanding regarding the entirety of the PDP was limited, as no RPM was previously defined, and the company followed an agile approach. Furthermore, the company is currently developing its first prototype, so no project had been concluded so far. In no small part, the staff was composed of working students with limited practical experience, many employees worked part-time, and the overall availability of staff was often unclear, hindering the planning of interviews.

Due to these challenges, mostly related to the limited process maturity and experience, concrete tailoring rules could be defined only for two identified context factors. The effect of different context values on the process is illustrated on these two examples:

- **“Medical certification required?”:** The first example describes whether a medical certification is required for the product or module under development. This in turn mainly depends on the target market. If a medical certification is required (context value “yes”), specific quality management processes need to be executed in addition to the regular technical documentation. These *inserted* activities, in turn, require more effort, affecting scheduling and budgeting for this project. Furthermore, roles with particular skills need to be included in the particular project.
- **“In-house development of modules”:** The second example addresses the fact that not all electronic product modules are developed in-house. If a module is outsourced (context value “no”), the respective activities of the Electronics development stream within the PDP can be *removed,* and instead, activities related to communication and coordination with the external development partner are *inserted* into the process.

Tailoring workshop

After the information acquisition and the design of the reference process model along with initial tailoring rules, a tailoring workshop has been conducted on a hypothetical yet realistic example: The RPM was tailored for a particular project[59], which is expected to be conducted in the near future. Due to these boundary conditions, not all context factors could be used for tailoring, as not all values could be clearly defined. Where possible, different tailoring scenarios have been discussed based on the defined tailoring rules. In all other cases, the PDP reference model was used to guide the workshop, with each phase being subject to discussion.

The workshop took 4 hours in total, with two 15-minute breaks. In an introductory session, the problem, concept of tailoring, as well as workshop objective has been presented, and the tools and data basis used are explained. For this reason, example scenarios for possible process adaptation are presented, with the example being the in-house vs. external development of a specific product module. The central part of the workshop is the discussion of the individual reference process phases, milestones, and subprocesses using the identified context factors as well as general guiding questions, which address responsibilities (roles, disciplines), process interfaces, tasks, and methods/tools. Impacts of context factors on impacted phases have been visualized as a domain mapping matrix (DMM).

8.3.3 Evaluation results and discussion

The evaluation of the tailoring methodology within the case study is based on two aspects: The self-observation of the applicant as well as a questionnaire-based evaluation of the tailoring workshop. The evaluation data can be found in Appendix A4.4 (p. 376).

[59] The objective and characteristics need to remain confidential at request of the company.

Information acquisition, modeling, and documentation

The setting presented several **challenges** for the application of the methodology, as previously described. The familiarity of the employees with the overall development process and project management was comparatively low since the start-up is relatively young, with a workforce consisting of part-time working students. The company's environment is highly dynamic and rapidly changing. During the case study, no PD project had yet been completed, with the product still being in a prototype stage. This limited the acquisition of context factors. However, an initial set of context factors has been acquired and documented using the defined attributes, which was used as input for the tailoring workshop (cf. Appendix A4.4).

Tailoring workshop

The **tailoring workshop** has nonetheless been evaluated as positive. In discussions, tailoring workshops were seen as a viable method to introduce tailoring in an organization with limited previous knowledge regarding process tailoring. Project experience has been mentioned as essential in order for tailoring to be carried out effectively. Due to the low maturity of the RPM within the organization, the tailoring workshops addressed some aspects which should be unnecessary within more mature environments. These are, for example, a general introduction to process management, the overall design and content of the RPM, and the distribution of responsibilities for the project due to lack of a stable role structure. Also, a considerable amount of time and effort had to be invested in presenting and discussing the RPM itself. The tailoring workshop at this stage was seen primarily as a means for the company to increase the maturity of the reference process.

The evaluation is furthermore based on a questionnaire answered by eleven participants of the workshop, identical to the one used in C.1. The questionnaire uses in total 19 question items with a 5-step Likert response scale from "completely agree" to "completely disagree" (cf. Appendix A4.4) plus additional open and closed questions to gather feedback for the moderator. Question items Q1-Q6 address the quality of the workshop, while items Q7-Q19 address workshop benefits.

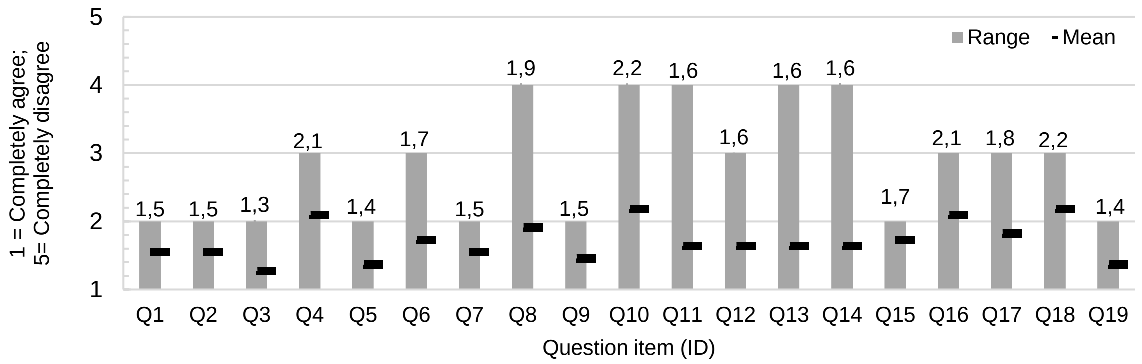


Figure 8-5: Tailoring workshop evaluation results (Case study E)

Tailoring and corresponding workshops are seen as useful tools for the particular company and – with limitations – for start-ups in general (Q7, Q10). In particular, project leaders are supported through process tailoring (Q19), overall workflow efficiency can be increased (Q15), and documentation for project retrospectives can be improved (Q11). A methodical approach is generally seen favorable (Q17), which the tailoring methodology and workshop in particular provides. Overall, the tailoring approach is seen to lead to a more agile and flexible development process (Q8) while simultaneously aiding in the design of process interfaces and the distribution of responsibilities between disciplines (Q9). The tailoring workshop supports stakeholders in organizing and structuring themselves (Q11), as well as to formulate a shared vision of the development process (Q12). Finally, tailoring workshops are seen to support collaboration within the project team (Q13) and to better understand the tasks and activities of colleagues (Q14). However, while the workshop overall has been evaluated as mostly positive and useful, enthusiasm for further workshops was limited (Q18). This can be traced back to the involved effort and the current situation at the company. One point of discussion was the difference between the current development activities, which are mostly related to the development of a first working prototype, as well as series development with increased product maturity. The usefulness of the workshop was largely seen within the latter.

To summarize, the workshop was seen as positive and worthwhile. In this case, the applicants did not have extensive knowledge regarding process and project management, as well as the particular company's process as it was newly defined. Within the startup company, a more "hands-on" approach has been followed so far. However, the need for a more structured process has been identified within the company. The evaluation shows that tailoring workshops have the potential to be beneficial even without extensive process knowledge.

Challenges during the workshop arose due to the effort required. Other priorities within the company, which is currently involved in intensive prototype assembly and testing, distracted stakeholders from the workshop and limited discussions. This could be alleviated by splitting the workshop into phase-specific blocks conducted at process milestones. The time when a tailoring workshop is conducted is crucial, either before project start or at the beginning of particular process phases. Not all required stakeholders could attend the workshops, and not all attending stakeholders had extensive process knowledge since they had been hired recently. The prepared tailoring handout, which had been distributed before the workshop, was insufficient to convey the required basic knowledge. More intensive training for key tailoring stakeholders is required. Due to the circumstances, the stakeholder analysis from the tailoring methodology could not be applied. Furthermore, too many different tools and visualizations have been applied within the tailoring workshop, leading to confusion.

The evaluation is limited to immediate results from the tailoring workshop. Any medium- or long-term effects in terms of process quality or project performance could not be evaluated. For this, continued workshops, lessons learned reviews, as well as PDP reference model reviews, would be necessary in the future.

8.3.4 Conclusion and lessons learned

Within this case study, tailoring has been introduced in a small organization with a predominantly agile environment, demonstrating the scalability of the approach. The case study did not indicate a contradiction between the established agile approach and the more structured approach consisting of the developed RPM and tailoring workshop. The tailoring workshop has been evaluated to contribute to increased flexibility and communication and can potentially facilitate the transition from a purely agile approach to a more structured/hybrid approach. This non-trivial transition was seen as necessary by the management of the start-up company due to the continued growth and the different technical disciplines involved, contributing to complexity, as well as external drivers (certification).

The case study also shows that the tailoring methodology depends on the availability of a certain process understanding, which is required to formulate tailoring rules. While it remains assumptive at this point, future repetition of the tailoring workshops can lead to a more comprehensive data set regarding context factors as well as reference process elements. Also, future repetitions would see the amount of work required for communicating the RPM itself reduced, enabling to focus more on actual tailoring.

8.4 Application and evaluation of tailoring analysis framework

The **support evaluation** of the analysis framework was conducted through iterative reflection and discussion during the development of the software prototype. An initial expert interview was used to evaluate the initial applicability, leading to the formulation of the extended tailoring role model, the adaptation of the initial reports for requirements by different tailoring roles, and the addition of the stakeholder report on node level. Data from case study D (PE-Philipp, 2017) was subsequently utilized and extended to form a comprehensive **test case** to evaluate the feasibility and applicability of the analysis framework within the **application evaluation** (section 8.4.1). The applicability and benefit of the analysis framework were further initially evaluated through an **interview study** involving process and project-management experts from various companies (**initial success evaluation**) (cf. section 8.4.2).

8.4.1 Application evaluation of software demonstrator

The application evaluation of the analysis framework is based on the demonstrator implemented using the *Soley Studio* platform (PE-Kölsch, 2018) and the data acquired during case study D.1 (PE-Philipp, 2017). The software demonstrator is implemented in a modular manner in order to facilitate the reuse of functions, e.g. for the matric calculation. In order to enable the application of the analysis framework on the previously acquired data, the generic metamodel (chapter 6) was adapted accordingly for the software implementation (cf. Appendix A4.5). The data from the case study was documented in a relational database containing data regarding the acquired context factors, the investigated process, and corresponding tailoring rules. The data was cleaned of orphaned nodes. Since the data of the organizational domain only included roles, **additional data regarding individuals was added for the test case**. The final resulting graph contains 948 nodes and 1553 edges (Figure 8-6). The number of nodes per domain and the number of edges show that during case study D.1, a high number of PTRs was defined based on the conducted project data analyses (cf. Section 7.3.3), but not connected to tailoring rationale. This indicates that while the model can be used to test the analysis routines, which primarily focus on PTR, activity, and organizational nodes, the information content itself is not yet particularly mature and requires further information acquisition activities.

Generated test case graph model

Node Type	No.
Activity	648
ContextValue	34
ContextVariable	7
Person	100
PTR	127
Role	32

Edge Type	No.
isValueOf	34
hasCondition	26
hasImpact	137
precedes	284
isPartOf	440
executes	499
manages	101
isResponsibleFor	32

Figure 8-6: Graph model for test case

Generated example reports

The generated **PTR report** (network level) (refer to Appendix A4.5 for all generated reports) gives an initial overview of the tailoring rules from the test case, with the table showing the minimum and maximum values of the structural metrics and the portfolio showing the overall complexity of tailoring impacts. For example, the excerpt shows that several PTRs have only a small number of dependent activities but a comparatively large number of affected stakeholders, with a maximum number of ten stakeholders per PTR. The table shows that PTR 3 affects a very central activity within the network (*centrality* = 523). PTR 2 affects an activity with considerable centrality (212) and has the highest Snowball Factor (83), which indicates a high number of downstream activities.

The **stakeholder report** (network level) shows that based on the available data, three stakeholders (*id* 35, 63, and 77) have significantly more dependencies with activities as well as PTRs. When carrying out process tailoring, these individuals should be included early in the activity, and their attendance at the tailoring workshops should be ensured. In preparation, particular care should be taken to train these stakeholders. Furthermore, the report shows the mapping of the 23 individual stakeholders, which are affected by tailoring decisions, to their corresponding tailoring groups, as derived by the clustering algorithm (cf. section 7.5.4). The mapping is non-uniform due to the calculated needs for communication (cf. Appendix Figure A-25). One stakeholder (*id* 51) has insufficient commonalities with other stakeholders to warrant inclusion in other workshop groups. Reasons for this result can be found in either the modeled organizational structure, the dependencies between stakeholders and activities, or the selected clustering algorithm, which was unable to derive uniform clusters due to the high number of dependencies between stakeholders. An analysis of the influence of the clustering algorithm and its corresponding refinement should be the subject of further work.

However, although the number of stakeholders varies between clusters, **cluster reports** can be derived. The cluster reports indicate the prospective participants of the tailoring workshop with their corresponding IDs. The table within the report for cluster 2 (Figure A-26) shows that stakeholders with IDs 58 and 77 are affected by PTR 1 and should be consulted together when the decision is made whether to apply the respective tailoring rule. Structural metrics for each PTR are also provided, indicating a possible PTR prioritization for a workshop. Rules with more critical impacts (IDs 3, 2, 1, 6, 4, and 5) should therefore be addressed first in order to maximize the efficiency of the tailoring workshop. Dependencies between clusters form the final section of the cluster report (Figure A-28). The focused workshop group 2 has PTRs as well as activities in common with clusters 1 and 3. The respective IDs are given in the table. The consolidation of tailoring decisions between both tailoring workshops is the task of the tailoring organizer(s).

Besides these aggregated reports, **node-level reports** have been created for the test case. The example for the node-level **PTR** report shows that PTR 72 only has one context variable as its condition and only impacts one activity (137) (Figure A-30). The final section of the report shows that PTR 72 shares its context factor, the impacted activity, and four affected stakeholders with PTR 36. In contrast, PTR 98 affects four activities, but no final contextual condition has been defined for this PTR (Figure A-31).

The exemplary node-level **activity** report shows the structural metrics for activity 137 (Figure A-32). Using the provided visualizations, the significance of the activity can be assessed in the context of the overall process (maximum, minimum, and mean values for each structural metric), which are rather low within the overall activity network. Activity 137 has no modes.

In contrast to the other reports, the **context variable** report (Figure A-33) does not include structural metrics. Instead, it shows the corresponding context values along with the PTR IDs for which the context values represent conditions. The conclusion of this report is formed by dependencies between context variables via common PTRs. In the example, this section is empty as no dependencies of context variable 68 to other context variables exist within the model. This can point to a potential model error, as the context variable simultaneously provides several values for the same PTR (161), which would require other context values to formulate distinctive PTRs.

The final report created for the test case is the node-level **stakeholder** report. The report for stakeholder 21 is given as an example (Figure A-34). Using the report, the corresponding person can prepare for tailoring workshops. The upper section of the report shows all PTRs the stakeholder is affected by, along with the structural metrics and corresponding communication partners. The lower section shows the activities the stakeholder is responsible for, equally providing the dependent stakeholders. In the example case, PTRs 56 and 57 show a comparatively high mean C_B as well as high mean SBF with overall low mean Cr and nine dependent stakeholders as communication partners. The report concludes with an overview of the aggregated communication requirements for the stakeholder (cf. Figure A-34). In this case, stakeholders 67 and 77 represent the communication partners with the highest Alignment.

Discussion

To summarize, the application evaluation has shown that the developed analysis framework is applicable to prepare and condense the structural information contained in the TSM in the form of reports. Using the approach, information is filtered and aggregated for different tailoring roles, in essence providing different global and local “views” for tailoring roles as well as individual stakeholders in order to increase transparency (Maurer, 2017, pp. 120–123). The information has the potential to support decision making within the tailoring workshops. Therefore, the overall approach for the analysis can be evaluated as feasible and applicable.

Limitations can currently be found regarding the clustering algorithm, which can be further refined to derive more uniform tailoring groups of manageable sizes. For example, future advancements could include a set limit of participants in a particular workshop group. The tailoring reports currently do not show the respective operator of a particular PTR. Further limitations concern the data itself, as the information acquisition could not be carried out completely.

As the test case could not evaluate the reception of the analysis approach in industry, i.e. its usefulness, this aspect has been further addressed in an interview study involving industry experts.

8.4.2 Interview-based success evaluation

The second aspect of the analysis framework evaluation addresses the industrial applicability as well as the usefulness of the analysis framework (PE-Kölsch, 2018). The interview-based approach allows gathering a broad perspective from experts with different organizational backgrounds. This approach was chosen since no long-term application and observation of the usefulness of the tailoring methodology in an industrial setting was possible.

Design of interviews

In order to ensure the reliability of the interview feedback, several requirements regarding the background of the interview partners have been set:

- An academic background
- Previous experience in the area of process- or project management
- Experience in iPD/Working at an iPD company

In order to get feedback from different perspectives, eleven[60] experts from five companies of various sizes and backgrounds have been interviewed, as shown in Table 8-4. Interviews were conducted mainly in a one-on-one setting, with two interview sessions conducted with multiple experts due to constraints set by the industry partners, as indicated in the table. The interview partners have been selected from the conducted case studies as well as independently, in order to bring in new perspectives.

[60] While the approach has been presented to and discussed with eleven experts, only eight questionnaires have been filled out and returned, with three questionnaires missing from interview company 2.

Table 8-4: Overview of interview partners and their characteristics

Characteristics	**C1**	**C2**	**C3**	**C4***	**C5**	**Sum/Avg.**
Industry	Household appliances	Imaging Electronics	Construction equipment	Commercial vehicles	Heating Systems	
Company size (total no. of employees)	~62,000	~1,500	~5,000	~54,000	~12,000	–
Number of interviewed experts	2	6	1	1	1	11
Completed questionnaires	2	3	1	1	1	8
Avg. process mgmt. experience (years)	~6	~7	~4	~7	~1	~6
Avg. project mgmt. experience (years)	~4	~7	~4	~12	~15	~8
Avg. process tailoring experience (years)	~2	~0	~2	~4	~0	~2
Key: *C = Company; * same as case study C.1*						

The interviews themselves consisted of **two phases**: First, the motivation, as well as the overall approach for workshop-based tailoring, was presented, addressing all constituent elements. Within this phase, **qualitative feedback** was gathered in **an open discussion** with the respective interview partners, the presentation of the tailoring methodology acting as a semi-structured interview guideline. This allowed the clarification of any misunderstandings and deep-dives into individual aspects of the tailoring methodology, fostering discussions. The presentation addressed the following aspects (in this particular order):

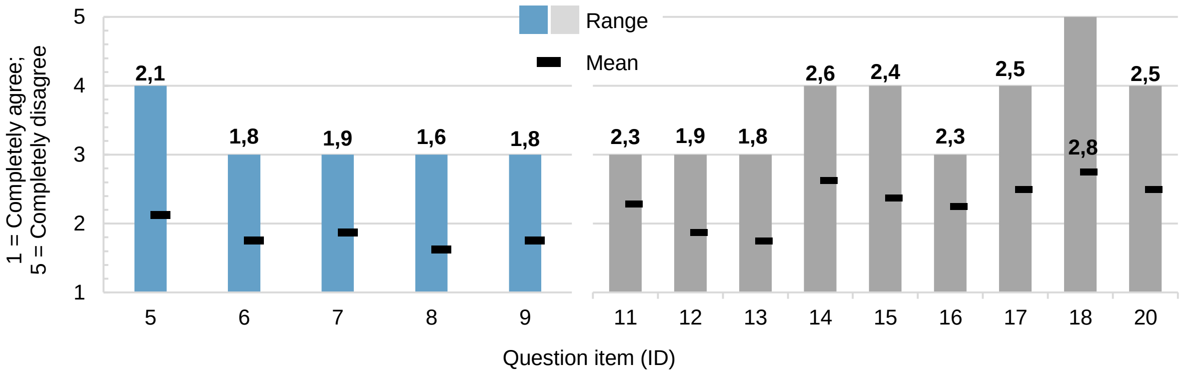
1. Introduction and definition of process tailoring
2. Challenges associated with process tailoring in industry and academia
3. The intended impact of the approach: Support of workshop-based tailoring
4. An industry example of a complex process network to illustrate the complexity challenge
5. Overview of the tailoring methodology’s constituent elements
6. Overview of the metamodel
7. Overview of the methodology
8. Examples of context factors from case study C.1 (anonymized)
9. Example for the creation of the TSM (using two anonymized context factors)
10. Overview of the structural analysis of the TSM using academic example graphs
11. Explanation of selected metrics and their significance
12. Explanation of tailoring roles
13. Explanation of individual reports and their contents using templates with exemplary data
14. Explanation of stakeholder clustering
15. Explanation of report usage

Within the second phase of the interviews, each interview was concluded with a **questionnaire**, which was presented and explained to the interview partners. The interview partners filled out the questionnaire either directly after the presentation and interview or, if prevented by their schedules, afterward at convenience, sent back electronically. The questionnaires consisted of several open as well as closed questions (five-step Likert scales, from 1 “completely agree” to 5 “completely disagree”). The questionnaire and detailed results are presented in Appendix A4.6. The questionnaire contains question items grouped in the following sections:

- Descriptive question items regarding interviewee and company background
- Section A: Process tailoring challenges and their significance
- Section B: Expected benefits of the tailoring methodology, focusing on TSM analysis

Results and interpretation

The results from the evaluation questionnaires indicated that the **challenges**, which are subsequently addressed by the developed tailoring methodology, are regarded as relevant by the interview partners (Figure 8-7, left, Likert-items).



ID	Question item - Challenges
5	Structuring the procedure for executing process tailoring poses a particular challenge.
6	The internal coordination/communication between involved stakeholders poses a particular challenge.
7	The identification of dependencies between stakeholders regarding the tailoring procedure and the associated communication needs poses a particular challenge.
8	The complexity of the tailoring procedure poses a particular challenge. Complexity includes the number of elements to be considered and their dependencies.
9	Estimating the effect of an individual tailoring rule/decision on the process poses a particular challenge

ID	Question item – Expected benefit
11	The individual metrics (Cr, CB, SBF) can indicate inconsistencies in process modeling during an early phase of tailoring implementation.
12	Using the analysis of internal communication needs regarding the tailoring procedure, adequate workshop groups can be derived.
13	The individual metrics (Criticality, Centrality, Snowball Factor) aid in structuring and prioritizing tailoring rules and process activities.
14	The individual reports aid in making the complex tailoring procedure more manageable and clear/transparent.
15	The individual reports support and facilitate internal communication regarding the tailoring process.
16	The individual metrics (Criticality, Centrality, Snowball Factor) within a cluster (workshop) support in deriving a possible agenda.
17	Using the individual reports, tailoring workshop participants can prepare for a tailoring workshop in a targeted manner (important rules, activities, and interfaces).
18	The individual visualizations are designed in a helpful and understandable way.
20	The information required for a structured execution of tailoring is present [within in the reports]

Figure 8-7: Rating of process tailoring challenges and expected analysis framework benefits

The interview partners see a general need for support to structure the tailoring activity (Q 5). The structural complexity involved in process tailoring itself is seen as particularly challenging (Q 8). Furthermore, coordinating the tailoring activity for a particular project and the necessary communication is seen as challenging (Q 6), as is assessing the impact individual tailoring rules or decisions have on the process (Q 9). These challenges are closely followed by the assessment of stakeholder dependencies (Q 7), which are however closely associated with coordinating the communication during tailoring.

The second part of the questionnaire addressed the **expected benefits** from the tailoring methodology, in particular, the presented analysis approach and its deliverables in the form of reports (Figure 8-7, right). Overall, the presented and discussed aspects of the design approach have been evaluated as positive, with the tailoring reports generally containing the information required to execute process tailoring in a structured manner (Q 20). The most positively rated aspect was the prioritization and structuring of PTRs and process activities using the presented structural metrics (Q 13). This facilitates the assessment of the PTRs' impact on the process (cf. Challenges above) and also enables the derivation of efficient workshop agendas, by ranking PTRs according to the criticality of their impacts and thus the need for discussion regarding each PTR (Q 16). This aspect is closely followed by the computational derivation of workshop groups (Q 12). Still positively rated by the interviewees were the use of node-level stakeholder reports to prepare and train individual stakeholders (Q 17), the function of the reports to support communication (Q 15) and their potential to make the overall complexity of the tailoring process more manageable and transparent (Q 14). The individual visualizations require advanced knowledge regarding structural metrics and are not intuitive (Q 18), with the results indicating different opinions regarding this question item.

The **limitations** regarding the expected benefits can be attributed to the format of the presented reports. They represent prototypes and can benefit from some redesign in order to increase their usability. This could, for example, be achieved through the development of interactive reports, realized for example through web-based technologies. However, as none of the aspects were rated neutral or negative, the provision of the reports would still represent an improvement over the current state. Lastly, the individual questions have been evaluated differently by the interviewees in regard to their tailoring experience. The average response of the presented tailoring reports by interview partners without previous tailoring experience (N = 4) was 2.5, while individuals with tailoring experience (N = 4) evaluated them as slightly more positive (2.0). Therefore, individuals with previous tailoring experience seemingly found them more helpful. This may be traced back to their first-hand experience with the associated challenges.

Besides these quantitative insights, the discussion with the respective interview partners also provided qualitative feedback summarized in Table 8-5 (Qs 10, 19, 21, 22). While the interview partners confirmed its overall benefit and applicability, the qualitative feedback focused more on the identification of current limitations and potential for improvement.

To summarize, the approach regarding the metric-based TSM analysis and generation of structural reports has the potential to support workshop-based process tailoring by providing a basis for decision-making. However, since no prolonged application of this aspect of the support in industry was possible, no further statements can be made regarding actual long-term effects.

Table 8-5: Qualitative feedback from interview sessions

Strengths	The approach offers a concrete guideline for supporting and implementing process tailoring.
	All involved stakeholders and their dependencies can be captured by using the approach.
	It provides a quantitative basis for discussion and making of individual tailoring decisions.
	It enables individuals to navigate within the complex process network and increases their decision-making ability.
Weaknesses and limitations	Using the reports requires basic knowledge and expertise, creating additional training effort.
	The applicability of the tailoring support depends on the size, respectively duration of a project. With smaller projects, the effort-benefit relation deteriorates.
	Stakeholder clustering is only beneficial for projects with a certain number of stakeholders.
	Interpretation of the results requires explanation; visualizations are not self-explanatory.
	The approach requires the availability of data to a certain level of detail.
	The approach is complex.

8.5 Summative discussion of results and research approach

To summarize the evaluation, the tailoring methodology is reflected against the requirements posed in section 3.3 by qualitatively assessing their fulfillment. After this reflection and a general discussion of the tailoring methodology, the applied research procedure is reflected, discussing strengths as well as limitations of the chosen approach.

8.5.1 Discussion of the developed tailoring methodology

In order to summarize the evaluation, the developed tailoring methodology is first summarily evaluated by qualitatively reflecting it in Table 8-6 along the proposed requirements (section 3.3) based on the results and experiences gained from all evaluation case studies. The requirements are structured according to the principal constituent elements of the tailoring methodology: General properties (G), procedure (P), knowledge documentation (D), structural analysis (A), and operationalization (O).

Overall, the tailoring methodology can be considered suitable for **project-level tailoring**, where the number of elements and dependencies, and thus the complexity to be considered is high, and tailoring decisions impact a larger number of stakeholders within different departments at different points within the PDP.

As specified per the objective and requirement, the approach focuses on **reductive tailoring**, which is realized by modeling the RPM and reductive tailoring operations. This approach has been generally shown to be relevant for as well as applicable in practice. The applicability, in general, is not limited to particular industries or products (cf. Table 8-1). However, the approach benefits from a mature RPM and process understanding, and companies with more extensive processes would arguably benefit more. Furthermore, a certain amount of commonality between projects is required, excluding environments with highly variant project characteristics, which cannot be expressed by the presented context modeling approach.

Table 8-6: Qualitative summative assessment of requirements fulfillment of the developed tailoring methodology

ID	Requirement	Assessment
G1	Reductive tailoring	Metamodel supports the formulation of reductive tailoring operations. An application is possible on different process hierarchies
G2	Broad applicability	Applicability is shown in different contexts (case studies).
G3	Complexity-focus	Approach is shown to be able to support tailoring of complex PDPs and corresponding RPMs through integration of structural analysis.
G4	Low implementation threshold	Approach is scalable and can be used even with limited preparation. Utilized software is mature and commercially available. The approach does not require adaptation of or integration into existing process management systems.
P1	Structure	Phase structure includes all required activities to support the introduction of workshop-based process tailoring.
P2	Adaptability	Approach is adaptable through purposeful iterations, selection of acquisition methods, and introduction of "pause"-points (cf. section 7.1.2).
P3	Activity support	Procedure contains guidelines, methods, and tool support for each phase.
P4	Review and improvement	Procedure can be carried out iteratively in order to review, update, and maintain tailoring knowledge. Tailoring workshops support generation of new knowledge.
D1	Rule- and model-based	Metamodel provides constructs to model tailoring rules as graph patterns, as well as to capture the process context.
D2	Adaptability	Base metamodel provides capabilities for extension and adaptation and can capture different hierarchical levels for process and organization.
D3	Integrated knowledge basis	The TSM provides a central repository for derivation of tailoring rules and analysis results, e.g. indirect dependencies and calculated metrics.
D4	Compatibility with analysis	A graph-based approach has been selected to ensure compatibility with structural analysis via graph rewriting
D5	Process dependencies	As identified from empirical studies, dependencies between activities, as well as between stakeholders and activities are included in the metamodel. Further, analytical dependencies are calculated.
A1	Input information	Analysis uses structural information already included in the RPM, as well as information added from the information acquisition.
A2	Generation and provision	Results obtained by structural analysis are provided via stakeholder-specific reports, including appropriate visualizations (e.g. stakeholder histogram).
A3	Analysis methods	Structural metrics have been selected and adapted to the objective of supporting process tailoring. Matrix-based clustering is applied to derive workshop groups
A4	Automation	Analyses can be automated via graph-rewriting
A5	Flexibility	Software demonstrator is adapted to the presented base metamodel; analysis can be adapted to different input data. Robust calculation of metrics
O1	Stakeholder integration	Analysis framework allows identification of relevant tailoring stakeholders, and workshop-concept allows integration of relevant stakeholders in different groups
O2	Communication support	Workshops facilitate direct communication regarding common tailoring concerns. Structural analysis facilitates identification of relevant communication partners

Through its integrated analysis component, the approach aids the handling of structurally **complex** processes during tailoring. Further complexity management aspects are integrated as well, such as the “divide et impera” approach during preparation, by defining appropriate system boundaries and relegating information acquisition to corresponding experts.

The approach presents a **low threshold** for implementation compared to existing tailoring approaches, as no particular software systems (e.g. process configurators) are required. Tailoring workshops can be set up relatively quickly and with limited resources (cf. E.1). The software used for analysis is mature and commercially available.

Procedure

The phase structure of the procedure has been synthesized on theoretical grounds, by comparing existing tailoring approaches and extending these with the analysis derived from structural complexity management in combination with the workshop-based tailoring approach (section 5.2). The procedure provides a vehicle to enable the implementation of workshop-based tailoring and has been proven to be applicable in practice via the conducted case studies. As evaluated in case study A.3, the individual steps of the procedure are understandable, but their distinction can be difficult in practice, necessitating purposeful iterations in particular when the RPM is not mature.

The procedure does not just address tailoring itself but also the preparation of the RPM, which has been seen as necessary in practice (C.1, F.1), to increase its tailorability by deriving context-induced, necessary alterations in order to detail the RPM or add new elements. During F.1, the approach was used to accompany the development of an RPM for a development sub-department, similarly to its application in E.1.

The developed procedure is adaptable to different situations, such as different degrees of process maturity, (mature RPM vs. accompanying its design), or different company/project sizes. The adaptation scenarios in section 7.1.2 have been derived empirically from case studies (e.g. C, E.1, and A.3). The adaptability of the procedure is further highlighted by its capability to incorporate different methods for information acquisition, depending on the data available in a particular application case and the intended information to be generated.

Information acquisition methods

In order to support information acquisition, first, a framework has been derived based on method categories and the intended information to be acquired (cf. section 5.2). Concrete **acquisition methods** have subsequently been defined due to needs in the individual case studies and collated into a catalog of methods. This catalog has not been evaluated explicitly. The specific methods are suitable to gain the desired information within the respective case studies. From observation and comparison of the case studies can be inferred that the combination of explicit and implicit sources provides the highest benefit, with explicit sources best used to prepare acquisition interviews.

The **information acquisition** and necessary close examination of the process context have been shown to be the most challenging aspect of the methodology, corroborating the importance of adequately documenting the acquired information. In most cases, information is primarily available in implicit form, in particular during the initial application of the methodology. In particular when the RPMs maturity is low, accessing and formalizing this implicit information can prove challenging. Conversely, in case of extensive RPMs, managing the quantity and variety of information related to context factors and process variance can be challenging, requiring a systematic acquisition procedure and adequate information management. However, information acquisition when handling any complex problem “represents a difficult and laborious task,” with severe implications for the result (Maurer, 2017, p. 114). This highlights the strategic nature of process tailoring, which requires long-term planning as well as continuous, cyclic learning through generation, application, validation, and review of tailoring knowledge in parallel to project execution, in order to incrementally build up and maintain tailoring knowledge. The importance of implicit knowledge further corroborates the relevance of stakeholder integration during tailoring as well as the validity of a workshop-based approach. This cyclic approach closely resembles the knowledge spiral as discussed in section 2.2

Metamodel

Similar to the procedure, the metamodel has been initially derived from existing metamodels and modeling approaches (section 5.3). The graph-based approach ensures **compatibility** with the analysis framework. The metamodel is **extendable**, in particular via the incorporation of additional process element and dependency types, and provides element types for each required domain, along with constructs to model tailoring rules. For the organizational structure, the metamodel already provides node types on different levels of detail in order to capture the organizational structures, process roles, and individual persons. Any extension requires the corresponding adaptation and extension of the analysis framework.

The metamodel has been evaluated through the iterative application as well as the final implementation in the analysis framework software demonstrator. Different implementations have been used in case studies in order to evaluate feasibility and applicability, e.g. presentation slides (C.2), spreadsheet software (C.1), and relational databases (D.1; PE-Musch, 2018). While the expressiveness of the modeling language is limited in comparison to some approaches defined in literature, for example in the possible tailoring operations (e.g. Hallerbach et al. (2010)), it was able to address the modeling needs identified during practical applications sufficiently. In general, practitioners preferred a low degree of complexity in the formulation of tailoring rules (C.2, F.1).

The application of the metamodel requires previous knowledge by the applicant and thus is dependent on the level of this knowledge. The absence of a user-friendly tool to adapt the metamodel and create the TSM represents a limitation.

As per objective, the tailoring methodology does not automate tailoring via model transformation. However, as the information required for tailoring automation is already included in the model or can be integrated (e.g. variable selection and execution of tailoring operations), automation through graph rewriting should be feasible in future work.

Tailoring roles

The developed tailoring role model is based on similar role models in literature. The tailoring roles have not been explicitly evaluated within the case studies but indirectly included in the software demonstrator (via report types) and discussed in the evaluation interviews. The overall responsibilities of the roles (cf. Appendix A3.1) indicate that the *tailoring expert*-role could benefit from further decomposition into sub-roles, e.g. a modeling expert. In case of large RPMs, several tailoring experts will be required, with particular expertise regarding different subsections of the PDP, e.g. particular departments.

Tailoring analysis framework

Application of structural analysis in the form of the analysis framework arguably represents the aspect of highest novelty within the developed tailoring methodology. This element of the approach could not be applied as part of an application case study. Instead, it was evaluated separately, using data from case study D.1 and an interview study. The test case based on this data and carried out with the implemented software prototype showed that the analysis is applicable. The implementation of the individual algorithms for metric calculation represented the highest effort but can be reused. The implementation allows to execute the analysis and report generation in an automated manner with minimal effort.

The simple and combined structural metrics used within the analysis framework have been reused from previous work and adapted as necessary. Using metrics has been evaluated positively for supporting the structuring and prioritization of tailoring rules and process activities, for example in order to create workshop agendas.

The primary TSM elements in this function are PTR nodes, which capture the associated complexity-related information, i.e. metrics. However, the analysis results also provide additional information, which can be utilized for “rule-less” tailoring (free discussion during workshops). For example, activity metrics can be used without aggregation onto PTR nodes.

The tailoring reports have been evaluated positively by the interviewed experts, as they can enable decision making regarding tailoring decisions within the scope of complex RPM. However, they were not seen as intuitive and require skills and expertise in understanding the calculated metrics.

While the analysis framework has been evaluated to be applicable as well as beneficial, it only represents the first step. It has served to prove that structural analysis can provide a significant contribution to process tailoring and provides a starting point for further elaboration (cf. section 9.3). Further evaluation should focus on the understandability of individual metrics. Further elaboration of the analysis framework should investigate further information needs of stakeholders, as well as the relevance and suitability of further structural patterns and metrics, particularly regarding “rule-less” tailoring. Future work can also address the derivation of suitable tailoring points from the TSM, i.e. by clustering rules and identifying the first tailoring-affected process element per cluster

Tailoring workshops

The developed tailoring workshop concept has been evaluated as positive in two independent case studies with different boundary conditions. In particular, tailoring workshops can contribute to forming a shared vision among the project team regarding the project-specific process, allow a deeper understanding of respective colleagues’ work, and to define interfaces.

The tailoring workshops primarily address the lack of consideration of social aspects in current process tailoring approaches. While the documentation of tailoring knowledge is essential to increase reuse and thus reduce tailoring efforts, in particular regarding critical and recurring rules, tailoring workshops introduce a human element, enabling to reflect on individual tailoring decisions. Tailoring approaches based on automation can only tailor what has previously been modeled and implemented in the respective tailoring tool. Both template-based, as well as automated tailoring approaches, cannot satisfy all tailoring needs, requiring project stakeholders to fine-tailor the process on a case-basis. Furthermore, through stakeholder integration, the commitment regarding the resulting project-specific process can be expected to be higher, which should be investigated in detail in future work.

As a secondary effect, the documented tailoring knowledge (tailoring rules) this knowledge is regularly applied, discussed, and reflected. New knowledge can be generated within tailoring workshops, as the RPM as well as the process context can be expected to evolve over time, leading to the formulation of new tailoring rules (cf. knowledge spiral section 2.2). In contrast, if instead this knowledge were to be documented and applied automatically, outdated tailoring rules are more difficult to recognize and recognized later, e.g. during projects.

Considerations on effort and benefit of the process tailoring methodology

As stated before, the evaluation did not allow for a long-term evaluation of efforts and benefits associated with the presented tailoring methodology and the continued execution of tailoring workshops. Due to their nature, benefits or return on investment of initiatives related to knowledge management and organizational management are generally difficult to measure (cf. section 2.2). Therefore, this subsection presents **initial considerations** regarding effort and benefit, factors influencing these, and their evolution over time. These considerations demand further work and thus are intended as starting points for future research activities (without claim for completeness). The discussion addresses aspects related to overall effort-benefit ratio, as well as effort per individual project.

Table 8-7 presents an attempt at breaking down the constituents of the overall effort and benefit on project-independent and project-dependent levels.

Table 8-7: Decomposed constituents of overall effort and benefit of tailoring methodology

	Effort	Benefit
Project-independent	• Information acquisition from explicit sources • Information acquisition from implicit sources • Modeling (TSM creation)	• Increase in process knowledge • Increase in process transparency • Increase in process adaptability • Knowledge increase regarding context influences
Project-dependent	• Preparing tailoring workshops • Conducting tailoring workshops • Workshop postprocessing • Preparation of project plan	• Reduction of process errors • Reduction of project cost/schedule risks • Increase in communication • Reduction of communication errors • Reduction of time spent on tailoring workshops • Increased traceability of tailoring decisions

As can be seen, the **overall effort** mostly relates to time (work-hours) spent on information acquisition and modeling, as well as preparation, execution, and postprocessing of tailoring workshops. On the other hand, the **overall benefits** gained by applying the tailoring methodology are difficult to measure, as they are primarily targeted at increasing intangible aspects such as the stage of process knowledge (cf. section 2.2; Bohn, 1994). In terms of project-specific benefits, workshops and the use of analysis results are expected to reduce tailoring errors due to a lack of communication and intransparency due to structural complexity.

As stated in the objective of this thesis, the developed tailoring methodology aims at addressing **high RPM complexity** (Figure 8-8, a), x-axis). For this **target area**, the highest total benefit is expected due to the transparency gained by applying the developed analysis framework in combination with tailoring workshops. Conversely, this represents a considerable baseline acquisition and modeling effort due to the high complexity and size of the PDP RPM involved. The information acquisition effort within this target area is additionally **affected** by the initial stage of knowledge, i.e. the amount, quality, and accessibility of explicit information, for example in the form of RPM maturity or documented historical project plans (Figure 8-8, a), y-axis and b). Ideally, the developed methodology is applied in a situation facing a complex RPM with considerable pre-existing information, thereby reducing the information acquisition effort. In this case, the effort for information acquisition is lower, and the stage of knowledge can be increased faster. In case of unfavorable conditions, additional effort needs to be invested in acquisition from implicit sources (e.g. via interviews), which is arguably more time-intensive than the analysis of explicit information (higher number of people involved is higher, lower expected output quality and quantity of individual interviews due to insufficient preparation).

The effort required for information acquisition can be expected to **decrease** over time with repeated applications of the methodology (reviews, cf. Figure 8-8, b) and c)): The highest investment is required at the initial application of the methodology. Later reviews can build upon initial information and are thus unlikely to require the same amount of information acquisition. Fluctuations are possible due to e.g. (partial) PDP redesign or employee turnover. Conversely, the benefit can be expected to **increase** over time, due to the amount and maturity of knowledge gained, redistribution of knowledge, and the increasing familiarity of tailoring stakeholders with the approach. Furthermore, the project-independent information acquisition efforts can be expected to **shift** from breadth (acquiring the spectrum of relevant context factors) to depth (scrutinizing and further deconstructing acquired context factors) (cf. section 2.2, stages of knowledge stage 5; Bohn, 1994).

The effort invested and benefit gained can be **attributed** to the five phases of the tailoring methodology. They are unevenly distributed (Figure 8-8, d)): As observed during the case studies, information acquisition and modeling require the most effort, by itself delivering moderate benefits in terms of knowledge gained (depending on the a priori state of knowledge, cf. above). The highest benefit can be expected from phase 5, in the application of the gained and analyzed knowledge. The lowest amount of effort is expected for the analysis in phase 4, which can largely be automated after implementation. The tailoring methodology, therefore, requires an upfront effort to realize the benefits gained.

The accrued information acquisition effort is **distributed to individual projects**. Therefore, the methodology pays higher dividends, the higher the number of projects tailored using the methodology. Conversely, each project incurs additional effort for tailoring workshops. While necessary, the effort required for tailoring workshops is expected to decrease over time as well, due to learning effects (e.g. familiarity with tailoring rules, impacts, and communication partners). It also needs to be noted that some of this effort may already occur in a company, but less systematically (i.e. implicitly), depending on the way process tailoring is performed before the introduction of the developed tailoring methodology, and thus does not necessarily constitute additional effort.

On the level of **individual projects**, an additional perspective needs to be considered in the effort-benefit ratio: The **time spent on tailoring workshops vs. the overall project lead time**. This ratio improves with project duration, if time spent on tailoring workshops is reduced, or the output from tailoring workshops is maximized. On the other hand, it implies that for longer projects, more time can be spent on tailoring workshops without negatively affecting the effort/benefit ratio. However, the time to spend on tailoring also depends on factors, such as project risk and uncertainty, novelty, team size (number of workshops), and the maturity/complexity of the RPM segment tailored at a particular tailoring point.

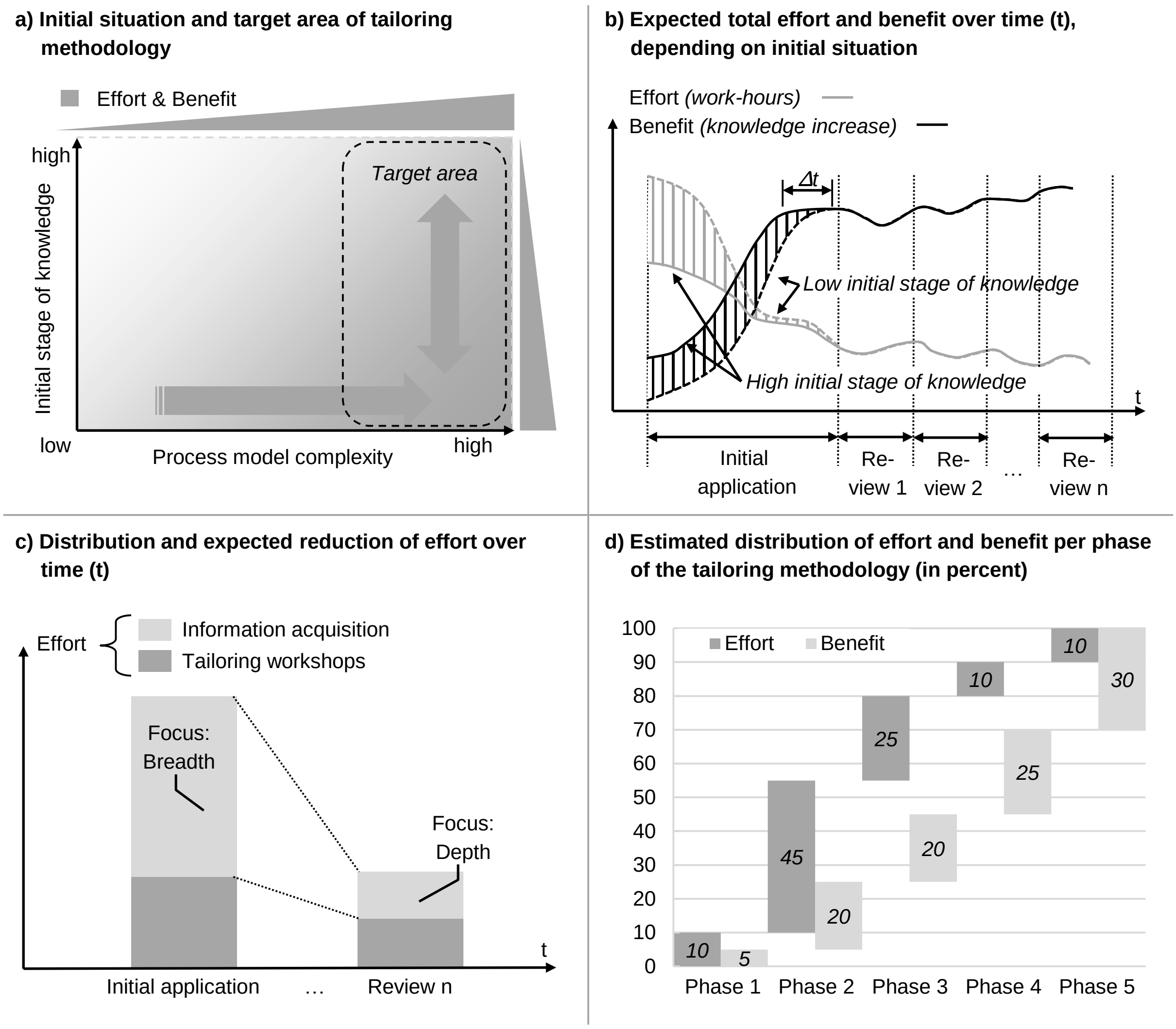


Figure 8-8: Initial considerations on effort and benefits associated with the developed tailoring methodology

As stated previously, neither quantitative nor qualitative long-term assessment of the discussed efforts and benefits was possible within the scope of this thesis. As illustrated above, both depend on a multitude of influencing factors. Hence, future work should aim at addressing this limitation by applying the proposed tailoring methodology in prolonged case studies, observing the discussed learning curves, the overall benefits gained, and the eventual contribution to tailoring and planning quality. This work could eventually result in empirically-derived mathematical models with which to calculate (and subsequently optimize) the tailoring effort required per project (in hours), e.g. as a function of factors such as RPM maturity/size, project lead time etc., and insights into the effects of the gained knowledge on tailoring and project planning. Additionally, such studies could use theories and methods from adaptability valuation in technical systems in order to value the adaptability – e.g. alternative activity modes – gained through process tailoring (e.g. real options theory, cf. review in Schrieverhoff (2014)).

8.5.2 Discussion of the research approach

To conclude the evaluation, the DRM-based approach (Blessing & Chakrabarti, 2009) used to plan this research and laid out in section 1.3.1 is critically reflected along the individual phases, highlighting encountered challenges and measures taken to address them. Furthermore, iterations performed between PS and DS II and their significance for the overall research approach are discussed (Figure 8-9).

Research clarification

The central importance and simultaneous lack of process tailoring in iPD practice were identified early on in the research process, through the experiences made in the project A²TEMP (cf. section 1.3.2). However, this only provided a general research direction, which required further inquiries into underlying issues of process tailoring. A combination of four factors complicated the RC: 1) The **focus of existing approaches** on tailoring automation and corresponding lack of comparison of different approaches, 2) the **lack of awareness and application** of systematic, explicit tailoring in practice, 3) a **lack of previous empirical studies** of requirements and issues regarding process tailoring in practice, and 4) the **complex, socio-technical nature** of process tailoring itself, being subject to many possible influencing factors.

In light of these challenges, an iterative, action-research oriented approach has been chosen, resulting in an initially strong exploratory character within the set research direction. Through the development, application, and reflection of tentative solutions in different case studies, in this case a procedure for the operationalization of process tailoring, new problem areas could be identified, (cf. iterations between PS and DS II below) (cf. Guertler et al., 2017). Therefore, this work underlies an interpretivist paradigm, as social reality is highly subjective and requires exploration to gain interpretive understanding (Collis & Hussey, 2014, p. 44). Qualitative research methods such as the presented case studies are used in order to investigate the subject in its natural environment. Interviews have been used selectively for further inquiry and within case studies, e.g. for evaluation. In the case of this work, this resulted in the insight that structurally complex RPMs pose difficulties during tailoring, as well as the importance of social aspects such as communication-intensiveness and stakeholder integration during the tailoring activity itself, both of which are interrelated.

Descriptive Study I

The DS I is based on the identification and analysis of related work in literature (cf. chapters 2 and 4) as well as on empirical studies investigating the current state of application of process tailoring in practice (chapter 3).

Since the **research areas** related to tailoring are not clearly distinct, the use of terminology in related work is often ambiguous and inconsistent, hindering the identification of relevant sources. An initial, broad investigation of research areas related to process tailoring was performed in order to gain a comprehensive overview. The iterative concretization of both the research objectives together with the tailoring approach allowed to increase the focus of literature reviews and analyses, resulting in more relevant literature (cf. chapter 4). For example, as the analysis of related work showed, the problem areas identified in response to early applications of the tailoring methodology have so far not extensively been addressed. However, the relevance of their absence could only be evaluated once a corresponding empirical foundation had been established.

On the empirical side of the DS I, the challenges mentioned above, combined with the general availability of companies due to organizational and resource constraints, resulted in only a small sample of organizations being available for further consideration within limited timeframes. The problem areas laid out in section 1.1.2 have been encountered in multiple organizations and also represent issues of general prominence within PD and process/project management research (reuse of knowledge, communication-intensiveness, and complexity), this convergence led to the assumption that the problem areas represent valid issues to be addressed.

Although method and data source triangulation has been applied (cf. Collis & Hussey, 2014, p. 71), future research should focus on extending the coverage for further validation, e.g. by performing industry surveys regarding the prevalence of process tailoring in practice, the importance of its social nature, and the challenges posed by structural process complexity.

Prescriptive Study

The development of the tailoring methodology can be differentiated into two stages of the DRM application, as depicted in Figure 8-9.

In the first stage, an initial procedure for tailoring operationalization and initial metamodel for tailoring knowledge documentation were derived from literature, elaborated, and applied in initial case studies (DS II, A.1, B.1, and A.2). This approach omits the software implementation necessary for existing approaches, lowering the threshold for application. The initial applications allowed to introduce and test the basic approach in iPD organizations, which did not apply explicit, systematic process tailoring. The resulting immersion allowed to adapt and concretize the initial research objective further (cf. "pivoting," Guertler et al. (2017)). This resulted in the insight that social aspects and handling of structural process complexity are of more pressing concern to practitioners as, for example, comprehensive tailoring automation. In the second stage, the initial approach was consequently adapted, focusing on the elaboration of the tailoring workshop concept as well as the analysis framework on a conceptual and implementation level.

The tailoring methodology was developed purely from a PD research perspective. Further elaboration of the support should integrate further disciplines, for example, in order to investigate and enhance decision-making within tailoring workshops from a psychological perspective.

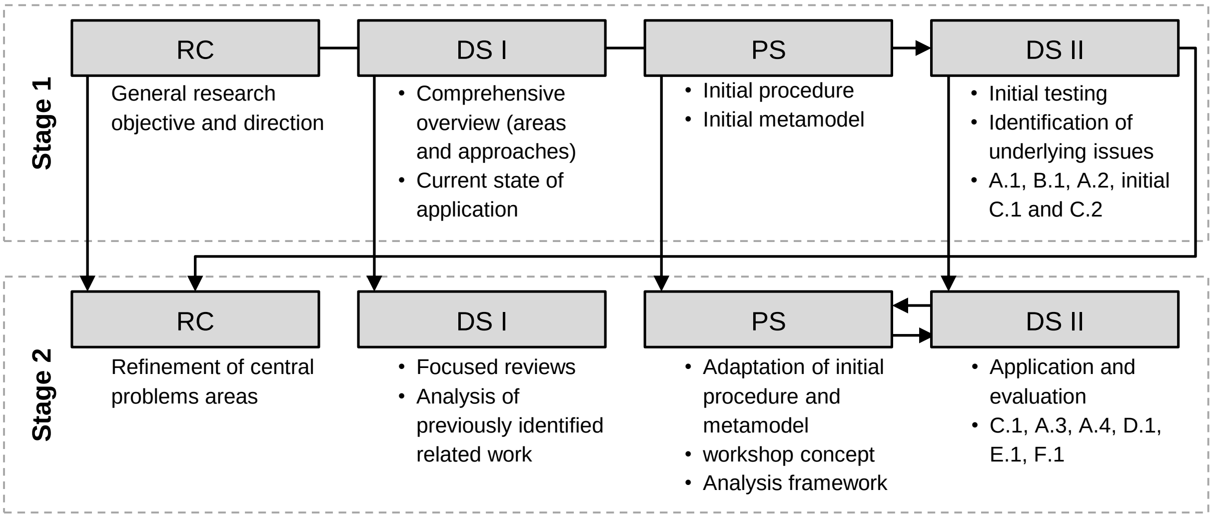


Figure 8-9: Development of tailoring methodology in two stages

Descriptive Study II

The evaluation of the initial, as well as final tailoring methodology, faced several particular challenges: Activities related to the improvement of process and project management were often **not of high priority** in organizations and had to give way to more pressing matters of daily business. Therefore, time windows for conducting case studies were often limited, resulting in multiple case studies that had to be carried out simultaneously. Long-term effects of the tailoring methodology could not be observed, for example on project performance or organizational learning, since the **time for completion** of PD projects was longer than the time available for observation (cf. Blessing & Chakrabarti, 2009, p. 183). Furthermore, **changing priorities and organizational restructuring** hindered the implementation of sequel case studies in some cases, which would have been beneficial for extended application to observe mid- to long-term effects, for example over multiple tailoring workshops (e.g. D.1 and C.1). The time-intensiveness of information acquisition limited the time available to carry out additional activities within the case studies. Case study C.1. had a comparatively significant impact, as it accompanied the research process to a large extent. The concept of tailoring workshops originated from this case study and was subsequently elaborated further.

Immediately observable effects showed that applying the tailoring methodology led to an improved understanding regarding process variability through the formulation of context factors and tailoring rules, which can subsequently be utilized with the tailoring workshops as well as to redesign the PDP RPM to increase tailorability (cf. e.g. B.1, C.1). Experts during case study F.1 furthermore mentioned the implications of the acquired information for project planning, allowing for faster initial scheduling.

Arguably the most challenging aspects of evaluating the tailoring methodology were **confidentiality issues** with industry partners. As the PDP RPMs often include sensitive information, industry partners were reluctant to release documentation in the first place and, if so, only under confidentiality agreements prohibiting publication. Therefore, results related to RPM content had to be abstracted, diminishing the richness of publishable results. Names and recognizable characteristics of involved companies have been omitted categorically.

In order to alleviate these issues and to establish a presence and the industry partner, case studies were conducted via **proxies**, embedding master students within the respective UoA in order to carry out the application. The resulting familiarity of employees with the respective students consequently allowed to acquire more implicit information than would have been possible during selective short-term on-site visits by the author. Furthermore, this approach introduced elements of external evaluation (Stockmann, 2007, pp. 60–61), by applying the support through different, unbiased applicants. The case studies indicate that applicants have achieved comparable, positive results. While it can be argued that the application of the tailoring methodology by company-internal experts could yield superior results, this factor has not been focused within the evaluation and remains a topic of further research.

Due to these facts, **no end-to-end evaluation** of the tailoring methodology could be conducted. While the tailoring workshops have been evaluated positively in two instances with different boundary conditions, tailoring rules have only been used as a supporting aspect within these workshops, still requiring open discussion regarding individual activities. The difference between both modes has not been further investigated. However, since no complete coverage of tailoring rules can be expected, both modes will have to be carried out simultaneously in tailoring workshops nonetheless. Furthermore, the analysis framework could not be used in a real-life application, but the performed interview study indicates its applicability and benefit for such a setting. The collated acquisition methods have not been summarily evaluated; individual methods were only evaluated in terms of their applicability to acquire necessary information within a particular setting. Similarly, the defined tailoring rules have only been implicitly evaluated as part of the analysis framework. In summary, the evaluation has indicated that the developed tailoring methodology can improve conditions for explicit tailoring of structurally complex PDPs in regard to communication and stakeholder integration.

Further evaluation of the developed tailoring methodology should therefore strive for **long-term cooperation** with companies in order to ensure commitment. The general interest in industry experienced throughout this research emphasizes that the endeavor is worthwhile to pursue in future research. On the other hand, since the evaluation was built on a limited number of case studies, the reliability of the approach needs to be tested further.

Based on these limitations, which are partly universal in the area of PD research, as well as the possible existence of further influences unattributed to the developed tailoring methodology, the evaluation findings can overall only be regarded as an initial evaluation and not as a complete proof of general applicability and success (Blessing & Chakrabarti, 2009, p. 209).

9 Conclusion and future work

The concluding chapter summarizes the main research results, followed by a reflection of the contributions to academia and industry. Furthermore, the remaining limitations regarding the tailoring methodology are summarized. From these limitations, avenues of future research are derived, addressing the advancement of the developed tailoring methodology as well as the broader field of process tailoring in interdisciplinary product development.

9.1 Summary of research results

The variety of product development (PD) projects within a companies' project portfolio requires organizations to tailor generic reference process models (RPMs) of their product development process (PDP) to project-specific characteristics. This activity is complicated by several factors, which are elaborated in section 1.1.2. In particular, the structural complexity of RPMs resulting from a multitude of drivers (cf. section 1.1.1) hinders tailoring decision-making. In light of this complexity, tailoring requires communication and collaboration between a variety of project stakeholders. These issues currently only receive limited attention in related work. Therefore, the work presented in this thesis pursued the overall objective of developing an approach to support the implementation and application of collaborative tailoring of structurally complex, interdisciplinary PDP.

In order to address this objective, a **research approach** based on the Design Research Methodology has been defined, with which the final tailoring methodology was developed in two stages. From the overall objective, **research questions** have been derived, which resulted in the development of the tailoring approach within this thesis. Research questions RQ1, RQ2, and RQ3 have been derived directly from the initial overall objective. Based on an **empirical and literature-based analysis** within the overall research approach, several gaps in existing tailoring approaches were identified, which relate to the social nature of process tailoring as well as the lack of consideration of structural complexity within the tailoring activity, resulting in the formulation of research questions RQ4 and RQ5.

The presented tailoring methodology **contributes to achieving the overall objective** by answering the individual derived research questions in the manner indicated above, consequently addressing the problem areas presented in section 1.1.2. Figure 9-1 summarizes the research questions, the corresponding sources and methods, and the resulting constituent elements of the tailoring methodology. The generic **tailoring implementation procedure** derived from literature and combined with the approach of Structural Complexity Management (due to RQ4, cf. section 5.2) contributes to answering RQ 1 (*Which activities are required and how can they be structured?*) by giving an overview of the necessary activities. The **base metamodel** has been developed in response to RQ2 (*How can tailoring-relevant knowledge be documented?*), initially derived from related approaches in the literature, and subsequently adapted to accommodate the analysis-related requirements from RQ4. The individual **supporting methods** within the phases of the tailoring implementation methodology, in particular for information acquisition, have been developed due to RQ3 (*Which methods are* *required for further operative support?).* The **tailoring workshop concept**, which provides a platform for communication and collaboration between project stakeholders, was developed to answer RQ4 (*How can collaboration and communication during tailoring be supported?*). Finally, the metric-based **structural analysis framework**, with which tailoring-relevant structural characteristics of the TSM are quantified and subsequently condensed, visualized, and prepared as stakeholder-specific reports, answers RQ5 (*How can documented tailoring-relevant knowledge be analyzed and prepared?*). A detailed overview of the artifacts produced during the development of the tailoring methodology is given in Appendix A3, Table A-35.

The developed **approach has been successfully evaluated** using a combination of ten partial application case studies with six different industry partners together with a synthetic test case and evaluation interview study focusing on the analysis framework. The different contexts and evaluation methods allowed the evaluation of the methodologies' general applicability and success.

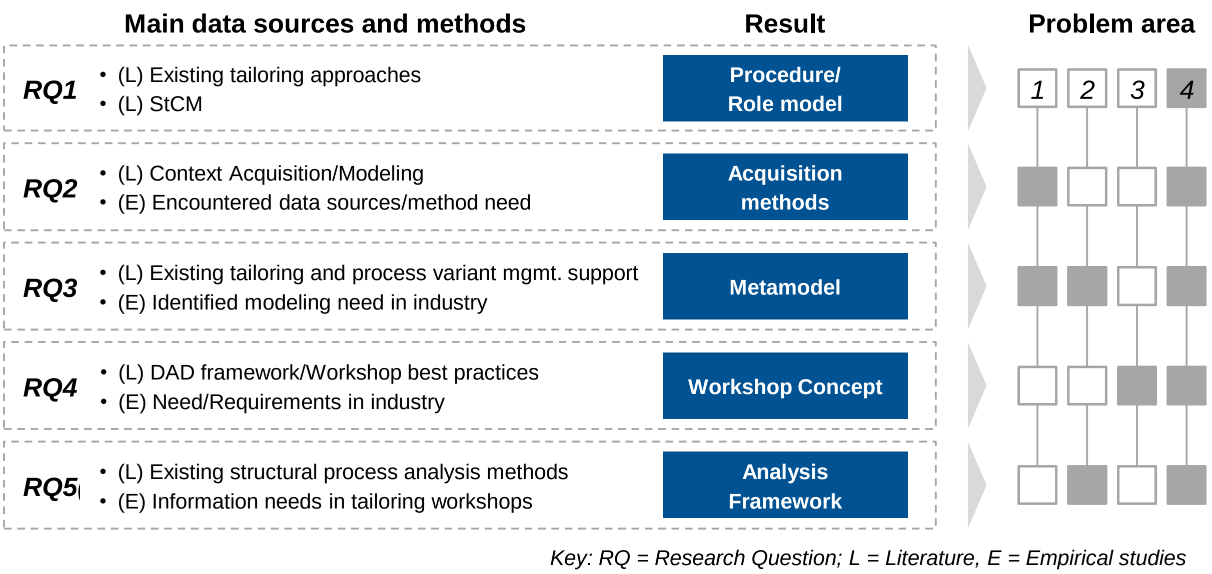


Figure 9-1: Summary of research questions, developed tailoring methodology elements, and addressed problem areas

9.2 Contribution to research and practice

The developed tailoring methodology and achieved insights generated through this work can contribute to handling process variety via tailoring in light of differing project characteristics as well as high structural process complexity. This section presents a reflection on the contributions to the academic body of knowledge as well as the industrial practice.

Academic contribution

The **theoretical foundation** of this work is based on a comprehensive analysis regarding the state of the art of process tailoring as well as adjacent research areas, by identifying characteristic traits and comparing existing approaches in order to identify strengths and limitations.

First, this contributes to an **increased understanding** regarding the current state of the art by structuring the research area, providing an overview, and characterizing different forms of tailoring approaches. Second, it contributes to **transferring** the ideas and concepts from their original software engineering environment to interdisciplinary product development research. Third, the characterization and comparison show several **research gaps** in existing work. These gaps mainly relate to the perceived inability of existing approaches regarding the handling of structurally complex PD processes (PA.2) and the lack of consideration of the social nature of process tailoring (PA.3). The relevance of these gaps could be established due to the **action-research** oriented approach underlying this work, which enabled the identification of these hitherto insufficiently considered aspects in existing tailoring support.

Conversely, existing approaches provide quite **extensive support** in other areas, such as the **documentation** of tailoring knowledge and the subsequent tailoring **automation**, which is the main focus of many existing approaches. While tailoring automation reduces effort and introduces strictness and tailoring governance, it also limits applicable tailoring operations to previously documented[61] knowledge. As empirical research indicates, tailoring operations are often difficult to express completely and accurately, at least initially. Tailoring based on automation via documented information thus limits the possibility to address unique project circumstances and prolongs reaction time for integrating new insights.

These theoretical and empirical insights provided the **starting point** for the development of the tailoring methodology in this thesis and can be **used by other researchers** in developing further tailoring support. The interest in systematic and explicit process tailoring exhibited by the investigated companies further corroborates the importance of process tailoring and associated research activities (e.g. management of process variants).

The **prescriptive methodology** developed within this thesis serves as a vehicle to structure the necessary steps for implementing workshop-based tailoring in practice. Compared to existing approaches, the developed tailoring methodology explicitly represents a **hybrid approach**, combining documented tailoring knowledge via tailoring rules with implicit tailoring knowledge during tailoring workshops. In this manner, the methodology contributes to

[61] cf. also the statement “you can’t tailor what you haven’t modeled” (Kuhrmann, 2014)

organizational learning through regular application, reflection, and documentation of tailoring knowledge (cf. section 2.2, knowledge spiral). The methodology is extendable and can provide a **framework** for the integration of additional methods and analysis routines developed in future work. Two possible extensions are presented in section 7.7, which further leverage the acquired information in additional analyses in order to increase process tailorability. Besides this, the developed methodology can also serve as a **means to carry out further research into process tailoring**, e.g. by investigating the relevance of different context factors in different organizations, as well as mechanisms in decision-making processes during tailoring workshops.

The developed tailoring approach draws from previous work in the area of **structural complexity management** and **structural analysis**. It thereby serves to **corroborate the importance** of this previous work further and simultaneously **extends the field of application** of the developed approaches and underlying theories. In particular, the usefulness of structural metrics for providing a decision-making basis during tailoring could be established and should be explored further.

The iterative application and testing of the developed tailoring methodology has been performed in case studies in different organizations with a broad range of boundary conditions. Therefore, the research contributes to increasing the empirical foundation of process tailoring research regarding the number as well as variety of case studies.

Industrial contribution

The conducted empirical studies corroborate the **importance of considering process tailoring as a distinct activity** during project planning and performing it explicitly and systematically. This work highlights the importance of process tailoring in practice as a **nexus for communication** between different project stakeholders in order to achieve **synchronization and commitment**. As the conducted case studies show, process tailoring is an essential preparatory step for subsequent planning activities and closely connected to aspects such as scheduling and budgeting. The case studies further indicate the **value of the examination of the process application context** and the resulting increased transparency and understanding of project variability, for tailoring as well as the design of RPMs. The developed methodology enforces this examination and supports it by providing a catalog of methods.

The developed tailoring methodology has been shown to be applicable and increase the capability for process tailoring in PD organizations. The methodology is **adaptable** to different boundary conditions. It can be executed iteratively in parallel to the execution of PD projects. The support furthermore has a **comparatively low threshold of implementation**, due to three factors: First, tailoring workshops can be set up relatively easy. Second, the methodology does not require a deep integration in existing process management systems, as the required process data can be imported from existing process management systems and enriched with tailoring-relevant information. Third, the analysis framework can be implemented using commercially available software. The implementation demonstrates its feasibility and the low effort required once set up.

The analysis frameworks' application and evaluation indicate that **structural metrics** can contribute to facilitating the handling of structurally complex RPMs during workshop-based tailoring, increase the quality and traceability of the respective decision-making processes, and support targeted and relevant communication between project stakeholders. The use of structural analysis to support process tailoring can make the associated approaches more accessible and widespread in practice, increasing familiarity due to process tailoring being a regular activity. However, they also showed that while this approach provides a well-founded decision basis, it requires a certain amount of training and is not necessarily self-explanatory, due to the nature of the structural metrics.

9.3 Limitations and future work

Although the overall objective of this work has been shown to be achieved, consequently contributing to extending academic knowledge as well as applicability in practice, several limitations remain. These limitations, pertaining to the developed tailoring methodology as well as the applied research methodology, as discussed in section 8.5, represent opportunities for further research, which are elaborated in this concluding section.

Further evaluation and empirical studies

An essential aspect of advancing the tailoring methodology is its **continued application and evaluation**, in particular in the form of an **end-to-end evaluation** of the methodology within a single industrial case study. **Longitudinal** case studies should be conducted, in order to observe the evolution of the tailoring capabilities of an organization over multiple applications of the tailoring methodology, and workshops in particular. Within such a longitudinal case study, the stated benefits of process tailoring for aspects such as process efficiency and organizational learning, as well as the necessary effort, should be investigated.

Future application case studies should be categorized and investigate **factors influencing the tailoring strategies** defined in different organizations in order to identify differences on organizational (adaptation of the methodology for different organizational characteristics) and project level (different implementation for different projects). Based on this empirical data, the situatedness of the tailoring approach can be increased, enabling the selection of different tailoring strategies within organizations, for example depending on the RPMs structure and tailorability, as well as the extensiveness and depth of tailoring required for different projects.

Relationships between tailoring and other planning activities

The relationships between process tailoring and **subsequent planning activities** should be explored further, in particular scheduling and budgeting. In practice, these activities are closely related; iterations between them are possible but have not been further investigated in this work. For example, scheduling can provide further input for tailoring or require additional tailoring due to constricted schedules.

Furthermore, the relationship between process tailoring and the **management of project risk and value** should be extended in the future. In particular, risk- and value analysis approaches could provide valuable extensions for the tailoring methodology. They could support detailed tailoring to unique, non-recurring circumstances, which has not been covered in this work (cf. tailoring levels, section 2.5.1). Additionally, criteria for **tailoring quality** could be derived from exploring these relationships.

Further extension of methodology and method support

While information acquisition methods have been developed within this work, future work should focus on developing strategies for **more efficient information acquisition**, e.g. based on existing data. As the presented methods focus on the discovery of existing activity variants and project characterization, future work should investigate methods for a more proactive elaboration of activity modes, e.g. based on risk or value analyses (cf. above). Additionally, methods regarding strategic foresight can be investigated in order to facilitate the early anticipation of future project characteristics and activity variants. Combined with the aforementioned increase of situatedness, this would eventually result in a **toolbox of tailoring support methods**, instead of monolithic “one-size-fits-all” tailoring support.

The approach can further be extended in order to integrate **graph rewriting-based tailoring automation**. This would contribute to closing the gap to other tailoring approaches and extend the tailoring methodology to downstream activities, further reducing manual effort. The methodology can be extended even further by integrating simulation of the deployed processes, e.g. using system dynamics, in particular to address rework-related issues (cf. Kasperek, 2016; Lévárdy & Browning, 2009).

While the approach is not directly related to agile project management, it can contribute to an increase in agility in PD environments, which have already established and use RPMs in order to manage the emerging complexity. Therefore, the impact of the approach in organizations which additionally apply **agile approaches** should be further investigated, as initially done in case study E.1.

Metamodel

The **metamodel** has been designed in order to enable the documentation of the most relevant tailoring aspects and enable the subsequent structural analyses. Although the case studies indicated that only a limited expressiveness is required in practice, further research should seek to increase the expressiveness of graph-based modeling of tailoring decisions and increase the applicability through software-implementation of a corresponding modeling tool.

For example, further tailoring operators could be implemented, such as moving activities within the overall activity network. The introduction of **probabilities** for tailoring operators would enable further flexibility in order to capture “fuzziness” (cf. Ittner (2006)), e.g. in case multiple tailoring operations are feasible in response to a particular context value. Element type tailorability could be extended methods, tools, or deliverables, with corresponding analysis routines. Role variability currently is not explicitly addressed but could be derived, e.g. depending on selected activity modes. Also, the metamodel can currently only capture element variability. Variability in dependencies (process sequence) is currently not incorporated. For example, activity modes could be extended by adding mode-specific activity dependencies, which replace the dependencies of the baseline activity. As activity iterations and feedback loops are currently not regarded, in this way, different probabilities and impacts for rework could be added, depending on the particular activity mode (Lévárdy & Browning, 2009, p. 607). While in the base metamodel, generic activity dependencies are modeled, further empirical analyses should investigate whether further tailoring-relevant dependencies exist, which are not yet regarded.

In order to increase the scope of the metamodel, three further avenues of extension are possible: The integration of **management-related attributes**, such as the status of rules, the integration of **strategic attributes** regarding the long-term development of context factors (cf. Bauer, 2016), and the integration of **data from previously tailored process instances** directly into the TSM. While the approach supports handling the structural complexity of PDP RPMs, the issue of managing the complexity of the TSM during its creation and maintenance remains and requires corresponding software support.

Analysis framework and structural metrics

While the organizational domain is currently represented by modeling the defined department and role structure, future work could integrate the acquisition and depiction of **the real communication structure**, based on communication data such as emails (cf. Parraguez, 2015).

The analysis framework has been developed opportunistically, by analyzing previous work regarding process analysis via structural metrics, selecting, and transferring them to the context of process tailoring according to the general information requirements observed in the empirical studies. Future work should conduct a more **detailed analysis of the information needs** for decision-making related to rule-based as well as manual ("rule-less") tailoring, in order to refine the information provision via the selected metrics and visualizations.

Further structural metrics should be tested for their potential to provide information for tailoring, either for supporting tailoring workshops or the strategic management of tailoring knowledge. For example, the *Forerun factor* (Kreimeyer, 2010, p. 348) could be used to identify activities that are dependent on many preceding activities. Also, the **organizational heterogeneity of tailoring rules** could be analyzed, e.g. by calculating the organizational distance between affected stakeholders or measuring compositional diversity (cf. section 2.4.3). Relevant activity patterns and their significance for tailoring should be explored, such as **coupled activities** (Browning, 2001, p. 297) and **iterations** (Wynn & Eckert, 2017), which are currently not explicitly addressed[62] (cf. "metamodel" above). As the analysis framework currently uses project-independent tailoring knowledge, the analysis phase could consequently be split into two phases: Analysis of the project-independent TSM for decision-making and subsequent analysis of the resulting deployed process to resolve potentially remaining **process inconsistencies** and analyze the specific deployed process (cf. addition of simulation to methodology above).

The **reporting system** can be extended, e.g. by providing a network-level overview of activities, including a portfolio comparing their significance and their probability for tailoring (via the number of impacting PTRs). A dedicated overview of clusters can further facilitate the harmonization of tailoring decisions by listing PTR overlaps between clusters.

The **clustering** of workshop groups has currently been implemented using basic clustering algorithms and provides potential for further refinement, e.g. to identify the optimal cluster size based on the number of tailoring stakeholders and the analysis of overlapping clusters.

[62] A characteristic shared with other tailoring approaches identified in related work.

Since the acquisition of information requires considerable effort, ways should be investigated to **leverage this data further**. The initial extensions of the tailoring methodology in section 7.7 provide starting points: Process variants and process modularization represent two ways to increase RPM tailorability further and reduce tailoring effort. The context data could be further used for context-dependent identification and analysis of process weaknesses or best practices (Hollauer et al., 2018f).

Further **implementation** of the analysis framework is required to increase its applicability, e.g. by using web-based technologies instead of static reports. Simultaneously, the interactivity could be increased in this manner, allowing to navigate and configure visualizations.

Tailoring workshops

Based on the developed tailoring workshop concept, multiple successive instances of tailoring workshops should be observed within longitudinal case studies (cf. further evaluation above), within a single (multiple tailoring points) as well as over multiple projects. In particular, the benefits of the developed tailoring reports and the individual metrics and visualizations therein should be further analyzed regarding their impact.

From such observations, factors influencing group and individual decision-making processes could be derived. Due to the social nature of the tailoring workshops, such analyses would require interdisciplinary cooperation, involving researchers from engineering, psychology, and sociology in order to further deepen the investigation of the social aspects of process tailoring.

To summarize, the work performed in this thesis resulted in a methodology for collaborative, workshop-based process tailoring which specifically addresses the social nature of tailoring and provides means to externalize and analyze expert knowledge in order to create a basis for collaborative decision making regarding structurally complex reference process models in interdisciplinary product development.

The multi-layered and diverse nature of process tailoring, in general, provides a multitude of future research opportunities, illustrating the vitality and relevance of the research area for future work.

10 Bibliography

Ågerfalk, P. J. & Fitzgerald, B. (2006). Exploring the Concept of Method Rationale: A conceptual tool to understand method tailoring. In: Erickson, J. & Siau, K. (Eds.) *Advanced Topics in Database Research, Volume 5:* IGI Global, pp. 63–78. DOI: 10.4018/978-1-59140-935-9.ch004.

Aguilar-Savén, R. S. (2004). Business process modelling: Review and framework. In: *International Journal of Production Economics, 90*(2), pp. 129–149. DOI: 10.1016/S0925-5273(03)00102-6.

Ahmed, S. (2005). Encouraging reuse of design knowledge: A method to index knowledge. In: *Design Studies, 26*(6), pp. 565–592. DOI: 10.1016/j.destud.2005.02.005.

Akbar, R.; Hassan, M. F. & Abdullah, A. (2011). Review of Prominent Work on Agile Processes Software Process Improvement and Process Tailoring Practices. In: Zain, J.; Wan Mohd, W. & El-Qawasmeh, E. (Eds.) *Software Engineering and Computer Systems (ICSECS 2011)*, Kuantan, Pahang, Malaysia, pp. 571–585. DOI: 10.1007/978-3-642-22203-0_49.

Akbar, R.; Hassan, M. F. & Abdullah, A. (2012). A framework of software process tailoring for small and medium size IT companies. In: *International Conference on Computer & Information Science (ICCIS), 2012*. Piscataway, NJ: IEEE, pp. 914–918. DOI: 10.1109/ICCISci.2012.6297156.

Alavi, M. & Leidner, D. E. (2001). Review: Knowledge Management and Knowledge Management Systems: Conceptual Foundations and Research Issues. In: *MIS Quarterly, 25*(1), pp. 107–136.

Albers, A. & Braun, A. (2011). A generalised framework to compass and to support complex product engineering processes. In: *IJPD, 15*(1/2/3), p. 6. DOI: 10.1504/IJPD.2011.043659.

Amigo, C. R.; Iritani, D. R.; Rozenfeld, H. & Ometto, A. (2013). Product Development Process Modeling: State of the Art and Classification. In: Abramovici, M. & Stark, R. (Eds.) *Smart product engineering. Proceedings of the 23rd CIRP Design Conference, Bochum, Germany, March 11th - 13th, 2013*, pp. 169–179. DOI: 10.1007/978-3-642-30817-8_17.

Andreasen, M.; Hansen, C. & Cash, P. (2015). *Conceptual design: Interpretations, mindset and models*. Cham: Springer. DOI: 10.1007/978-3-319-19839-2.

Antunes, B.; Correia, F. & Gomes, P. (2010). Context Capture in Software Development. In: *3rd Artificial Intelligence Techniques in Software Engineering Workshop,* Larnaca, Cyprus.

Armbrust, O.; Katahira, M.; Miyamoto, Y.; Münch, J.; Nakao, H. & Ocampo, A. (2009). Scoping software process lines. In: *Softw. Process: Improve. Pract., 14*(3), pp. 181–197. DOI: 10.1002/spip.412.

Asadi, M.; Esfahani, N. & Ramsin, R. (2010). Process Patterns for MDA-Based Software Development. In: Ormandjieva, O. (Ed.) *Eighth ACIS International Conference on Software Engineering Research, Management and Applications (SERA), 2010*. Piscataway, NJ: IEEE, pp. 190–197. DOI: 10.1109/SERA.2010.32.

Ashby, W. (1956). *An introduction to cybernetics*. London, UK: Chapman and Hall Ltd.

Austin, S.; Steele, J.; Macmillan, S.; Kirby, P. & Spence, R. (2001). Mapping the conceptual design activity of interdisciplinary teams. In: *Design Studies, 22*(3), pp. 211–232. DOI: 10.1016/S0142-694X(00)00026-0.

Austin, S. A.; Baldwin, A.; Li, B. & Waskett, P. (2000). Integrating Design in the Project Process. In: *Proceedings of the ICE: Civil Engineering, 138*(4), pp. 177–182.

Avnet, M. S. (2009). *Socio-cognitive analysis of engineering systems design: shared knowledge, process, and product*. PhD thesis. Boston, USA: Engineering Systems Division, Massachusetts Institute of Technology.

Backhaus, K.; Erichson, B.; Plinke, W. & Weiber, R. (2016). *Multivariate Analysemethoden: Eine anwendungsorientierte Einführung*. Berlin, Heidelberg: Springer Gabler. DOI: 10.1007/978-3-662-46076-4.

Badke-Schaub, P. & Frankenberger, E. (2004). *Management kritischer Situationen: Produktentwicklung erfolgreich gestalten*. Berlin [u.a.]: Springer.

Barnes, S. (2002). *Knowledge management systems: Theory and practice*. London: Thomson Learning.

Barreto, A.; Murta, L. G. & da Rocha, Ana Regina Cavalcanti (2011). Software Process Definition: a Reuse-based Approach. In: *J. UCS, 17*(13), pp. 1765–1799.

Bartolomei, J. E. (2007). *Qualitative knowledge construction for engineering systems: Extending the design structure meatrix methodology in scope and procedure*. PhD Thesis. Boston, MA, USA: Engineering Systems Division, Massachusetts Institute of Technology.

Basili, V. R.; Caldiera, G. & Rombach, H. D. (1994). Goal Question Metric Paradigm. In: Marciniak, J. (Ed.) *Encyclopedia of software engineering*. New York, NY: Wiley, pp. 528–532.

Batallas, D. A. & Yassine, A. A. (2006). Information Leaders in Product Development Organizational Networks: Social Network Analysis of the Design Structure Matrix. In: *IEEE Trans. Eng. Manage., 53*(4), pp. 570–582. DOI: 10.1109/TEM.2006.883706.

Bauer, W. (2016). *Planung und Entwicklung änderungsrobuster Plattformarchitekturen*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Baumberger, G. (2007). *Methoden zur kundenspezifischen Produktdefinition bei individualisierten Produkten*. München: Verl. Dr. Hut.

Becerril, L.; Stahlmann, Jan-Timo, Beck, Jesco & Lindemann, U. (2018). Usability of processes in engineering design. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.;

Škec, S. & Kokkolaras, M. (Eds.) *Proceedings of the 21st International Conference on Engineering Design (ICED17) Vol 2: Design processes, Design organisation and management*. Red Hook, NY: Curran Associates Inc, pp. 249–258.

Beer, S. (1959). *Cybernetics and management*. London: Wiley.

Beer, S. (1995). *Diagnosing the system for organizations*. Chichester: Wiley.

Beermann, S.; Schubach, M. & Augart, E. (2015). *Workshops: Vorbereiten, durchführen, nachbereiten*. Freiburg: Haufe-Lexware GmbH & Co. KG.

Behncke, F. H. (2017). *Beschaffungsgerechte Produktentwicklung: Abstimmung von Produktarchitektur und Liefernetzwerk in frühen Phasen der Entwicklung*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Bender, B. & Gericke, K. (2016). Entwicklungsprozesse. In: Lindemann, U. (Ed.) *Handbuch Produktentwicklung*. München: Hanser, pp. 401–424.

Bichlmaier, C.; Lindemann, U. & Grunwald, S., Reinhart, G. (1999). PMM: Process Module Methodology for Integrated Design and Assembly Planning. In: Sturges, B. (Ed.) *4th Design for Manufacturing Conference. [September 12 - 15, 1999, Las Vegas, Nevada, USA], Bd.* 4, Las Vegas, Nevada, USA.

Biedermann, W. (2014). *A minimal set of network metrics for analysing mechatronic product concepts*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Birkhofer, H.; Jänsch, J. & Kloberdanz, H. (2005). An extensive and detailed view of the application of design methods and methodology in industry. In: Samuel, A. (Ed.) *Engineering design and the global economy. 15th International Conference on Engineering Design - ICED 05, 15 - 18 August 2005, Melbourne, Australia,* Melbourne, AUS, pp. 267–277.

Blessing, L. & Chakrabarti, A. (2009). *DRM, a Design Research Methodology*. Guildford, Surrey: Springer London.

Boardman, J. & Sauser, B. (2006). System of Systems - the meaning of of. In: *IEEE/SMC International Conference on System of Systems Engineering, 2006,* Los Angeles, California, USA, pp. 118–123. DOI: 10.1109/SYSOSE.2006.1652284.

Boehm, B. (2002). Get ready for agile methods, with care. In: *Computer*, *35*(1), pp. 64–69. DOI: 10.1109/2.976920.

Bohn, R. (1994). Measuring and Managing Technological Knowledge. In: *Sloan management review, 36*(1), pp. 61–73.

Bosch-Rekveldt, M.; Jongkind, Y.; Mooi, H.; Bakker, H. & Verbraeck, A. (2011). Grasping project complexity in large engineering projects: The TOE (Technical, Organizational and Environmental) framework. In: *JPMA*, *29*(6), pp. 728–739. DOI: 10.1016/j.ijproman.2010.07.008.

Bradley, J. A. & Yassine, A. A. (2006). On the Use of Network Analysis in Product Development Teams. In: *ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference,* Philadelphia, Pennsylvania, USA, pp. 231–242. DOI: 10.1115/DETC2006-99443.

Braha, D. (2016). The Complexity of Design Networks: Structure and Dynamics. In: Cash, P.; Stanković, T. & Štorga, M. (Eds.) *Experimental Design Research*. Cham: Springer International Publishing, pp. 129–151. DOI: 10.1007/978-3-319-33781-4_8.

Braha, D. & Bar-Yam, Y. (2007). The Statistical Mechanics of Complex Product Development: Empirical and Analytical Results. In: *Management Science*, *53*(7), pp. 1127–1145. DOI: 10.1287/mnsc.1060.0617.

Brandes, U. (2001). A faster algorithm for betweenness centrality*. In: *The Journal of Mathematical Sociology, 25*(2), pp. 163–177. DOI: 10.1080/0022250X.2001.9990249.

Braun, T. E. (2005). *Methodische Unterstützung der strategischen Produktplanung in einem mittelständisch geprägten Umfeld*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich.

Brinkkemper, S.; Saeki, M. & Harmsen, F. (1999). Meta-modelling based assembly techniques for situational method engineering. In: *Information Systems*, *24*(3), pp. 209–228. DOI: 10.1016/S0306-4379(99)00016-2.

Brosch, M. & Krause, D. (2010). Beherrschung der durch Produktvielfalt induzierten Prozessvielfalt. In: Krause, D.; Paetzold, K. & Wartzack, S. (Eds.) *DFX2010: Proceedings of the 21st Symposium on Design for X,* Buchholz/Hamburg, Germany.

Browning, T. (2018). Building Models of Product Development Processes: An Integrative Approach to Managing Organizational Knowledge. In: *Systems Engineering*.

Browning, T. R. (2001). Applying the design structure matrix to system decomposition and integration problems: A review and new directions. In: *IEEE Trans. Eng. Manage., 48*(3), pp. 292–306. DOI: 10.1109/17.946528.

Browning, T. R. (2002). Process integration using the design structure matrix. In: *Syst. Engin., 5*(3), pp. 180–193. DOI: 10.1002/sys.10023.

Browning, T. R. (2009). The many views of a process: Toward a process architecture framework for product development processes. In: *Syst. Engin., 12*(1), pp. 69–90. DOI: 10.1002/sys.20109.

Browning, T. R. (2010). On the alignment of the purposes and views of process models in project management. In: *Journal of Operations Management, 28*(4), pp. 316–332. DOI: 10.1016/j.jom.2009.11.007.

Browning, T. R. (2014a). A Quantitative Framework for Managing Project Value, Risk, and Opportunity. In: *IEEE Trans. Eng. Manage., 61*(4), pp. 583–598. DOI: 10.1109/TEM.2014.2326986.

Browning, T. R. (2014b). Managing complex project process models with a process architecture framework. In: *International Journal of Project Management, 32*(2), pp. 229–241. DOI: 10.1016/j.ijproman.2013.05.008.

Browning, T. R. (2014c). Program Agility and Adaptability. In: *INSIGHT, 17*(2), pp. 18–22. DOI: 10.1002/inst.201417218.

Browning, T. R. (2016). Design Structure Matrix Extensions and Innovations: A Survey and New Opportunities. In: *IEEE Trans. Eng. Manage., 63*(1), pp. 27–52. DOI: 10.1109/TEM.2015.2491283.

Browning, T. R.; Fricke, E. & Negele, H. (2006). Key concepts in modeling product development processes. In: *Syst. Engin., 9*(2), pp. 104–128. DOI: 10.1002/sys.20047.

Browning, T. R. & Ramasesh, R. V. (2007). A Survey of Activity Network-Based Process Models for Managing Product Development Projects. In: *Production and Operations Management, 16*(2), pp. 217–240. DOI: 10.1111/j.1937-5956.2007.tb00177.x.

Browning, T. R. & Yassine, A. A. (2016). Managing a Portfolio of Product Development Projects under Resource Constraints. In: *Decision Sciences, 47*(2), pp. 333–372. DOI: 10.1111/deci.12172.

Buede, D. (2009). *The Engineering Design of Systems*. Hoboken, NJ, USA: John Wiley & Sons, Inc. DOI: 10.1002/9780470413791.

Bustard, D. W. & Keenan, F. (2005). Strategies for systems analysis: Groundwork for process tailoring. In:, pp. 357–362.

Cameron, J. (2002). Configurable development processes. In: *Commun. ACM, 45*(3), pp. 72–77. DOI: 10.1145/504729.504731.

Cardoso, J. (2005). How to Measure the Control-flow Complexity of Web Processes and Workflows. In: Fischer, L. (Ed.) *Workflow Handbook 2005*.

Cardoso, J. (2006). Approaches to Compute Workflow Complexity. In: Leymann, F.; Reisig, W.; Thatte, S. & van der Aalst, W. (Eds.) *The Role of Business Processes in Service Oriented Architectures*.

Cesare, S. de; Patel, C.; Iacovelli, N.; Merico, A. & Lycett, M. (2008). Tailoring Software Development Methodologies in Practice: A Case Study. In: *Journal of Computing and Information Technology, 16*(3), pp. 157–168. DOI: 10.2498/cit.1000898.

Choi, S.; Kim, S. & Kim, J. (2016). A Commonality & Variability Analysis Method for Process Tailoring. In: *Mechanical Engineering 2016*, pp. 65–69. DOI: 10.14257/astl.2016.129.13.

Choo, C. W. (1996). The knowing organization: How organizations use information to construct meaning, create knowledge and make decisions. In: *International Journal of Information Management, 16*(5), pp. 329–340. DOI: 10.1016/0268-4012(96)00020-5.

Chrissis, M.; Konrad, M. & Shrum, S. (2007). *CMMI: Guidelines for process integration and product improvement*. Upper Saddle River, NJ: Addison-Wesley.

Chroust, G. (1992). *Modelle der Software-Entwicklung*. München: Oldenbourg.

Chroust, G. (2000). Software Process Models: Structure and Challenges. In: Feng, Y.; Notkin, D. & Gaudel, M. (Eds.) *Software :Theory and Practice - Proceedings, IFIP Congress 2000*, pp. 279–286.

Clarke, P. & O'Connor, R. V. (2012). The situational factors that affect the software development process: Towards a comprehensive reference framework. In: *Advances in functional size measurement and effort estimation - Extended best papers, 54*(5), pp. 433–447. DOI: 10.1016/j.infsof.2011.12.003.

Clarkson, J. & Eckert, C. (2005). *Design process improvement: A review of current practice*. London [U.K.]: Springer.

Clarkson, P. J. & Hamilton, J. R. (2000). 'Signposting', A Parameter-driven Task-based Model of the Design Process. In: *Research in Engineering Design, 12*(1), pp. 18–38. DOI: 10.1007/s001630050021.

Collins, S. T.; Bradley, J. A. & Yassine, A. A. (2010). Analyzing Product Development Task Networks to Examine Organizational Change. In: *IEEE Trans. Eng. Manage., 57*(3), pp. 513–525. DOI: 10.1109/TEM.2009.2033047.

Collins, S. T.; Yassine, A. A. & Borgatti, S. P. (2009). Evaluating product development systems using network analysis. In: *Syst. Engin., 12*(1), pp. 55–68. DOI: 10.1002/sys.20108.

Collis, J. & Hussey, R. (2014). *Business research: A practical guide for undergraduate & postgraduate students*. Basingstoke: Palgrave Macmillan.

Conant, R. C. & Ashby, R. W. (1970). Every good regulator of a system must be a model of that system. In: *International Journal of Systems Science, 1*(2), pp. 89–97. DOI: 10.1080/00207727008920220.

Cooper, R. (2001). *Winning at new products: accelerating the process from idea to launch*: Cambridge, MA: Perseus.

Cooper, R. G. (2014). What's Next?: After Stage-Gate. In: *Research technology management, 57*(1), pp. 20–31.

Cooper, R. G. & Sommer, A. F. (2016). Agile-Stage-Gate: New idea-to-launch method for manufactured new products is faster, more responsive. In: *Industrial Marketing Management, 59*, pp. 167–180. DOI: 10.1016/j.indmarman.2016.10.006.

Costa, L. d.; Rodrigues, F. A.; Travieso, G. & Villas Boas, P. R. (2007). Characterization of complex networks: A survey of measurements. In: *Advances in Physics, 56*(1), pp. 167–242.

Costache, D.; Kalus, G. & Kuhrmann, M. (2011). Design and validation of feature-based process model tailoring. In: *Proceedings of the 19th ACM SIGSOFT symposium and the 13th European conference on Foundations of software engineering - SIGSOFT/FSE '11*, p. 464. DOI: 10.1145/2025113.2025192.

Crowston, K. (2000). Process as Theory in Information Systems Research. In: *Proceedings of the IFIP TC8. 2 International Working Conference on the Social and Organizational Perspective on Research in Information Technology,* Aalborg, DK, pp. 149–164.

Czarnecki, K. & Eisenecker, U. (2005). *Generative programming: Methods, tools, and applications*. Boston [u.a.]: Addison Wesley.

Dai, F. & Li, T. (2007). Tailoring Software Evolution Process. In: *Eighth ACIS International Conference on Software Engineering, Artificial Intelligence, Networking, and Parallel/Distributed Computing (SNPD 2007):* IEEE, pp. 782–787. DOI: 10.1109/SNPD.2007.25.

Danilovic, M. & Browning, T. R. (2007). Managing complex product development projects with design structure matrices and domain mapping matrices. In: *International Journal of Project Management, 25*(3), pp. 300–314. DOI: 10.1016/j.ijproman.2006.11.003.

Davenport, T. & Prusak, L. (2000). *Working knowledge: How organizations manage what they know*. Boston, Mass.: Harvard Business School Press.

Davenport, T. H.; Barth, P. & Bean, R. (2012). How 'Big Data' is Different. In: *MIT Sloan Management Review, 54*(1), pp. 22–24.

Davenport, T. H. & Marchand, D. (1999). Is KM just good information management? In: *The Financial Times Mastering Series: Matering Information Management*, pp. 2–3.

Davies, A.; Gann, D. & Douglas, T. (2009). Innovation in Megaprojects: Systems Integration at London Heathrow Terminal 5. In: *California Management Review, 51*(2), pp. 101–125.

de Carvalho, D. D.; Fernandes Chagas, L. & Lima Reis, C. A. (2014). Definition of Software Process Lines for Integration of Scrum and CMMI. In: Ezzatti, P. (Ed.) *2014 XL Latin American Computing Conference (CLEI).*

de Weck, O.; Ross, A. M. & Rhodes, D. H. (2012). *Investigating Relationships and Semantic Sets among System Lifecycle Properties (Illities),* Massachusetts Institute of Technology. Engineering Systems Division.

de Weck, O. de; Roos, D. & Magee, C. (2011). *Engineering systems: Meeting human needs in a complex technological world*. Cambridge, Cambridge, Massachusetts: Mit press.

Diestel, R. (2017). *Graph Theory*. Berlin, Heidelberg: Springer Berlin Heidelberg. DOI: 10.1007/978-3-662-53622-3.

Dougherty, D. (2001). Reimagining the Differentiation and Integration of Work for Sustained Product Innovation. In: *Organization Science, 12*(5), pp. 612–631. DOI: 10.1287/orsc.12.5.612.10096.

Drawehn, J.; Kicherer, F. & Koppberger, Dietmar, Zähringer, Daniel (2008). Einleitung. In: Spath, D. (Ed.) *Business process management tools 2008*. Stuttgart: Fraunhofer-IRB-Verl., pp. 7–23.

Du Preez, N.; Basson, A.; Lutters, D. & Nieberding, H. (2008). Structuring the Development Process According to the Project Context: Two Case Studies. In: *Management of Engineering & Technology, 2008. PICMET 2008. Portland International Conference on Management of Engineering & Technology:* IEEE, pp. 1189–1205.

Du Preez, N.; Lutters, D. & Nieberding, H. (2009). Tailoring the development process according to the context of the project. In: *CIRP Journal of Manufacturing Science and Technology*, *1*(3), pp. 191–198. DOI: 10.1016/j.cirpj.2008.10.003.

Dvir, D.; Lipovetsky, S.; Shenhar, A. & Tishler, A. (1998). In search of project classification: a non-universal approach to project success factors. In: *Research Policy*, *27*, pp. 915–935.

Easterby-Smith, M. & Lyles, M. (2011). *Handbook of organizational learning and knowledge management*. Chichester: Wiley.

Eckert, C.; Maier, A. & McMahon, C. (2005). Communication in design. In: Clarkson, J. & Eckert, C. (Eds.) *Design process improvement*. London [U.K.]: Springer, pp. 232–261.

Ehrlenspiel, K. & Meerkamm, H. (2013). *Integrierte Produktentwicklung*. München: Carl Hanser Verlag GmbH & Co. KG. DOI: 10.3139/9783446436275.

Eito-Brun, R. (2014). Ontology-based Tailoring of Software Process Models. In: *Terminology and Knowledge Engineering 2014*.

Elezi, F. (2015). *Supporting the Design of Management Control Systems in Engineering Companies from Management Cybernetics Perspective*.

Eppinger, S. & Browning, T. (2012). *Design structure matrix methods and applications*. Cambridge, Mass: Mit press.

Eppinger, S. D. (2001). Innovation at the speed of information. In: *Harvard Business Review, 79 1*, 149-58, 178.

Estefan, J. A. (2008). *Survey of Candidate Model-Based Systems Engineering (MBSE) Methodologies, rev. B.* Seattle, WA, USA.

Estrada, E.; Fox, M.; Higham, D. & Oppo, G.-L. (2010). *Network Science*. London: Springer London. DOI: 10.1007/978-1-84996-396-1.

Fabrizio, K. (2006). The use of university research in firm innovation. In: Chesbrough, H.; van Haverbeke, W. & West, J. (Eds.) *Open innovation*. Oxford: Oxford Univ. Press, pp. 134–160.

Ferratt, T. W. & Mai, B. (2010). Tailoring Software Development. In: Gallivan, M. (Ed.) *Proceedings of the 2010 Special Interest Group on Management Information System's 48th annual conference on Computer personnel research on Computer personnel research*, pp. 165–170.

Ferreira, F.; Marques, A. L.; Faria, J. & Azevedo, A. (2016). Hybrid Process Management: A Collaborative Approach Applied to Automotive Industry. In: *Procedia CIRP*, *56*, pp. 539–544. DOI: 10.1016/j.procir.2016.10.106.

Fink, A. (2013). *Conducting research literature reviews: From the Internet to paper*: SAGE Publications.

Fink, C. (2003). *Prozessorientierte Unternehmensplanung: Analyse, Konzeption und Praxisbeispiele*. Wiesbaden: Deutscher Universitätsverlag.

Fitzgerald, B.; Russo, N. L. & O'Kane, T. (2003). Software development method tailoring at Motorola. In: *Commun. ACM, 46*(4), pp. 64–70. DOI: 10.1145/641205.641206.

Fontoura, L. M. & Price, R. T. (2007). A Framework for Tailoring Software Process. In: *Proceedings / SEKE 2007, the 19th International Conference on Software Engineering & Knowledge Engineering. Technical program, July 9 - 11, 2007, Hyatt Harborside Hotel, Boston, Massachusetts, USA*, pp. 63–66.

Fontoura, L. M. & Price, R. T. (2008). Systematic Approach to Risk Management in Software Projects through Process Tailoring. In: *Proceedings of the Twentieth International Conference on Software Engineering and Knowledge Engineering*. Skokie, Ill.: Knowledge Systems Institute Graduate School.

Freeman, L. C. (1977). A Set of Measures of Centrality Based on Betweenness. In: *Sociometry, 40*(1), p. 35. DOI: 10.2307/3033543.

Gericke, K. & Blessing, L. (2012). An Analysis of Design Process Models Across Disciplines. In: *Proceedings of the international DESIGN conference 2012 (DESIGN 2012),* Dubrovnik, Croatia.

Gericke, K.; Meißner, M. & Paetzold, K. (2013). Understanding the context of product development. In: *International Conference on Engineering Design (ICED) 2013*.

Ginsberg, M. P. & Quinn, L. H. (1995). *Process Tailoring and the Software Capability Maturity Model: Technical Report CMU/SEI-94-TR-024*, Software Engineering Institute, Carnegie Mellon University. Pittsburgh, Pennsylvania.

Glazer, H. (2001). Dispelling the Process Myth: Having a Process Does Not Mean Sacrificing Agility or Creativity. In: *Journal of Defense Software Development*(November), pp. 27–30.

Gnatz, M. (2005). *Vom Vorgehensmodell zum Projektplan*. PhD Thesis. Munich, Germany: Institut für Informatik, Technical University of Munich (TUM).

Gokpinar, B.; Hopp, W. J. & Iravani, S. M. (2010). The Impact of Misalignment of Organizational Structure and Product Architecture on Quality in Complex Product Development. In: *Management Science, 56*(3), pp. 468–484. DOI: 10.1287/mnsc.1090.1117.

Golra, F. R. (2014). *A Refinement based methodology for software process modeling*. Rennes: IRISA, Université de Rennes 1.

González, F.; Silvestre, L.; Solari, M. & Bastarrica, M. C. (2014). Template-Based vs. Automatic Process Tailoring. In: *XXXIII Conferencia Internacional de la Sociedad Chilena de Ciencias de la Computación (SCCC 2014)*.

Goodhue, D. L. & Thompson, R. L. (1995). Task-Technology Fit and Individual Performance. In: *MIS Quarterly, 19*(2), p. 213. DOI: 10.2307/249689.

Göpfert, J. (1998). *Modulare Produktentwicklung: Zur gemeinsamen Gestaltung von Technik und Organisation*. Wiesbaden: Deutscher Universitätsverlag.

Graviss, M.; Sakrani, S. & Mazzuchi, T. A. (2016). Tailoring a Large Organization's Systems Engineering Process to Meet Project-Specific Needs. In: *Defense Acquisition Research Journal: A Publication of the Defense Acquisition University, 23*(3), pp. 274–297.

Gross, J. & Yellen, J. (2008). *Handbook of graph theory*. Boca Raton: CRC Press.

Gruber, T. R. (1993). A translation approach to portable ontology specifications. In: *Knowledge Acquisition, 5*(2), pp. 199–220. DOI: 10.1006/knac.1993.1008.

Guertler, M. R. (2016). *Situational Open Innovation: Enabling Boundary-Spanning Collaboration in Small and Medium-sized Enterprises*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Guertler, M. R.; Kriz, A. & McGregor, C. Bankins, S. Bucolo, S. (2017). "And Action!" - Rigour Meets Relevance in Action Innovation Management (AIM). In: Bitran, I.; Conn, S.; Huizingh, K.; Kokshagina, O.; Torkkeli, M. & Tynnhammar, M. (Eds.) *Composing the innovation symphony. XXVIII ISPIM Innovation Conference : ISPIM Vienna 2017 : 18-21 June 2017,* Vienna, Austria.

Gulliksen, J.; Boivie, I. & Göransson, B. (2006). Usability professionals—current practices and future development. In: *Interacting with Computers, 18*(4), pp. 568–600. DOI: 10.1016/j.intcom.2005.10.005.

Hab, G. & Wagner, R. (2017). *Projektmanagement in der Automobilindustrie: Effizientes Management von Fahrzeugprojekten entlang der Wertschöpfungskette*. Wiesbaden: Springer Fachmedien Wiesbaden. DOI: 10.1007/978-3-658-10472-6.

Haberfellner, R. (2015). *Systems Engineering: Grundlagen und Anwendung*. Zürich: Orell Füssli.

Hales, C. & Gooch, S. (2004). *Managing engineering design*. London: Springer.

Hallerbach, A. (2009). *Management von Prozessvarianten*. PhD thesis. Ulm: Institut für Datenbanken und Informationssysteme, Universität Ulm.

Hallerbach, A.; Bauer, T. & Reichert, M. (2010). Capturing variability in business process models: The Provop approach. In: *Journal of Software Maintenance and Evolution, 22*(6-7), pp. 519–546. DOI: 10.1002/smr.491.

Hamilton, P. (2016). *The workshop book: How to design and lead successful workshops*. Harlow, England: Pearson Education.

Hammer, M. (2001). Seven insights about processes. In: *Proceedings of the Conference on Strategic Power Process Ensuring Survival Creating Competitive Advantage, Boston, MA, US*.

Hammer, M. & Stanton, S. (1999). How Process Enterprises Really Work. In: *Harvard Business Review, 77*(6).

Hanssen, G. K.; Westerheim, H. & Bjørnson, F. O. (2005). Tailoring RUP to a Defined Project Type: A Case Study. In: Hutchison, D.; Kanade, T.; Kittler, J.; Kleinberg, J.; Mattern, F.; Mitchell, J.; Naor, M.; Nierstrasz, O.; Pandu Rangan, C.; Steffen, B.; Sudan, M.; Terzopoulos, D.; Tygar, D.; Vardi, M.; Weikum, G.; Bomarius, F. & Komi-Sirviö, S. (Eds.) *Product Focused Software Process Improvement*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 314–327. DOI: 10.1007/11497455_26.

Harmsen, A. F. (1997). *Situational Method Engineering*. PhD Thesis. Utrecht: Faculty of Electrical Engineering, Mathematics & Computer Science, University of Twente.

Hauschildt, J. & Kirchmann, E. (2001). Teamwork for innovation - the 'troika' of promotors. In: *R&D Management, 31*(1), pp. 41–49. DOI: 10.1111/1467-9310.00195.

He, X.-y.; Wang, Y.; Teng, Y.-x. & Guo, J.-g. (2008). A Systematic Method for Process Tailoring Based on Knowledge Reuse. In: *SEKE*. Skokie, Il.: Knowledge Systems Institute Graduate School, pp. 38–41.

Heckel, R. (2006). Graph transformation in a nutshell. In: *Electronic Notes in Theoretical Computer Science, 148*(1 SPEC. ISS), pp. 187–198. DOI: 10.1016/j.entcs.2005.12.018.

Heimberger, N. (2017). *Strukturbasierte Koordinationsplanung in komplexen Entwicklungsprojekten*. PhD Thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Heisig, P. (2009). Harmonisation of knowledge management – comparing 160 KM frameworks around the globe. In: *Journal of Knowledge Management, 13*(4), pp. 4–31. DOI: 10.1108/13673270910971798.

Held, M.; Weidmann, D.; Kammerl, D.; Hollauer, C.; Mörtl, M.; Omer, M. & Lindemann, U. (2018). Current challenges for sustainable product development in the German automotive sector: A survey based status assessment. In: *Journal of Cleaner Production, 195*, pp. 869–889. DOI: 10.1016/j.jclepro.2018.05.118.

Helms, B. (2013). Object-Oriented Graph Grammars for Computational Design Synthesis.

Helms, B. & Kissel, M. (2016). Engineering Intelligence: Von der graphenbasierten Modellierung zur wissensbasierten Datenanalyse. In: Lindemann, U. (Ed.) *Handbuch Produktentwicklung*. München: Carl Hanser Verlag, pp. 979–1012.

Henderson-Sellers, B. & Gonzalez-Perez, C. (2010). Granularity in Conceptual Modelling: Application to Metamodels. In: Parsons, J.; Saeki, M.; Shoval, P.; Woo, C. & Wand, Y. (Eds.) *Conceptual modeling - ER 2010*. Berlin: Springer.

Henderson-Sellers, B. & Ralyté, J. (2010). Situational Method Engineering: State-of-the-Art Review. In: *j-jucs, 16*(3), pp. 424–478.

Henderson-Sellers, B.; Ralyté, J.; Ågerfalk, P. J. & Rossi, M. (2014). Method Engineering as a Social Practice. In: Henderson-Sellers, B.; Ralyté, J.; Ågerfalk, P. & Rossi, M. (Eds.) *Situational method engineering*. Berlin: Springer, pp. 53–68.

Herrmann, C.; Bergmann, L.; Halubek, P. & Thiede, S. (2008). Lean Production System Design from the Perspective of the Viable System Model. In: Mitsuishi, M.; Ueda, K. & Kimura, F. (Eds.) *Manufacturing Systems and Technologies for the New Frontier*. London: Springer London, pp. 309–314. DOI: 10.1007/978-1-84800-267-8_63.

Hicks, B. J.; Culley, S. J.; Allen, R. D. & Mullineux, G. (2002). A framework for the requirements of capturing, storing and reusing information and knowledge in engineering design. In: *International Journal of Information Management, 22*(4), pp. 263–280. DOI: 10.1016/S0268-4012(02)00012-9.

Highsmith, J. (2006). *Agile software development ecosystems*. Boston, Mass.: Addison-Wesley.

Höfferer, P. (2007). Achieving Business Process Model Interoperability Using Metamodels and Ontologies. In: *Ecis*.

Höhn, M.; Hollauer, C.; Wilberg, J.; Kammerl, D.; Mörtl, M. & Omer, M. (2018). Investigating usage data support in development processes - A case study. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.) *Proceedings of the 21st International Conference on Engineering Design (ICED17) Vol 7: Design theory and research methodology*. Red Hook, NY: Curran Associates Inc, pp. 91–100.

Hollauer, C.; Frisch, B.; Wilberg, J.; Omer, M. & Lindemann, U. (2018a). Design of flexible product development processes - An automotive case study. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.) *Proceedings of the 21st International Conference on Engineering Design (ICED17) Vol 2: Design processes, Design organisation and management*. Red Hook, NY: Curran Associates Inc, pp. 289–298.

Hollauer, C.; Kattner, N. & Lindemann, U. (2016). Towards a methodology to support the development of flexible company-specific engineering design processes. In: PICMET (Ed.) *Proceedings of PICMET '16 -*, Honolulu, Hawaii.

Hollauer, C.; Kölsch, F. & Lindemann, U. (2018b). Supporting Workshop-based Tailoring of Product Development Processes by Metric-based Structural Analysis. In: Leardi, C.; Browning, T.; Eppinger, S. & Becerril, L. (Eds.) *Proceedings of the 20th International Dependency and Structure Modeling Conference (DSM2018),* Trieste, Italy.

Hollauer, C.; Langner, M. & Lindemann, U. (2018c). Supporting Tailoring of Complex Product Development Processes: An Approach Based on Structural Modelling and Analysis. In: Marjanović D., Štorga M., Škec S., Bojčetić N., Pavković N. (Ed.) *Proceedings of the 15th International Design Conference (DESIGN18),* pp. 769–780. DOI: 10.21278/idc.2018.0407.

Hollauer, C. & Lindemann, U. (2017). Design process tailoring: A review and perspective on the literature: (accepted for publication). In: Chakrabarti, A. & Chakrabarti, D. (Eds.)

Research into Design for Communities, Volume 1. Proceedings of ICoRD 2017, Guwahati, India.

Hollauer, C.; Pavlitzek, G.; Mortl, M. & Lindemann, U. (2017). Context-oriented strategy for modularization of engineering design processes: An automotive case study. In: *2017 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),* Singapore, pp. 686–690. DOI: 10.1109/IEEM.2017.8289978.

Hollauer, C.; Rast, J. & Lindemann, U. (2018d). Development and Evaluation of a Workshop Concept to Support Tailoring of Complex Product Development Processes. In: *2018 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM),* Bangkok, Thailand.

Hollauer, C.; Thomas, R.; Rhodes, D. H. & Lindemann, U. (2018e). Context-oriented Modularization of Product Development Processes using Matrix-Based Clustering. In: Leardi, C.; Browning, T.; Eppinger, S. & Becerril, L. (Eds.) *Proceedings of the 20th International Dependency and Structure Modeling Conference (DSM2018),* Trieste, Italy.

Hollauer, C.; Wilberg, J.; Omer, M. & Lindemann, U. (2018f). Context-specific process design: An integrated process lifecycle model and situations for context factor use. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.) *Proceedings of the 21st International Conference on Engineering Design (ICED17) Vol 2: Design processes, Design organisation and management*. Red Hook, NY: Curran Associates Inc, pp. 81–90.

Horváth, P.; Gleich, R. & Seiter, M. (2015). *Controlling*. München: Franz Vahlen. DOI: 10.15358/9783800649556.

Hurtado, J. A. & Bastarrica, C. (2009). Process model tailoring as a mean for process knowledge reuse. In: *2nd Workshop on Knowledge Reuse (KREUSE),* Falls Church, Virginia, USA.

Hurtado, J. A.; Ochoa, S. F.; Quispe, A. & Bastarrica, C. (2011). *A Context Modeling Language to Support Tailoring of Software Processes*, Computer Science Department, FCFM, University of Chile.

Hurtado Alegria, J. A. (2012). *A Meta-process for Defining Adaptable Software Processes*. PhD thesis: Departamento de ciencias de la computación, University of Chile.

Hurtado Alegría, J. A.; Bastarrica, M. C.; Quispe, A. & Ochoa, S. F. (2011). An MDE approach to software process tailoring. In: *ICSSP 2011*, Waikiki, Honolulu, USA, p. 43. DOI: 10.1145/1987875.1987885.

Hurtado Alegría, J. A.; Bastarrica, M. C.; Quispe, A. & Ochoa, S. F. (2014). MDE-based process tailoring strategy. In: *J. Softw. Evol. and Proc., 26*(4), pp. 386–403. DOI: 10.1002/smr.1576.

IEEE (1990). *IEEE standard glossary of software engineering terminology: Approved September 28, 1990, IEEE Standards Board*. New York, NY: Inst. of Electrical and Electronics Engineers.

Illik, J. (2009). *Formale Methoden der Informatik: Von der Automatentheorie zu Algorithmen und Datenstrukturen*. Renningen: expert-Verl.

ISO/IEC TR 24748-1, 2018. *Systems and software engineering -- Life cycle management -- Part 1: Guidelines for life cycle management.* International Organization for Standardization.

Introna, L. D. & Whitley, E. A. (1997). Against method- ism. In: *Info Technology & People, 10*(1), pp. 31–45. DOI: 10.1108/09593849710166147.

Isermann, R. (2005). *Mechatronic Systems: Fundamentals*. London: Springer. DOI: 10.1007/1-84628-259-4.

ISO/IEC 33001, 2015. *Information technology -- Process assessment -- Concepts and terminology.* ISO/IEC.

ISO/IEC/IEEE 15288, 2015. *Systems and software engineering -- System life cycle processes.* ISO/IEC/IEEE.

Ittner, J. (2006). *Software assisted tailoring of process descriptions*. Saarbrücken: VDM Verlag Dr. Müller.

Jaber, H. (2016). *Modeling and analysis of propagation risks in complex projects: Application to the development of new vehicles*. PhD Thesis. Paris: Chemical and Process Engineering, Université Paris-Saclay.

Jashapara, A. (2004). *Knowledge management: An integrated approach*. Harlow: Financial Times/Prentice Hall.

Jaufman, O. & Münch, J. (2005). Acquisition of a Project-Specific Process. In: Hutchison, D.; Kanade, T.; Kittler, J.; Kleinberg, J.; Mattern, F.; Mitchell, J.; Naor, M.; Nierstrasz, O.; Pandu Rangan, C.; Steffen, B.; Sudan, M.; Terzopoulos, D.; Tygar, D.; Vardi, M.; Weikum, G.; Bomarius, F. & Komi-Sirviö, S. (Eds.) *Product Focused Software Process Improvement*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 328–342. DOI: 10.1007/11497455_27.

Jeusfeld, M. A. (2009). Metamodel. In: Liu, L. & Özsu, M. (Eds.) *Encyclopedia of database systems*. New York, NY: Springer, pp. 1727–1730.

Kain, A.; Kirschner, R.; Goldt, M.; Lindemann, U.; Gunkel, J.; Klendauer, R.; Schneider; M. & Wastian, M. (2009). A method to identify relevant stakeholders to be integrated in new product development processes. In: Chakrabarti, A. (Ed.) *Proceedings of the 2nd International Conference on Research into Design (ICORD 09),* Bangalore, India, pp. 191–198.

Kalus, G. (2013). *Projektspezifische Anpassung von Vorgehensmodellen: Feature-basiertes Tailoring*. PhD thesis. Munich, Germany: Fakultät für Informatik, Technical University of Munich (TUM).

Kalus, G. & Kuhrmann, M. (2013). Criteria for software process tailoring: a systematic review. In: *Proceedings of the 2013 International Conference on Software and System Process - ICSSP 2013,* p. 171. DOI: 10.1145/2486046.2486078.

Kang, D.; Song, I.-G.; Park, S.; Bae, D.-H.; Kim, H.-K. & Lee, N. (2008). A Case Retrieval Method for Knowledge-Based Software Process Tailoring Using Structural Similarity. In: *2008 15th Asia-Pacific Software Engineering Conference*, pp. 51–58. DOI: 10.1109/APSEC.2008.15.

Kang, K. C.; Cohen, S. G.; Hess, J. A.; Novak, W. E. & Peterson, A. S. (1990). *Feature-Oriented Domain Analysis (FODA) Feasibility Study*.

Kang, K. C. & Lee, H. (2013). Variability Modeling. In: Capilla, R.; Bosch, J. & Kang, K.-C. (Eds.) *Systems and Software Variability Management*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 25–42. DOI: 10.1007/978-3-642-36583-6_2.

Karlsson, F. (2008). Method Tailoring as Negotiation. In: *Proceedings of the Forum at the CAiSE'08 conference*, Montpellier, France, pp. 1–4.

Karlsson, F. & Hedström, K. (2009). Negotiating a systems development method. In: Papadopoulos, G.; Wojtkowski, G.; Wojtkowski, W.; Wrycza, S. & Zupancic, J. (Eds.) *Information Systems Development*. Boston, MA: Springer-Verlag US. DOI: 10.1007/b137171_51.

Kasperek, D. (2016). *Structure-based System Dynamics Analysis of Engineering Design Processes*. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Kasperek, D.; Maisenbacher, S.; Kohn, A.; Lindemann, U. & Maurer, M. (2015). Increasing the reproducibility of structural modelling. In: *Journal of Engineering Design*, *26*(7-9), pp. 259–281. DOI: 10.1080/09544828.2015.1026883.

Keller, R.; Eckert, C. M. & Clarkson, P. J. (2016). Matrices or Node-Link Diagrams: Which Visual Representation is Better for Visualising Connectivity Models? In: *Information Visualization*, *5*(1), pp. 62–76. DOI: 10.1057/palgrave.ivs.9500116.

Kerzner, H. (2013). *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*. New York: John Wiley & Sons Incorporated.

Keuneke, S. (2005). Qualitatives Interview. In: Mikos, L. & Wegener, C. (Eds.) *Qualitative Medienforschung*. Konstanz: UVK Verl.-Ges, pp. 254–267.

Khan, H. H.; Mahrin, N. b. & Chuprat, S. b. (2014). Factors for Tailoring Requirements Engineering Process: A Review. In: *International Journal of Software Engineering and Technology, 1*(1).

Killisperger, P.; Stumptner, M.; Peters, G.; Grossmann, G. & Stückl, T. (2009). Meta Model Based Architecture for Software Process Instantiation. In: Wang, Q. (Ed.) *Trustworthy software development processes*. Berlin: Springer, pp. 63–74. DOI: 10.1007/978-3-642-01680-6_8.

Killisperger, P.; Stumptner, M.; Peters, G.; Grossmann, G. & Stückl, T. (2010). A Framework for the Flexible Instantiation of Large Scale Software Process Tailoring. In: Hutchison, D.; Kanade, T.; Kittler, J.; Kleinberg, J.; Mattern, F.; Mitchell, J.; Naor, M.; Nierstrasz, O.; Pandu Rangan, C.; Steffen, B.; Sudan, M.; Terzopoulos, D.; Tygar, D.; Vardi, M.; Weikum, G.; Münch, J.; Yang, Y. & Schäfer, W. (Eds.) *New Modeling Concepts for Today's Software Processes*, pp. 100–111.

Kissel, M. P. (2014). Mustererkennung in komplexen Produktportfolios.

Kitchenham, B. (2004). *Procedures for performing systematic reviews.* Keele, Staffs: Software Engineering Group Department of Computer Science, Keele University.

Knippenberg, S. (2018). *Managing Complex Systems in Technical Product Development Using Structural Metrics*. Unpublished Research Internsip report. München: Chair of Product Development, Technical University of Munich.

Knippenberg, S. C.; Schweigert-Recksiek, S.; Becerril L. & Lindemann, U. (2018). Analyzing Complex Socio-Technical Systems in Technical Product Development using Structural Metrics. In: Leardi, C.; Browning, T.; Eppinger, S. & Becerril, L. (Eds.) *Proceedings of the 20th International Dependency and Structure Modeling Conference (DSM2018),* Trieste, Italy, pp. 203–213.

Kossiakoff, A. (2011). *Systems engineering: Principles and practice*. Hoboken, N.J: Wiley-Interscience. DOI: 10.1002/9781118001028.

Kreimeyer, M. (2010). *A structural measurement system for engineering design processes*. München: Verl. Dr. Hut.

Kronsbein, D.; Meiser, D. & leyer, m. (2014). Conceptualisation of Contextual Factors for Business Process Performance. In: Ao, S. (Ed.) *Proceedings of the International MultiConference of Engineers and ComputerScientists 2014 Vol II,* Hong Kong.

Kruchten, P. (2011). A plea for lean software process models. In: Raffo, D.; Pfahl, D. & Zhang, L. (Eds.) *Proceeding of the 2011 International Conference on Software and Systems Process*, Waikiki, Honolulu, HI, USA, p. 235. DOI: 10.1145/1987875.1987919.

Kruchten, P. (2013). Contextualizing agile software development. In: *J. Softw.: Evol. and Proc.*, *25*(4), pp. 351–361. DOI: 10.1002/smr.572.

Kühne, T. (2006). Matters of (Meta-) Modeling. In: *Softw Syst Model*, *5*(4), pp. 369–385. DOI: 10.1007/s10270-006-0017-9.

Kuhrmann, M. (2007). *Konstruktion modularer Vorgehensmodelle: Methodisches Erstellen und Pflegen von Entwicklungsstandards und Vorgehensmodellen für Prozessingenieure*. PhD thesis. Munich, Germany: Fakultät für Informatik, Technical University of Munich (TUM).

Kuhrmann, M. (2014). You can't tailor what you haven't modeled. In: Zhang, H.; Huang, L. & Richardson, I. (Eds.) *2014 International Conference on Software and Systems Process (ICSSP)*. New York: Association for Computing Machinery, Inc, pp. 189–190. DOI: 10.1145/2600821.2600851.

Kuhrmann, M.; Méndez Fernández, D. & Tiessler, M. (2014). A mapping study on the feasibility of method engineering. In: *J. Softw. Evol. and Proc.*, *26*(12), pp. 1053–1073. DOI: 10.1002/smr.1642.

Kuhrmann, M.; Ternité, T.; Friedrich, J.; Rausch, A. & Broy, M. (2016). Flexible software process lines in practice: A metamodel-based approach to effectively construct and manage families of software process models. In: *Journal of Systems and Software, 121*, pp. 49–71. DOI: 10.1016/j.jss.2016.07.031.

Kumar, K. & Narasipuram, M. M. (2006). Defining requirements for business process flexibility. In: *CEUR Workshop Proceedings, 236*(Figure 1), pp. 137–148.

Kurz, A.; Stockhammer, C.; Fuchs, S. & Meinhard, D. (2009). Das problemzentrierte Interview. In: Buber, R. & Holzmüller, H. (Eds.) *Qualitative Marktforschung*. Wiesbaden: Gabler Verlag / GWV Fachverlage GmbH Wiesbaden, pp. 463–475. DOI: 10.1007/978-3-8349-9441-7_29.

La Rosa, M. & Dumas, M. (2008). Configurable Process Models: How To Adopt Standard Practices In Your Own Way? In: *BPTrends Newsletter*.

La Rosa, M.; van der Aalst, W. M.; Dumas, M. & Milani, F. P. (2017). Business Process Variability Modeling. In: *ACM Comput. Surv., 50*(1), pp. 1–45. DOI: 10.1145/3041957.

La Rosa, M.; Van der Aalst, Wil MP; Dumas, M. & Ter Hofstede, A. H. (2009). Questionnaire-based variability modeling for system configuration. In: *Software and Systems Modeling, 8*(2), pp. 251–274.

Lachnit, L. (1976). Zur Weiterentwicklung betriebswirtschaftlicher Kennzahlensysteme. In: *Zeitschrift für betriebswirtschaftliche Forschung, 28*(4), pp. 216–230.

Langer, S. & Lindemann, U. (2009). Managing Cycles in Development Processes - Analysis and Classification of External Context Factors. In: Norell Bergendahl, M.; Grimheden, M.; Leifer, L.; Skogstad, P. & Lindemann, U. (Eds.) *Proceedings of the 17th International Conference on Engineering Design (ICED'09)*, Palo Alto, California.

Lapouchnian, A.; Yu, Y. & Mylopoulos, J. (2007). Requirements-Driven Design and Configuration Management of Business Processes. In: Alonso, G.; Dadam, P. & Rosemann, M. (Eds.) *Business process management. 5th international conference, BPM 2007, Brisbane, Australia, September 24 - 28, 2007 ; proceedings, Bd.* 4714, pp. 246–261. DOI: 10.1007/978-3-540-75183-0_18.

LaValle, S.; Lesser, E.; Shockley, R.; Hopkins, M. S. & Kruschwitz, N. (2010). Big Data, Analytics and the Path from Insights to Value. In: *MIT Sloan Management Review, 52*(2), pp. 21–32.

Le, H. N. (2012). *A Transformation-Based Model Integration Framework to Support Iteration Management in Engineering Design*. PhD thesis. Cambridge, United Kingdom: EDC, University of Cambridge.

Lee, T. (2003). *Complexity Theory in Axiomatic Design*. PhD Thesis. Boston, MA: Department of Mechanical Engineering, Massachusetts Institute of Technology.

Lehner, F. & Maier, R. K. (2000). How can Organizational Memory Theories Contribute to Organizational Memory Systems. In: *Information Systems Frontiers, 2*(3/4), pp. 277–298. DOI: 10.1023/A:1026516627735.

Lettice, F.; Roth, N. & Forstenlechner, I. (2006). Measuring knowledge in the new product development process. In: *Int J Productivity & Perf Mgmt, 55*(3/4), pp. 217–241. DOI: 10.1108/17410400610653200.

Lévárdy, V. & Browning, T. R. (2009). An Adaptive Process Model to Support Product Development Project Management. In: *IEEE Trans. Eng. Manage., 56*(4), pp. 600–620. DOI: 10.1109/TEM.2009.2033144.

Liberati, M.; Munari, F.; Racchetti, P. & Spendiani, T. (2007). Social network techniques applied to design structure matrix analysis. The case of a new engine development at Ferrari Spa. In: Lindemann, U.; Danilovic, M.; Deubzer, F.; Maurer, M. & Kreimeyer, M. (Eds.) *Proceedings of the 9th International DSM Conference*. Herzogenrath: Shaker, pp. 35–47.

Lienhart, A. (2015). *Seminare, Trainings und Workshops lebendig gestalten*. Freiburg: Haufe.

Lindemann, U. (2009). *Methodische Entwicklung technischer Produkte*. Berlin, Heidelberg: Springer Berlin Heidelberg. DOI: 10.1007/978-3-642-01423-9.

Lindemann, U.; Maurer, M. & Braun, T. (2009). *Structural complexity management: An approach for the field of product design*. Berlin: Springer.

Lines, M. & Ambler, S. (2015). *Introduction to disciplined agile delivery: A small agile team's journey from scrum to continuous delivery*. Wroclaw: Disciplined Agile Consortium.

Lines, M. & Ambler, S. W. (2018a). *Process Tailoring Workshops*. Verfügbar unter: http://www.disciplinedagiledelivery.com/process/process-tailoring-workshops/ (zuletzt geprüft am 11.09.2018).

Lines, M. & Ambler, S. W. (2018b). *Why DAD?* Verfügbar unter: http://www.disciplinedagiledelivery.com/why-dad/ (zuletzt geprüft am 11.09.2018).

Lipp, U. & Will, H. (2001). *Das große Workshop-Buch: Konzeption, Inszenierung und Moderation von Klausuren, Besprechungen und Seminaren*. Weinheim: Beltz.

Little, J. D. (1970). Models and Managers: The Concept of a Decision Calculus. In: *Management Science*, *16*(8), B-466 - B-485.

Lo Storto, C. (2010). Assessing Product Development Performance Analyzing the INformation Flows Structure using Social Network Analysis Measurements. In: *World Academy of Science, Engineering and Technology, 65*, pp. 271–278.

Lorenz, W. G.; Brasil, M. B.; Fontoura, L. M. & Vaz Pereira, G. (2014). Activity-Based Software Process Lines Tailoring. In: *Int. J. Soft. Eng. Knowl. Eng., 24*(09), pp. 1357–1381. DOI: 10.1142/S0218194014500429.

Louis-Sidney, L.; Cheutet, V. & Lamouri, S. (2016). Proposal for a process oriented knowledge management system (PKMS). In: *IJPD, 21*(4), p. 267. DOI: 10.1504/IJPD.2016.080309.

Maffin, D. (1998). Engineering Design Models: Context, theory and practice. In: *Journal of Engineering Design*, *9*(4), pp. 315–327. DOI: 10.1080/095448298261462.

Maffin, D.; Alderman, N.; Braiden, P.; Hills, B. & Thwaites, A. (1995). Company Classification: A New Perspective on Modelling the Engineering Design and Product Development Process. In: *Journal of Engineering Design, 6*(4), pp. 275–289. DOI: 10.1080/09544829508907918.

Maier, A. (2008). *A grid-based assessment method of communication in engineering design*. PhD thesis. Cambridge, United Kingdom: Department of Engineering, University of Cambridge.

Maier, A.; Eckert, C. & Clarkson, P. (2005). A meta-model for communication in engineering design. In: *CoDesign, 1*(4), pp. 243–254. DOI: 10.1080/15710880500478353.

Maier, A. M. & Störrle, H. (2011). What are the characteristics of engineering design processes? In: *Proceedings of the 18th International Conference on Engineering Design (ICED 2011)*(August), pp. 188–198.

Malik, F. (2008). *Strategie des Managements komplexer Systeme: Ein Beitrag zur Management-Kybernetik evolutionärer Systeme*. Bern: Haupt.

Malone, T. W. & Crowston, K. (1994). The interdisciplinary study of coordination. In: *ACM Comput. Surv.*, *26*(1), pp. 87–119. DOI: 10.1145/174666.174668.

Markham, S. K. & Lee, H. (2013). Product Development and Management Association's 2012 Comparative Performance Assessment Study. In: *J Prod Innov Manag*, *30*(3), pp. 408–429. DOI: 10.1111/jpim.12025.

Marle, F. & Vidal, L.-A. (2016). Managing Complex, High Risk Projects. In: *(Keine Angabe)*, pp. 53–74. DOI: 10.1007/978-1-4471-6787-7.

Martinez-Ruiz, T.; Munch, J.; Garcia, F. & Piattini, M. (2012). Requirements and constructors for tailoring software processes: a systematic literature review. In: *Software Quality Journal*, *20*(1), pp. 229–260. DOI: 10.1007/s11219-011-9147-6.

Martínez-Ruiz, T.; Ruiz, F. & Piattini, M. (2013). Towards understanding software process variability from contextual evidence of change. In: Franch, X. & Soffer, P. (Eds.) *Advanced Information Systems Engineering Workshops*. Berlin/Heidelberg: Springer Berlin Heidelberg, pp. 417–431. DOI: 10.1007/978-3-642-38490-5_38.

Mathieson, J. & Summers, J. D. (2016). A protocol for modeling and tracking engineering design process through structural complexity metrics applied against communication networks. In: *Concurrent Engineering, 25*(2), pp. 108–122. DOI: 10.1177/1063293X16666936.

Maurer, M. (2017). *Complexity Management in Engineering Design – a Primer*. Berlin, Heidelberg: Springer Berlin Heidelberg. DOI: 10.1007/978-3-662-53448-9.

Maurer, M. S. (2007). Structural Awareness in Complex Product Design. In: *Chair of Product Development*.

Meißner, M. & Blessing, L. (2006). Defining an adaptive product development methodology. In: *9th International Design Conference, DESIGN 2006*, pp. 69–78.

Meißner, M.; Gericke, K.; Gries, B. & Blessing, L. (2005). Eine adaptive Produktentwicklungsmethodik als Beitrag zur Prozessgestaltung in der Produktentwicklung. In: Meerkamm, H. (Ed.) *DFX 2005: Proceedings of the 16th Symposium on Design for X, Neukirchen/Erlangen, Germany, 13.-14.10.2005*, pp. 67–76.

Mendling, J. (2008). *Metrics for Process Models: Empirical Foundations of Verification, Error Prediction, and Guidelines for Correctness*. Berlin, Heidelberg: Springer Berlin Heidelberg. DOI: 10.1007/978-3-540-89224-3.

Merriam-Webster (2016). *Defintion of "context"*. Verfügbar unter: http://www.merriam-webster.com/dictionary/context (zuletzt geprüft am 16.11.2016).

Milani, F. (2015). *On Sub-Processes, Process Variation and their Interplay: An Integrated Divide-and-Conquer Method for Modeling Business Processes with Variation:* Institute of Computer Science, University of Tartu, Estonia.

Milani, F.; Dumas, M.; Ahmed, N. & Matulevičius, R. (2016). Modelling families of business process variants: A decomposition driven method. In: *Information Systems, 56*, pp. 55–72. DOI: 10.1016/j.is.2015.09.003.

Milo, R.; Shen-Orr, S.; Itzkovitz, S.; Kashtan, N.; Chklovskii, D. & Alon, U. (2002). Network motifs: simple building blocks of complex networks. In: *Science (New York, N.Y.), 298*(5594), pp. 824–827. DOI: 10.1126/science.298.5594.824.

Mir, M.; Casadesús, M. & Petnji, L. H. (2016). The impact of standardized innovation management systems on innovation capability and business performance: An empirical study. In: *Journal of Engineering and Technology Management, 41*, pp. 26–44. DOI: 10.1016/j.jengtecman.2016.06.002.

Moser, B.; Grossmann, W. & Starke, P. (2015). Mechanisms of Dependence in Engineering Projects as sociatechnical systems. In: *Proceedings of the 22nd ISPE Concurrent Engineering Conference (CE2015)*.

Müller-Prothmann, T. (2007). Social Network Analysis: A Practical Method to Improve Knowledge Sharing. In: *SSRN Journal. DOI:* 10.2139/ssrn.1467609.

Muyun, S. (2017). The Relation between Organizational Network Distance and Knowledge Transfer Based on Social Network Analysis Method. In: *Int. J. Emerg. Technol. Learn., 12*(06), p. 171. DOI: 10.3991/ijet.v12i06.7094.

Negele, H. (1998). *Systemtechnische Methodik zur ganzheitlichen Modellierung am Beispiel der integrierten Produktentwicklung*. München: Utz Wiss.

Negele, H.; Fricke, E. & Igenbergs, E. (1997). ZOPH - A Systemic Approach to the Modeling of Product Development Systems. In: *Proceedings of the 7th Annual International Symposium of INCOSE, Bd.* 7, Los Angeles, USA, pp. 266–273. DOI: 10.1002/j.2334-5837.1997.tb02181.x.

Newman, M. (2003). The structure and function of complex networks. In: *SIAM Review, 45*(2), pp. 167–256.

Nickerson, J. & Zenger, T. (2004). A Knowledge-Based Theory of the Firm - The Problem-Solving Perspective. In: *Organization Science, 15*(6), pp. 617–632.

Nickols, F. (2012). The Knowledge in Knowledge Management. In: Woods, J. & Cortada, J. (Eds.) *The Knowledge Management Yearbook 2000-2001*. Hoboken: Taylor and Francis.

Nieberding, F. H. (2010). *Selecting and Tailoring Design Methodologies in the Form of Roadmaps for a Specific Development Project.* PhD Thesis. Stellenbosch, Südafrika: Department of Industrial Engineering, Stellenbosch University.

Nonaka, I. (1991). The Knowledge Creating Company. In: *Harvard Business Review, 69*, pp. 96–104.

Nonaka, I. (1994). A Dynamic Theory of Organizational Knowledge Creation. In: *Organization Science, 5*(1), pp. 14–37. DOI: 10.1287/orsc.5.1.14.

Nonaka, I. & Takeuchi, H. (1995). *The knowledge creating company: How Japanese companies create the dynamics of innovation*. New York: Oxford Univ. Press.

North, K. (2011). *Wissensorientierte Unternehmensführung*. Wiesbaden: Gabler. DOI: 10.1007/978-3-8349-6427-4.

Noy, N. F. & McGuiness, D. L. (2001). *Ontology Development 101: A Guide to Creating Your First Ontology (*zuletzt geprüft am 23.03.2018).

Oberholzer, G.; Eichholzer, A. & Ruberti, S. (2015). *Stimmt Booklets/Workshop Baukasten: Bauplan und Werkzeuge für herausragende Workshops*. Berlin: epubli GmbH.

Object Management Group (2016). *OMG Meta Object Facility (MOF) Core Specification v2.5.1,* Object Management Group.

Ocampo, A.; Bella, F. & Münch, J. (2005). Software process commonality analysis. In: *Softw. Process: Improve. Pract., 10*(3), pp. 273–285. DOI: 10.1002/spip.229.

O'Donovan, B.; Eckert, C.; Clarkson, J. & Browning, T. (2005). Design planning and modeling. In: Clarkson, J. & Eckert, C. (Eds.) *Design process improvement*. London [U.K.]: Springer, pp. 60–87.

Oehmen, J.; Thuesen, C.; Parraguez, P. & Geraldi, J. (2015). *Complexity Management for Projects, Programmes, and Portfolios: An Engineering Systems Perspective*: Project Management Institute, PMI.

Okoli, C. & Schabram, K. (2010). A guide to conducting a systematic literature review of information systems research. In: *Sprouts: Working Papers on Information Systems*(10(26)).

Ortega, D.; Silvestre, L.; Bastarrica, M. C. & Ochoa, S. F. (2012). A Tool for Modeling Software Development Contexts in Small Software Organizations. In: *2012 31st International Conference of the Chilean Computer Science Society (SCCC),* Valparaíso, Chile, pp. 29–35. DOI: 10.1109/SCCC.2012.11.

Pahl, G.; Beitz, W.; Feldhusen, J. & Grote, K.-H. (2007). *Engineering Design*. London: Springer London. DOI: 10.1007/978-1-84628-319-2.

Paige, R. F.; Kolovos, D. S. & Polack, F. A. (2014). A tutorial on metamodelling for grammar researchers. In: *Science of Computer Programming, 96*, pp. 396–416. DOI: 10.1016/j.scico.2014.05.007.

Park, S.; Na, H. Y. & Sugumaran, V. (2006). A semi-automated filtering technique for software process tailoring using neural network. In: *Expert Systems with Applications, 30*(2), pp. 179–189. DOI: 10.1016/j.eswa.2005.06.023.

Parraguez, P. (2015). *A Networked Perspecive on the Engineering Design Process: At the Intersection of Process and Organisation Architectures*. PhD thesis. Lyngby: Department of Management Engineering, DTU.

Payne, J. H. & Turner, J. R. (1999). Company-wide project management:: the planning and control of programmes of projects of different type. In: *International Journal of Project Management, 17*(1), pp. 55–59.

Pedreira, O.; Piattini, M.; Luaces, R. M. & Brisaboa, R. N. (2007). A systematic review of software process tailoring. In: *ACM SIGSOFT Software Engineering Notes, 32*(3), p. 1. DOI: 10.1145/1241572.1241584.

Pereira, E. B.; Bastos, R. M. & Oliveira, T. C. (2007). A Systematic Approach to Process Tailoring. In: *2007 International Conference on Systems Engineering and Modeling*, Haifa, Israel, pp. 71–78. DOI: 10.1109/ICSEM.2007.373335.

Pereira, G. V.; Severo, F. & Fontoura, L. (2012). A risk management approach based on situational method engineering. In: *15th Conferencia Iberoamericana on Software Engineering. (CIbSE 2012) ; Buenos Aires, Argentina 24 - 27 April 2012 ; [co-located workshops.. XV Requirements Engineering Workshop (WER) and the IX Experimental Software Engineering Latin American Workshop (ESELAW)]*.

Piccolo, S. A.; Jørgensen, S. L. & Maier, A. (2018a). Using data- and network science to reveal iterations and phase-transitions in the design process. In: Maier, A.; Kim, H.; Oehmen, J.; Salustri, F.; Škec, S. & Kokkolaras, M. (Eds.) *Proceedings of the 21st International Conference on Engineering Design (ICED17) Vol 1: Resource-sensitive design, Design research applications and case studies*, Vancouver, Canada, pp. 11–21.

Piccolo, S. A.; Lehmann, S. & Maier, A. (2018b). Design process robustness: A bipartite network analysis reveals the central importance of people. In: *Des. Sci., 4*, p. 129. DOI: 10.1017/dsj.2017.32.

Pillat, R. M.; Oliveira, T. C.; Alencar, P. S. & Cowan, D. D. (2015). BPMNt: A BPMN extension for specifying software process tailoring. In: *Information and Software Technology, 57*, pp. 95–115. DOI: 10.1016/j.infsof.2014.09.004.

Pillat, R. M.; Oliveira, T. C. & Fonseca, F. L. (2012). Introducing Software Process Tailoring to BPMN: BPMNt. In: Jeffery, R. (Ed.) *2012 International Conference on Software and System Process (ICSSP 2012)*. Piscataway, NJ: IEEE, pp. 58–62.

Piller, F. & Waringer, D. (1999). *Modularisierung in der Automobilindustrie: Neue Formen und Prinzipien ; Modular Sourcing, Plattformkonzept und Fertigungssegmentierung als Mittel des Komplexitätsmanagements*. Aachen: Shaker.

Ploesser, K.; Peleg, M.; Soffer, P.; Rosemann, M. & Recker, J. (2009). Learning from Context to Improve Business Processes Learning from Context to Improve Business Processes Why Context Matters. In: *BPTrends*, *6*(1), pp. 1–7.

PMI (2013). *A guide to the project management body of knowledge: (PMBOK guide)*. Newton Square, Pennsylvania: Project Management Institute, Inc.

PMI (2016). *The high cost of low performance*, Project Management Institute.

Polanyi, M. (1966). *The tacit dimension*. Garden City, NY, USA: Doubleday.

Ponn, J. C. (2007). *Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte*. PhD thesis. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Ramasesh, R. V. & Browning, T. R. (2014). A conceptual framework for tackling knowable unknown unknowns in project management. In: *Journal of Operations Management, 32*(4), pp. 190–204. DOI: 10.1016/j.jom.2014.03.003.

Reinhartz-Berger, I.; Sturm, A.; Clark, T.; Cohen, S. & Bettin, J. (2013). *Domain Engineering: Product Lines, Languages, and Conceptual Models*. Berlin, Heidelberg: Springer.

Renner, I. (2007). *Methodische Unterstützung funktionsorientierter Baukastenentwicklung am Beispiel Automobil*. München: Hut.

Riemenschneider, C. K.; Hardgrave, B. C. & Davis, F. D. (2002). Explaining software developer acceptance of methodologies: A comparison of five theoretical models. In: *IIEEE Trans. Software Eng.*, *28*(12), pp. 1135–1145. DOI: 10.1109/TSE.2002.1158287.

Ringel, M.; Taylor, A. & Zablit, H. (2015). *The most innovative companies 2015: Four factors that differentiate leaders*, The Boston Consulting Group. Boston.

Roelofsen, J. (2011). *Situationsspezifische Planung von Produktentwicklungsprozessen*. München: Hut.

Rombach, D. (2005). Integrated Software Process and Product Lines. In: Li, M.; Boehm, B. & Osterweil, L. (Eds.) *Unifying the Software Process Spectrum. Revised selected papers, Bd.* 3840, Beijing, China, pp. 83–90. DOI: 10.1007/11608035_9.

Rosemann, M. & Recker, J. (2006). Context-aware process design: Exploring the Extrinsic Drivers for Process Flexibility. In: *Tourism Management*, *23*(5), pp. 541–549. DOI: 10.1016/S0261-5177(02)00005-5.

Rosemann, M.; Recker, J. & Flender, C. (2008). Contextualisation of business processes. In: *International Journal of Business Process Integration and Management*, *3*(1), p. 47. DOI: 10.1504/IJBPIM.2008.019347.

Rouse, W. B. (2007). Complex engineered, organizational and natural systems. In: *Syst. Engin., 10*(3), pp. 260–271. DOI: 10.1002/sys.20076.

Ruedel, I. (2008). *Workshops: Optimal vorbereiten, spannend inszenieren, professionell nachbereiten*. Wien: Linde.

Rupani, S. (2011). *Standardization of product development processes in multi-project organizations*. PhD Thesis. Cambridge, Mass.: Engineering Systems Division, Massachusetts Institute of Technology.

Russo, N. L. & Stolterman, E. (2000). Exploring the assumptions underlying information systems methodologies. In: *Info Technology & People, 13*(4), pp. 313–327. DOI: 10.1108/09593840010359509.

Rychkova, I. & Nurcan, S. (2011). Towards adaptability and control for knowledge-intensive business processes: Declarative configurable process specifications. In: Sprague, R. (Ed.) *2011 44th Hawaii International Conference on System Sciences. (HICSS) ; 4 - 7 Jan. 2011, Koloa, Kauai, Hawaii*, pp. 1–10.

Sadiq, S.; Governatori, G. & Namiri, K. (2007). Modeling Control Objectives for Business Process Compliance. In: Alonso, G.; Dadam, P. & Rosemann, M. (Eds.) *Business Process Management*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 149–164. DOI: 10.1007/978-3-540-75183-0_12.

Saidani, O.; Rolland, C. & Nurcan, S. (2015). Towards a Generic Context Model for BPM. In: *2015 48th Hawaii International Conference on System Sciences (HICSS),* HI, USA, pp. 4120–4129. DOI: 10.1109/HICSS.2015.494.

Sanchez, R. & Mahoney, J. T. (1996). Modularity, flexibility, and knowledge management in product and organization design. In: *Strat. Mgmt. J., 17*(S2), pp. 63–76. DOI: 10.1002/smj.4250171107.

SCAMPI Upgrade Team (2011). *Appraisal Requirements for CMMI Version 1.3 (ARC, V1.3),* Software Engineering Institute, Carnegie Mellon University. Pittsburgh, PA.

Schatten, A.; Demolsky, M.; Winkler, D.; Biffl, S.; Gostischa-Franta, E. & Östreicher, T. (2010). *Best Practice Software-Engineering*. Heidelberg: Spektrum Akademischer Verlag. DOI: 10.1007/978-3-8274-2487-7.

Schenkl, S. A.; Behncke, F. G.; Hepperle, C.; Langer, S. & Lindemann, U. (2013). Managing Cycles of Innovation Processes of Product-Service Systems. In: *IEEE International Conference on Systems, Man and Cybernetics (SMC), 2014,* Manchester, United Kingdom, pp. 918–923. DOI: 10.1109/SMC.2013.161.

Schmidt, T.; Weiss, S. & Paetzold, K. (2018). *Agile Development of Physical Products: An Empirical Study about Motivations, Potentials and Applicability*. Neubiberg, Germany: Universität der Bundeswehr München.

Schrieverhoff, P. (2014). *Valuation of Adaptability in System Architecture*. Munich, Germany: Chair of Product Development, Technical University of Munich (TUM).

Schuh, G. (2014). *Produktkomplexität managen: Strategien ; Methoden ; Tools*. s.l.: Carl Hanser Fachbuchverlag. DOI: 10.3139/9783446443549.

Schulze, A. & Hoegl, M. (2016). Knowledge Creation in New Product Development Projects. In: *Journal of Management, 32*(2), pp. 210–236. DOI: 10.1177/0149206305280102.

Schwaninger, M. (2006). *Intelligent organizations: Powerful models for systemic management ; with 6 tables*.

Schweigert, S.; Luft, T.; Wartzack Sandro & Lindemann, U. (2017). Combination of Matrix-based and Graph-based Modeling for Product and Organizational Structures. In: *Proceedings of the 19th International DSM Conference,* Espoo, Finland.

Seidewitz, E. (2003). What models mean. In: *IEEE Softw., 20*(5), pp. 26–32. DOI: 10.1109/MS.2003.1231147.

Seol, H.; Kim, C.; Lee, C. & Park, Y. (2016). Design Process Modularization: Concept and Algorithm. In: *Concurrent Engineering, 15*(2), pp. 175–186. DOI: 10.1177/1063293X07079321.

Sharman, D. M. & Yassine, A. A. (2004). Characterizing complex product architectures. In: *Syst. Engin., 7*(1), pp. 35–60. DOI: 10.1002/sys.10056.

Sheard, S. A. & Mostashari, A. (2010). 7.3.1 A Complexity Typology for Systems Engineering. In: *INCOSE International Symposium, 20*(1), pp. 933–945. DOI: 10.1002/j.2334-5837.2010.tb01115.x.

Shenhar, J. A. (2001). One Size Does Not Fit All Projects: Exploring Classical Contigency Domains. In: *Management Science, 47*(3), pp. 394–414.

Silvestre, L. (2015). Automatic Generation of Transformations for Software Process Tailoring. In: *SRC@ MoDELS*.

Simidchieva, B. I.; Clarke, L. A. & Osterweil, L. J. (2007). Representing Process Variation with a Process Family. In: Wang, Q. & Pfahl, D. (Eds.) *Software process dynamics and agility*. Berlin: Springer, pp. 109–120. DOI: 10.1007/978-3-540-72426-1_10.

Skalak, S. (2002). *Implementing concurrent engineering in small companies*. New York: Marcel Dekker.

Skalak, S. C.; Kemser, H.-P. & Ter-Minassian, N. (1997). Defining a Product Development Methodology with Concurrent Engineering for Small Manufacturing Companies. In: *Journal of Engineering Design, 8*(4), pp. 305–328.

Slaughter, S. A.; Levine, L.; Ramesh, B.; Pries-Heje, J. & Baskerville, R. (2006). Aligning software processes with strategy. In: *MIS Quarterly, 30*(4), 891-918.

Smith, P. G. (1996). Your Product Development Process Demands Ongoing Improvement. In: *Research-Technology Management, 39*(2), pp. 37–44. DOI: 10.1080/08956308.1996.11671049.

Smith, R. P. & Morrow, J. a. (1999). Product development process modeling. In: *Design Studies, 20*(3), pp. 237–261. DOI: 10.1016/S0142-694X(98)00018-0.

Sosa, M. E.; Eppinger, S. D. & Rowles, C. M. (2004). The Misalignment of Product Architecture and Organizational Structure in Complex Product Development. In: *Management Science, 50*(12), pp. 1674–1689. DOI: 10.1287/mnsc.1040.0289.

Spear, S. & Bowen, H. (1999). Decoding the DNA of the Toyota production system. In: *Harvard Business Review, 77*(5), pp. 87–106.

Spender, J.-C. (1996). Making knowledge the basis of a dynamic theory of the firm. In: *Strat. Mgmt. J., 17*(S2), pp. 45–62. DOI: 10.1002/smj.4250171106.

Stachowiak, H. (1973). *Allgemeine Modelltheorie*. Wien: Springer.

Stegbauer, C. (2010). *Netzwerkanalyse und Netzwerktheorie*. Wiesbaden: VS Verlag für Sozialwissenschaften. DOI: 10.1007/978-3-531-92029-0.

Stephens, M. & Rosenberg, D. (2003). *Extreme programming refactored: The case against XP*. Berkeley, Calif.: Apress.

Stetter, R. & Pulm, U. (2009). Problems and Chances in Industrial Mechatronic Product Development. In: *Proceedings of the 17th international Conference on Engineering Design (ICED'09)*.

Steward, D. V. (1981). The design structure system: A method for managing the design of complex systems. In: *IEEE Transactions on Engineering Management, EM-28*(3), pp. 71–74. DOI: 10.1109/TEM.1981.6448589.

Stockmann, R. (2007). *Handbuch zur Evaluation: Eine praktische Handlungsanleitung*. Münster: Waxmann.

Takeuchi, H. & Nonaka, I. (1986). The New New Product Development Game. In: *Harvard Business Review, 64*(1).

Tatikonda, M. V. & Rosenthal, S. R. (2000). Successful execution of product development projects: Balancing firmness and flexibility in the innovation process. In: *Journal of Operations Management, 18*(4), pp. 401–425.

Teece, D. J. (2003). Knowledge and Competence as Strategic Assets. In: Holsapple, C. (Ed.) *Handbook on Knowledge Management 1: Knowledge matters*. Berlin, Heidelberg, New York, Hong Kong: Springer, pp. 129–152.

Ternité, T. (2010). *Variability of Development Models: An approach for the adaptation of development models*. PhD Thesis. Clausthal: Department of Informatics, Technische Universität Clausthal.

Thompson, J. (2008). *Organizations in action: Social science bases of administrative theory*. New Brunswick, NJ: Transaction Publ.

Thörn, C. & Sandkuhl, K. (2009). Feature Modeling: Managing Variability in Complex Systems. In: Tolk, A. & Jain, L. (Eds.) *Complex Systems in Knowledge-based Environments: Theory, Models and Applications*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 129–162. DOI: 10.1007/978-3-540-88075-2_6.

Tittmann, P. (2003). *Graphentheorie: Eine anwendungsorientierte Einführung ; mit zahlreichen Beispielen und 80 Aufgaben*. München: Fachbuchverl. Leipzig im Hanser-Verl.

Tukker, A. (2004). Eight types of product–service system: Eight ways to sustainability? Experiences from SusProNet. In: *Bus. Strat. Env., 13*(4), pp. 246–260. DOI: 10.1002/bse.414.

Tuomi, I. (1999). Data Is More than Knowledge: Implications of the Reversed Knowledge Hierarchy for Knowledge Management and Organizational Memory. In: *Journal of Management Information Systems, 16*(3), pp. 103–117.

Turau, V. & Weyer, C. (2015). *Algorithmische Graphentheorie*. Berlin: De Gruyter.

Ulrich, K. & Eppinger, S. (2008). *Product design and development*. Boston: McGraw-Hill/Irwin.

Vajna, S. (2005). Workflow for Design. In: Clarkson, J. & Eckert, C. (Eds.) *Design process improvement*. London [U.K.]: Springer.

Valenca, G.; Alves, C.; Alves, V. & Niu, N. (2013). A Systematic Mapping Study on Business Process Variability. In: *IJCSIT, 5*(1), pp. 1–21. DOI: 10.5121/ijcsit.2013.5101.

van Beek, T. J. & Tomiyama, T. (2008). Connecting Views in Mechatronic Systems Design, a Function Modeling Approach. In: *International Conference on Mechtronic and Embedded Systems and Applications (MESA'2008),* Beijing, China, pp. 164–169. DOI: 10.1109/MESA.2008.4735676.

van den Berg, H. A. (2013). Three shapes of organisational knowledge. In: *J of Knowledge Management, 17*(2), pp. 159–174. DOI: 10.1108/13673271311315141.

Varvasovszky, Z. & Brugha, R. (2000). A stakeholder analysis. In: *Health Policy and Planning, 15*(3), pp. 338–345.

Vasconcelos, R. R.; Schots, M. & Werner, C. (2013). *Recommendations for Context-Aware Visualizations in Software Development*. In: *10th Workshop on Modern Software Maintenance*, pp. 41–48.

VDI 2206, 2004. *Entwicklungsmethodik für mechatronische Systeme.* Verein Deutscher Ingenieure.

Vom Brocke, J. & Sonnenberg, C. (2011). Prozesstransparenz als Grundlage für das Management und Controlling von Geschäftsprozessen. In: *Z Control Manag, 55*(S2), pp. 55–68. DOI: 10.1365/s12176-012-0334-5.

Vom Brocke, J.; Zelt, S. & Schmiedel, T. (2016). On the role of context in business process management. In: *International Journal of Information Management, 36*(3), pp. 486–495. DOI: 10.1016/j.ijinfomgt.2015.10.002.

Walden, D.; Roedler, G.; Forsberg, K.; Hamelin, R. & Shortell, T. (2015). *Systems engineering handbook: A guide for system life cycle processes and activities*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Washizaki, H. (2006). Building software process line architectures from bottom up. In: Münch, J. & Vierimaa, M. (Eds.) *Product-focused software process improvement*. Berlin, New York: Springer, pp. 415–421.

Wasserman, S. & Faust, K. (1994). *Social Network Analysis: Methods and Applications*. Cambridge: Cambridge University Press. DOI: 10.1017/CBO9780511815478.

Webster, J. & Watson, R. (2005). Analyzing the past to prepare for the future: Writing a Literature Review, *253*(September), pp. 42–49.

Wenger, E.; McDermott, R. & Snyder, W. (2010). *Cultivating communities of practice: A guide to managing knowledge*. Boston, Mass.: Harvard Business School Press.

Whitaker, S. (2012). The Art of Tailoring: Making your Project Methodology Fit. In: *2012 PMI Global Congress Proceedings*, Vancouver, Canada, pp. 1–9.

Whitaker, S. (2014). *The Benefits of Tailoring: Making a Project Management Methodology Fit*, Project Management Institute.

Wiig, K. (1995). *Knowledge management*. Arlington, Tex.: Schema Press.

Wilberg, J.; Triep, I.; Hollauer, C. & Omer, M. (2017). Big Data in Product Development: Need for a Data Strategy. In: Kocaoglu, D. & Anderson, T. (Eds.) *PICMET '17. Portland International Conference on Management of Engineering and Technology : proceedings : Technology Management for the Interconnected World*, Portland, OR, pp. 1–10. DOI: 10.23919/PICMET.2017.8125460.

Wyatt, D. F.; Wynn, D. C. & Clarkson, P. J. (2014). A Scheme for Numerical Representation of Graph Structures in Engineering Design. In: *J. Mech. Des.*, *136*(1), p. 11010. DOI: 10.1115/1.4025961.

Wynn, D. C. & Clarkson, P. J. (2017). Process models in design and development. In: *Res Eng Design*, *41*(3), p. 458. DOI: 10.1007/s00163-017-0262-7.

Wynn, D. C. & Eckert, C. M. (2017). Perspectives on iteration in design and development. In: *Res Eng Design*, *28*(2), pp. 153–184. DOI: 10.1007/s00163-016-0226-3.

Wynn, D. C.; Eckert, C. M. & Clarkson, P. J. (2006). Applied Signposting: A Modeling Framework to Support Design Process Improvement. In: *ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, Philadelphia, Pennsylvania, USA, pp. 553–562. DOI: 10.1115/DETC2006-99402.

Wysocki, R. (2012). *Effective project management: Traditional, agile, extreme*. Hoboken, N.J: Wiley.

Xu, P. (2005). Knowledge Support in Software Process Tailoring. In: *Proceedings of the 38th Annual Hawaii International Conference on. DOI:* 10.1109/HICSS.2005.380.

Xu, P. & Ramesh, B. (2003). A Tool for the capture and use of Process knowledge in process tailoring. In: Sprague, R. (Ed.) *Proceedings of the 36th Annual Hawaii International Conference on System Sciences*. Los Alamitos, Calif.: IEEE Computer Soc.

Xu, P. & Ramesh, B. (2007). Software Process Tailoring: An Empirical Investigation. In: *Journal of Management Information Systems*, *24*(2), pp. 293–328. DOI: 10.2753/MIS0742-1222240211.

Xu, P. & Ramesh, B. (2008a). Impact of Knowledge Support on the Performance of Software Process Tailoring. In: *Journal of Management Information Systems, 25*(3), pp. 277–314. DOI: 10.2753/MIS0742-1222250308.

Xu, P. & Ramesh, B. (2008b). Using Process Tailoring to Manage Software Development Challenges. In: *IT Professional*, *10*(4), pp. 39–45. DOI: 10.1109/MITP.2008.81.

Yamada, T. (2009). A Generic Method for Defining Viewpoints in SysML. In: *INCOSE International Symposium, 19*(1), pp. 844–852. DOI: 10.1002/j.2334-5837.2009.tb00986.x.

Yoon, I.-C.; Min, S.-Y. & Bae, D.-H. (2001). Tailoring and verifying software process. In: *APSEC 2001. Eighth Asia-Pacific Software Engineering Conference : proceedings : 4-7 December, 2001, Macao, China*, Macao, China, pp. 202–209. DOI: 10.1109/APSEC.2001.991478.

Zakaria, N. A.; Suhaimi, I. & Naz'ri Mahrin, M. (2015a). A Proposed Value-Based Software Process Tailoring Framework. In: Atan, R. (Ed.) *2015 9th Malaysian Software Engineering Conference (MySEC2015)*. [Piscataway, NJ], [Piscataway, NJ]: IEEE, pp. 149–153.

Zakaria, N. A.; Suhaimi, I. & Naz'ri Mahrin, M. (2015b). The State of the Art and Issues in Software Process Tailoring. In: Zain, J. (Ed.) *2015 4th International Conference on Software Engineering and Computer Systems (ICSECS)*. [Piscataway, New Jersey]: IEEE, pp. 130–135.

Zhang, X.; Hao, Y. & Thomson, V. (2015). Taking Ideas from Paper to Practice: A Case Study of Improving Design Processes through Detailed Modeling and Systematic Analysis. In: *IFAC-PapersOnLine, 48*(3), pp. 1043–1048. DOI: 10.1016/j.ifacol.2015.06.221.

Zhiyang, L. & Lu, L. (2009). Complex Network Property Analysis of Knowledge Cooperation Networks. In: Luo, Q. (Ed.) *International Symposium on Intelligent Ubiquitous Computing and Education, 2009. IUCE 2009 ; 15 - 16 May 2009, Chengdu, China*, Chengdu, China, pp. 544–547. DOI: 10.1109/IUCE.2009.117.

Zhu, W.; Shao, L. & Huang, Z. (2007). Social Network Analysis Application in Tacit Knowledge Management. In: *Workshop on Intelligent Information Technology Application (IITA 2007),* Zhang Jiajie, China, pp. 294–297. DOI: 10.1109/IITA.2007.46.

11 Lists

11.1 List of figures

11.2 List of tables

11.3 List of supervised student theses

The chronologically listed student theses[63] were supervised and closely guided by the author in the context of this dissertation and delivered valuable content.

PE-Kajbring (2016)
Kajbring, M. (2016). *Mixed Project Environments – an approach to support project classification.* Unpublished Bachelor Thesis. Chair of Product Development, Technical University of Munich.

PE-Spath (2016)
Spath, T. (2016). *TUfast Urban Concept: Systematische Gestaltung eines kontextspezifischen Entwicklungssprozesses.* Unpublished Semester Thesis. Chair of Product Development, Technical University of Munich.

PE-Höhn (2016)
Höhn, M. (2016). *Datenunterstützung im Entwicklungsprozess – Case Study eines studentischen Konstruktionsprojektes* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Ralser (2017)
Ralser, F. (2017). *Modellbasierte Koordinationsplanung in komplexen Entwicklungsprojekten an einem industriellen Fallbeispiel.* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Frisch (2017a)
Frisch, B. (2017). *Kontextorientierte Prozessgestaltung – Anwendung und Weiterentwicklung einer Methodik zur Akquise, Modellierung und Analyse von Prozesskontexten in der Produktentwicklung.* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Frisch (2017b)
Frisch, A. (2017). *Kontextorientierte Analyse und Gestaltung von Freigabeprozessen in der Automobilindustrie.* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Pavlitzek (2017)
Pavlitzek, G. (2017). *Optimierung des Projekt- und Kostenmanagements im „<redacted>“ Entwicklungsprozess – Konzipierung eines Projektkonfigurators.* Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

[63] Some of the titles have been redacted within this thesis in order to protect the confidentiality of the industry partners, as indicated by “<redacted>”.

PE-Sowa (2017)

Sowa, J. (2017). *Systematische Definition anwenderspezifischer Views für ein Process Architecture Framework: Entwicklung und Anwendung eines Vorgehensmodells für das Projektmanagement.* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich, 2017

PE-Gantenbein (2017)

Gantenbein, F. (2017). *Ganzheitliche Methodik zur Erhebung, Modellierung und Analyse des Kontexts von Produktentwicklungsprozessen (MEMAP).* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich, 2017

PE-Langner (2017)

Langner, M. (2017). *Entwicklung eines Vorgehensmodells zur Einführung von Prozesstailoring: Umsetzungsmethoden, Kontextvariablen und deren Darstellung am Beispiel der <redacted>*. Unpublished Master Thesis, Chair of Product Development, Technical University of Munich, 2018

PE-Akiner (2017)

Akiner, B. A. (2017). *Prozesstailoring in der Produktentwicklung – Methodische Entwicklung eines Tailoringkonzeptes am Beispiel <redacted>*. Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Rogger (2018)

Rogger, L. (2018). *Variantenreiche Prozesse in der Produktentwicklung: Entwicklung einer Methode zur Erfassung und Abbildung eines tailorbaren Standardprozesses am Beispiel eines Nutzfahrzeugherstellers.* Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Rast (2018)

Rast, J. (2018). *Systematische Implementierungsplanung von Prozesstailoring am Beispiel <redacted>*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Wankmiller (2018)

Wankmiller, G. (2018). *Prozesstailoring in der Produktentwicklung – Methodischer Entwurf eines situationsspezifisch anpassbaren Entwicklungsprozesses für die Vorentwicklung eines mittelständischen Unternehmens.* Unpublished Master Thesis, Chair of Product Development, Technical University of Munich.

PE-Sapundziev (2018)

Sapundziev, D. (2018). *A graph-based approach for the analysis of context and process data.* Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Saad (2018)

Saad, D. (2018): *Entwicklung eines flexiblen Entwicklungsprozesses mittels Tailoring für ein Start-Up in der Medizintechnik.* Unpublished Semester Thesis. Chair of Product Development, Technical University of Munich.

PE-Thomas (2018)

Thomas, R. (2018). *Methodical development of context-oriented modular processes in product development*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Philipp (2017)

Philipp, K. (2017). *Kontextorientierte Entwicklung eines Prozessbaukastens für die Produktentwicklung bei <redacted>*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Musch (2018)

Musch, P. (2018). *Modellierung variantenreicher Prozesse als Grundlage für systematisches Tailoring*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Kölsch (2018)

Kölsch, F. (2018). *Methodisches Vorgehen zur systematischen Analyse von Tailoring-Wissen mittels Strukturmetriken*. Unpublished Semester Thesis. Chair of Product Development, Technical University of Munich.

PE-Schwertlein (2018)

Schwertlein, S. (2018). *Entwicklung einer Methodik zur Unterstützung des Sensorintegrationsprozesses für hochautomatisiertes Fahren auf Basis einer Prozesvarianzanalyse*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

PE-Gisdakis (2018)

Gisdakis, S. (2018). *Modellierung variantenreicher Prozesse in der Entwicklung am Beispiel eines Lessons Learned Prozess eines Automobil OEM*. Unpublished Master Thesis. Chair of Product Development, Technical University of Munich.

Appendix

A1 Supplementary material: Background and related work

A1.1 Process lifecycle model

Figure A-1 depicts a detailed PDP lifecycle model, which spans reference as well as deployed processes. It highlights context-related activities related to process tailoring

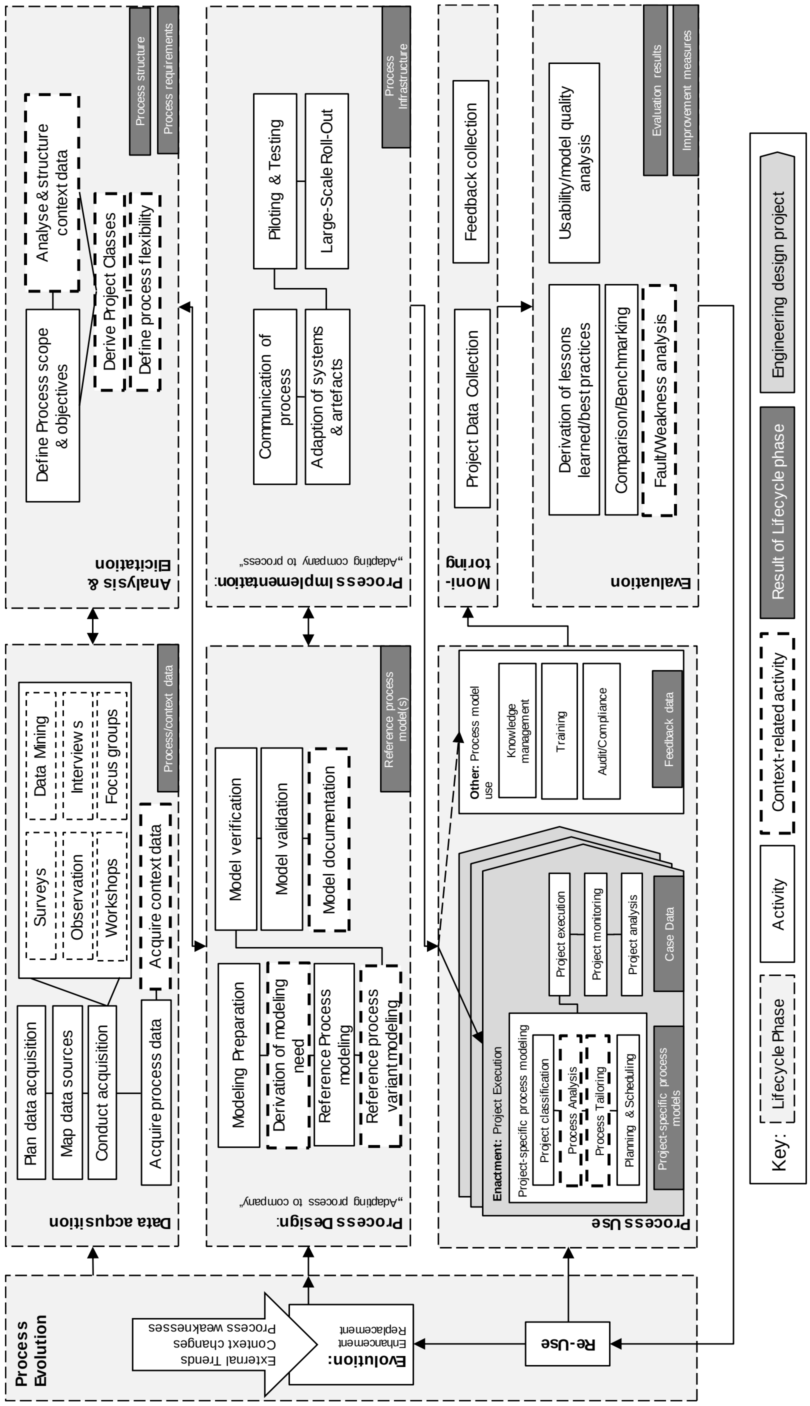


Figure A-1: Process lifecycle model (Hollauer et al., 2018f)

A1.2 Literature review data

In order to increase the coverage of the different related research areas, several individual literature reviews have been conducted as listed in Table A-1, compiling and cross-referencing the final results. While the individual literature reviews have a particular focus, overlaps in results are expected, due to the relationships between the research areas. All reviews focused on English literature.

Table A-1: Overview of conducted literature reviews

Topic/Focus	**Documented in**
Initial explorative review of tailoring literature	Hollauer & Lindemann, 2017
Tailoring approaches	PE-Langner, 2017
Context acquisition and documentation	PE-Gantenbein, 2017
Variant-rich process modeling and management	PE-Rogger, 2018
Variant-rich process modeling and management	PE-Musch, 2018
Analysis of tailoring knowledge	PE-Kölsch, 2018

The following subsections describe the individual literature reviews and the corresponding results. The systematic reviews predominantly focused on literature in English. As applicable, the following information is given for each review: The utilized keywords in form of a keyword matrix (combinations of keywords using AND OR operators), the derived search strings, yielded results, subsequent reduction via inclusion/exclusion criteria, and final list of relevant results.

For all results, full citations are given in case a publication is not further quoted within this thesis.

A1.2.1 Review: Process tailoring approaches

The initial, explorative literature focused on identifying related approaches for supporting process tailoring. The review and identified approaches have been published in Hollauer & Lindemann (2017).

The utilized keyword matrix is presented in Table A-2.

Table A-2: Keyword matrix for initial explorative review

	Topical aspects (AND-relationship)		
Synonyms (OR-relationship)	Engineering	Process	Tailoring
	Design	Project	

IEEEXplore, *WebofScience*, *Scopus*, *ScienceDirect*, and the database of the *German national library* (DNB) have been used as search databases, the latter focusing on PhD theses. The search has been limited to the years 1999 to 2016 with literature in German and English, Due to the low number of identified publications in the DNB data base (4), search parameters have been extended to general process management, adding 64 results. The initial results have been used as input for a backward and forward reference search. 63 final results were analyzed for the presented approaches.

The initial literature review resulted in a list of preliminary references (Hollauer & Lindemann, 2017), and – equally important – allowed to structure the subsequent reviews and derive more concrete keywords. As the results show, a broad range of approaches was initially identified, which were subsequently reduced.

Table A-3: Results for initial tailoring approach review

Approach	**Reference**
General requirements	Martinez-Ruiz et al., 2012
V-Model XT reference model	Armbrust, O.; Ebell, J.; Hammerschall, U.; Münch, J. & Thoma, D. (2008). Experiences and results from tailoring and deploying a large process standard in a company. In: Software Process: Improvement and Practice (13), pp. 301–309. DOI: 10.1002/spip.391.
Framework/ methodology	Ginsberg & Quinn, 1995
	Xu & Ramesh, 2008b
	Ittner, 2006
	Golra, 2014
	Fontoura & Price, 2007
	Eíto-Brun, R. (2015). A Layered Framework for Managing Access to Customer-provided Process Requirements. In: Rout, T.; O'Connor, R. & Dorling, A. (Eds.), *Software Process Improvement and Capability Determination*. Cham: Springer International Publishing, pp. 239–244. DOI: 10.1007/978-3-319-19860-6_19.

Approach	Reference
	Killisperger et al., 2010
CASPER	Hurtado Alegria, 2012
	Alegria, J. A. & Bastarrica, M. C. (2012). Building software process lines with CASPER. In: Jeffery, R. (Ed.), *International Conference on Software and System Process (ICSSP)*. Piscataway, NJ: IEEE, pp. 170–179. DOI: 10.1109/ICSSP.2012.6225962.
Metamodel	Wang, H.; Du, X. & Zhang, H. (2012). Software Project Process Models: From Generic to Specific. In: *Recent advances in computer science and information engineering.* Berlin: Springer, pp. 529–537. DOI: 10.1007/978-3-642-25789-6_72.
	Martinez-Ruiz, T.; Garcia, F.; Piattini, M. & Munch, J. (2011). Applying AOSE Concepts to Model Crosscutting Variability in Variant-Rich Processes. In: Biffl, S. (Ed.) *37th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA)* Oulu, Finland, pp. 334–338. DOI: 10.1109/SEAA.2011.58.
	Kalus, 2013
	Killisperger et al., 2009
Process lines	Kuhrmann, M.; Fernández, D. M. & Ternité, T. (2014). Realizing software process lines: insights and experiences. In: *Proceedings of the 2014 International Conference on Software and System Process (ICSSP 2014)*, pp. 99–108. DOI: 10.1145/2600821.2600833.
	Ternité, T. (2009). Process Lines: A product line approach designed for process model development. In: *35th Euromicro Conference on Software Engineering and Advanced Applications*. Piscataway, NJ: IEEE, pp. 173–180. DOI: 10.1109/Seaa.2009.48.
Unified lifecycle template	He, R.; Wang, H. & Lin, Z. (2009). A Software Process Tailoring Approach Using a Unified Lifecycle Template. In: *International Conference on Computational Intelligence and Software Engineering*. Piscataway, NJ: IEEE, pp. 1–7. DOI: 10.1109/CISE.2009.5362562.
Optimization	Magdaleno, A. M. (2010). An Optimization-based Approach to Software Development Process Tailoring. In: Briand, L. (Ed.) *Second International Symposium on Search Based Software Engineering (SSBSE)*. Piscataway, NJ: IEEE, pp. 40–43. DOI: 10.1109/SSBSE.2010.15.
Megamodel	Simmonds, J.; Perovich, D.; Bastarrica, M. C. & Silvestre, L. (2015). A megamodel for Software Process Line modeling and evolution. In: *ACM/IEEE 18th International Conference on Model Driven Engineering Languages and Systems (MODELS)*. Ottawa, ON, pp. 406–415. DOI: 10.1109/MODELS.2015.7338272.
MDE-based approach	Hurtado Alegría et al., 2011
	Hurtado Alegría et al., 2014
	Silvestre, L.; Bastarrica, M. C. & Ochoa, S. F. (2014). A Model-based Tool for Generating Software Process Model Tailoring Transformations. In: *2nd International Conference on Model-Driven Engineering and Software Development (MODELSWARD)*, pp. 533–540.
BMPNt	Pillat et al., 2015
Business process design environment	Dörner, C.; Yetim, F.; Pipek, V. & Wulf, V. (2011). Supporting business process experts in tailoring business processes. In: *Interacting with Computers (23)*, pp. 226–238. DOI: 10.1016/j.intcom.2011.03.001.

Approach	Reference
Project scoping	Armbrust, O. (2010). Determining organization-specific process suitability. In: Münch, J.; Yang, Y. & Schäfer, W. (Eds.) *New modeling concepts for today's software processes.* Berlin: Springer, pp. 26–38.
	Armbrust, O.; Katahira, M.; Miyamoto, Y.; Münch, J.; Nakao, H. & Ocampo, A. (2008). Scoping Software Process Models - Initial Concepts and Experience from Defining Space Standards. In: Wang, Q. (Ed.) *Making globally distributed software development a success story*. Berlin: Springer, pp. 160–172. DOI: 10.1007/978-3-540-79588-9_15.
	Armbrust et al., 2009
Project context modeling	Du Preez et al., 2008
	Du Preez et al., 2009
	Kalus & Kuhrmann, 2013
	Hurtado Alegría et al., 2014
	Hurtado & Bastarrica, 2009
	Ortega et al., 2012
Challenge assessment questionnaire	Xu & Ramesh, 2008b
Process slicing & case-based reasoning	Park, S.-H. & Bae, D.-H. (2013). Tailoring a large-sized software process using process slicing and case-based reasoning technique. In: *IET Software (7)*, pp. 47–55. DOI: 10.1049/iet-sen.2011.0192.
Process modules	Yoon et al., 2001
Process patterns	Khaari, M. & Ramsin, R. (2010). Process Patterns for Aspect-Oriented Software Development. In: Sterritt, R. (Ed.) *17th IEEE International Conference and Workshop on the Engineering of Computer Based Systems (ECBS 2010)*. Piscataway, NJ: IEEE, pp. 241–250. DOI: 10.1109/ECBS.2010.33.
	Fahmideh, M.; Sharifi, M.; Jamshidi, P.; Shams, F. & Haghighi, H. (2011). Process patterns for service-oriented software development. In: Staff, I. (Ed.) *Fifth International Conference on Research Challenges in Information Science*: IEEE, pp. 1–9. DOI: 10.1109/RCIS.2011.6006856.
	Asadi et al., 2010
Process configuration	Josefiak, F. (2013). *Intelligente, universal adaptive Prozessmodelle für ein integriertes Innovationsmanagement am Beispiel der Logistik*. Aachen: Shaker.
Situational method engineering	Bass, J. M. (2014). Scrum Master Activities: Process Tailoring in Large Enterprise Projects. In: *IEEE 9th International Conference on Global Software Engineering (ICGSE)*. 18 - 21 Aug. 2014, Shanghai, China, Shanghai, China, pp. 6–15. DOI: 10.1109/ICGSE.2014.24.
	Brasil, M. A.; Pereira, G. V. & Fontoura, L. M. (2012). Software process tailoring using Situational Method Engineering based on criteria of quality improvement. In: Donoso Meisel, Y. (Ed.) *XXXVIII Conferencia Latinoamericana en Informática (CLEI)*. Piscataway, NJ: IEEE, pp. 1–8. DOI: 10.1109/CLEI.2012.6427185.
	Pereira et al., 2012
Activity-based tailoring	Lorenz et al., 2014

Approach	Reference
Tool-chain tailoring	Wolff, C.; Krawczyk, L.; Hottger, R.; Brink, C.; Lauschner, U.; Fruhner, D.; Kamsties, E. & Igel, B. (2015). AMALTHEA — Tailoring tools to projects in automotive software development. In:, *IEEE 8th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications (IDAACS)*. Piscataway, NJ: IEEE, pp. 515–520. DOI: 10.1109/IDAACS.2015.7341359.
Feature-based tailoring	Kalus, 2013
Role-mapping	Borges, P.; Monteiro, P. & Machado, R. J. (2011). Tailoring RUP to Small Software Development Teams. In: Biffl, S. (Ed.) *37th EUROMICRO Conference on Software Engineering and Advanced Applications (SEAA)*, Oulu, Finland, pp. 306–309. DOI: 10.1109/SEAA.2011.55.
Knowledge based/support	Fontoura & Price, 2007
	Xu, 2005
Case-based reasoning	Xiong, F. & Cen, Y. (2010). Applying the Fuzzy Expert System to Tailoring Software Development Flow. In: *International Conference on E-Product, E-Service and E-Entertainment (ICEEE)*. Piscataway, NJ: IEEE, pp. 1–5. DOI: 10.1109/ICEEE.2010.5660429.
	Redenius, A. (2006). *Verfahren zur Planung von Entwicklungsprozessen für fortgeschrittene mechatronische Systeme*. Paderborn: Heinz-Nixdorf-Inst.
Rule-based process planning	Spieß, D. (2010). *Konzept zur regelbasierten Prozessplanung und -durchführung in der virtuellen Produktentwicklung*. Aachen: Shaker.
Neural network-based filtering	Park et al., 2006
Variability Modeling and management	Kuhrmann, M.; Fernandez, D. M. & Ternite, T. (2014). On the use of variability operations in the V-Model XT Software process line. In: *Journal of Software: Evolution and Process (26)*, pp. 1172–1192. DOI: 10.1002/smr.1751.
	Martínez-Ruiz et al., 2013
	Martínez-Ruiz, T.; García, F.; Piattini, M. & Münch, J. (2011). Modelling software process variability: An empirical study. In: *IET Softw. (5)*, p. 172. DOI: 10.1049/iet-sen.2010.0020.
Rationale modeling	Ocampo, A. & Münch, J. (2009). Rationale modeling for software process evolution. In: *Software Process Improvement and Practice (14)*, pp. 85–105. DOI: 10.1002/spip.387.
	Ocampo, A.; Münch, J. & Riddle, W. E. (2009). Incrementally Introducing Process Model Rationale Support in an Organization. In: Wang, Q. (Ed.) *Trustworthy software development processes*. Berlin: Springer, S. 330–341.
	Ocampo, A. & Soto, M. (2007). Connecting the Rationale for Changes to the Evolution of a Process. In: Münch, J. & Abrahamsson, P. (Eds.) *Product-focused software process improvement*. Berlin: Springer, S. 160–174.

A1.2.2 Review: Process tailoring approaches (PE-Langner, 2018)

This literature review focused on exploring the related work regarding process tailoring approaches.

The keyword matrix presented in Table A-4 is the result of several preceding iterations and represented the best compromise between conciseness (precise search strings with low number of resalts) and exhaustion of the search field (generic search strings but high number of results).

Table A-4: Keyword matrix – tailoring approaches

	Topical aspects (AND-relationship)			
Synonyms (OR-relationship)	Software	Development	Tailoring	Method
	Product	Project	Variability	Approach
		Design	Adaptation	Modelling*
		Process	Customisation/Customization	
			Context*	
			Environment*	

Key: ** = Only the indicated terms have been combined in separate search strings, i.e. "context modelling" and "environment modelling"*

The keyword matrix has been used to derived search strings using Boolean operators as indicated. *Google Scholar* and *SCOPUS* have been used as search databases. For performing the search, OR-relationships have been resolved and entered int the databases as distinct search strings. As additional criteria, only publications between the years 2006 and 2017 have been regarded. Patents and citations have been excluded in *Google Scholar*. Identified results have been analyzed to identify further relevant references (backward reference search)

After the results have been exported from the search databases, the results were filtered and reduced to a final set of relevant results, as presented in Table A-6, using the criteria listed in Table A-5.

Table A-5: Exclusion criteria for selection of relevant results

Exclusion	Reference provides no prescriptive tailoring method
	Search terms in title
	Reference does not address project-specific tailoring (e.g. tailoring of agile frameworks, or literature-based reference models such as V-Model or Rational Unified Process)
	Focus on tailoring automation
	Collection of context factors (Review articles were included and used for a backward reference search)

Table A-6: Reduction of initial search results

	Reduction steps (no. of references removed due to…)						
Results	**Title**	**Access rights**	**Language**	**Duplicates**	**Abstract**	**Content**	**Relevant hits**
1436*	595	44	19	522	182	45	29

** SCOPUS: 620; Google Scholar: 816*

The final 29 relevant search results (Table A-7) by the majority address process tailoring in software development (93.1%), although the search keywords addressed both software as well as general product development. Additionally, 51.7% of the final results constitute conference papers. Three references, Akbar et al. (2011), Martinez-Ruiz et al. (2012) and Pedreira et al. (2007) constitute literature reviews and are not listed in the table below. The full citation is given in case a reference is not otherwise quoted within this thesis.

Table A-7: Results for tailoring approaches

Reference
Adedjouma, M. & Hu, H. (2014). Process Model Tailoring and Assessment for Automotive Certification Objectives. In: *IEEE International Symposium on Software Reliability Engineering workshops (ISSREW)*. Piscataway, NJ: IEEE, pp. 503–508. DOI: 10.1109/ISSREW.2014.23.
Eito-Brun, 2014
Cesare et al., 2008
Choi et al., 2016
Costache et al., 2011
Dai & Li, 2007
Graviss et al., 2016
He et al., 2008
Hikichi, K.; Fushida, K.; Iida, H. & Matsumoto, K. (2006). A Software Process Tailoring System Focusing to Quantitative Management Plans. In: Münch, J. & Vierimaa, M. (Eds.) *Product-focused software process improvement*. Berlin: Springer, pp. 441–446. DOI: 10.1007/11767718_41.
Hurtado Alegría et al., 2011
Hurtado Alegría et al., 2014
Hurtado & Bastarrica, 2009
Kang et al., 2008
Killisperger et al., 2010
Magdaleno, A. M. (2012). An Optimization-based Approach to Software Development Process Tailoring. In: *2nd international symposium on search based software engineering*, Benevento, Italy, pp. 40–43. DOI: 10.1109/SSBSE.2010.15.
Park, S.-H. & Bae, D.-H. (2013). Tailoring a large-sized software process using process slicing and case-based reasoning technique. In: *IET Software (7)*, pp. 47–55. DOI: 10.1049/iet-sen.2011.0192.
Park et al., 2006

Reference
Pereira, E. B.; Bastos, R. M. & Oliveira, T. C. (2008). Process tailoring based on well-formedness rules. In: *SEKE*. Skokie, Il.: Knowledge Systems Institute Graduate School, pp. 185–190.
Pillat et al., 2012
Pillat et al., 2015
Rui, H.; Hao, W. & Zhiqing, L. (2009). A Software Process Tailoring Approach Using a Unified Lifecycle Template. In: *International Conference on Computational Intelligence and Software Engineering (CiSE 2009)*. Piscataway, NJ: IEEE, pp. 1–7.
Srivannaboon, S. (2006). Toward a Contingency Approach: Tailoring Project Management to Achieve a Competitive Advantage. In: *Technology Management for the Global Future - PICMET 2006 Conference*: IEEE, pp. 2187–2194.
Xu & Ramesh, 2007
Xu & Ramesh, 2008b
Zakaria et al., 2015a
Zakaria et al., 2015b

A1.2.3 Review: Context acquisition and modeling (PE-Gantenbein, 2018)

The literature review focused on identifying approaches related to context modeling, which can be used to elicit and document the context of deployed processes. The literature review was therefore split into two parts, methods for the acquisition as well as documentation of process contexts.

Context acquisition

The matrix used to structure the keywords is presented in Table A-8. The matrix has been successively extended over the execution of the review.

Table A-8: Keyword matrix – context acquisition

		Context								
		Context factor	Contextual factor	Context analysis	Context-aware	Influence factor	Contextual influence	Kontextfaktor	Einflussfaktor	**Additional combinations**
Product development process	Product development process	●		●		●	●			
	Product design process	●		●						
	Design process	●	●							Evaluation
	Design process model	●			●					Influence context
	Generic process model	●			●					Adaptation context
	Engineering design	●	●							Influence adaptation context
	Engineering design process	●		●						
	Produktentwicklungsprozess							●	●	
Adaptation of process	Process design	●	●	●	●	●	●			Evaluation “context factor”
	Process adaptation	●								
	Adapt process	●								
	Business process reengineering	●								
	Process variant modelling									Context

Key: ● *=combination of keywords for search string generation*

The keyword matrix has been used to derive search strings. *Google Scholar*, *SCOPUS* and *BASE* (Bielefeld Academic Search Engine) have been used as databases. Identified results have been analyzed to identify further relevant references (backward reference search).

The conducted searches and corresponding results are listed in Table A-9.

Table A-9: Search strings for context factor acquisition and number of results

	Number of results			
Search string	Google Scholar	BASE	Scopus	Relevant Results
"context factor" "product design process"	12	0	0	
collect "context factor" in product design processes	1910	6	0	
erhebung kontextfaktoren produktentwicklung	450	0	0	2
"design process" "context factor"	238	0	3	1
"engineering design process" "influence factor"	27	1	1	1
"engineering design process" "context analysis"	55	0	1	
"product design process" "context analysis"	69	0	0	
"process design" "influence factor"	458	24	14	
"process design" "influence factor" -manufacturing	287			
"process design" "context factor"	82	24	1	4
"process design" "contextual factor"	288	18	20	2
conceptualisation "contextual factor" process	4640			1
mining "context factor" process "Engineering design"	20	0	0	
mining "contextual factor" process "Engineering design"	24	0	0	
mining "context factor" "process design"	35	0	0	2
mining "contextual factor" "process design"	50	0	0	2
collect "contextual factor" "process design"	149	2	0	
collect "context factor" "process design"	75	0	0	
"context-aware" "process design"	1420	34	27	2
"context-aware" "process design" "product development"	244	0	1	
influence "engineering design process" adaption context	2240	5	0	5
"design process model" influence context	1780	12	0	
adapt process "context factor"	1960	45	5	2
"context analysis" "process design"	532	7	3	2
"Business process reengineering" "context factor"	26	1	0	1
adapt "generic process model" context	821		3	
"product development process" "context analysis"	213	3	1	1
"product development process" "context factor"	50	5	2	3
"product development process" "contextual influence"	50	3	1	1
"product development process" "influence factor"	108	20	6	2
"design process model" "context aware"	64	0	0	
"design process model" "context factor"	1	0	0	
"generic process model" "context factor"	2	0	0	1
" process adaptation" "context factor"	19	0	1	2
"process design" "contextual influence"	81	0	1	2

	Number of results			
Search string	**Google Scholar**	**BASE**	**Scopus**	**Relevant Results**
"design process " "contextual factor"	519	42	23	
"software process tailoring" "context factor"	2	0	0	
"process tailoring" "context factor" software	3	0	0	
"software design process" "context factor"	9	0	0	
"generic process model" context adaptation	1000	9	3	1
"generic process model" "context-aware"	61	0	1	1
"engineering design" context	124000			2
"process model" "context factor"	295	4	7	1
"context factor" "process design" evaluation	87	0	0	3
"process variant modelling" context	3	2	0	
"context factor evaluation"	5	0	1	
einflussfaktoren auf "Produktentwicklungsprozess"	886	3		1
kontextfaktoren "Produktentwicklungsprozess"	119	1		4
Final number of relevant results from keyword search (without duplicates):				**12**

Relevant results have been selected in case they provide a prescriptive support to acquire process context factors. In terms of backward reference search, in particular Gericke et al. (2013) provided six further references, creating a total of 18 results.

The final results are listed in Table A-10. The full citation is given in case a reference is not otherwise quoted within this thesis.

Table A-10: Categorized results for context acquisition methods

		Category	
Reference	**Supporting method**	**L**	**I**
Du Preez et al., 2008	Generic List	●	
Maffin et al., 1995	Generic List	●	
Gericke et al., 2013	Generic List	●	
Ponn, 2007	Generic List	●	
Kronsbein et al., 2014	Generic List	●	
Skalak, 2002	Generic List	●	
Kalus, 2013	Generic List	●	
Ulrich & Eppinger, 2008	Generic List	●	
Ehrlenspiel & Meerkamm, 2013	Generic List	●	
Vom Brocke et al., 2016	Morphological box	●	
Hales & Gooch, 2004	List/Guiding questions	●	●
Wörz, U. (2015). *A comprehensive approach for the empirical investigation of success factors in product development.* PhD Thesis. Berlin: Fakultät V - Verkehrs- und Maschinensysteme, Technische Universität Berlin.	Guiding questions		●
Reymen, I. M. M. J. (2001). *Improving design processes through structured reflection: A domain-independent approach.* PhD Thesis. Eindhoven: Stan Ackermans Instituut, Technische Universiteit Eindhoven.	Guiding questions		●
Lindemann, 2009	Question catalog		●
Badke-Schaub & Frankenberger, 2004	(no further support)		●
Ploesser et al., 2009	Performance indicators		●
McQuater, R. E.; Peters, A. J.; Dale, B. G.; Spring, M.; Rogerson, J. H. & Rooney, E. M. (1998). The management and organisational context of new product development: Diagnosis and self-assessment. In: *International Journal of Production Economics (55)*, pp. 121–131. DOI: 10.1016/S0925-5273(98)00063-2.	Categorization		●
Rosemann et al., 2008	Process sub-goals		●
de Vries, V.; Meier, M. & Bircher, M. (2004). Integration of influencing factors in the front end of the new product development process. In: *Proc. of The R and D Management Conference*. DOI: 10.3929/ethz-a-010090527	Influences on process-subgoals		●
Umeokafor, N.; Windapo & Abimbola Olukemi (2016). A framework for managing contextual influence on health and safety in construction projects. In: *9th cidb Postgratuate Conference: Emerging trends in construction organisational practices and project management knowledge area*, Cape Town, pp. 285–294.	Historical project data		●

Key: *L = List-based; I = Interview-based*

Context modeling

The matrix used to structure the keywords is presented in Table A-8. The matrix has been successively extended over execution of the review

Table A-11: Keyword matrix – context modeling

		Context	
		Context modelling	Context modeling
Process	process	●	●
	process adaptation	●	●

The second review focused on identifying method support for modeling context factors for describing process contexts. The conducted searches and corresponding results are listed in Table A-12.

Table A-12: Search strings for context factor modeling and number of results

	Number of results			
Search string	**Google Scholar**	**Base**	**Scopus**	**Relevant results**
“context modelling” process	5500	983	421	2
“context modeling process”	27900	983	421	2
“context modelling” “process adaptation”	39	2	1	1
“context modeling” “process adaptation”	102	2	1	1
Final number of relevant results from keyword search (without duplicates):				6

The final identified results are listed in Table A-13. The full citation is given in case a reference is not otherwise quoted within this thesis.

Table A-13: Identified relevant results for context modeling

Reference
Hurtado Alegría et al., 2011 *(more recent publications in this line of work have been subsequently identified and further used: Hurtado Alegria (2012) and Hurtado Alegría et al. (2014)*
Saidani et al., 2015
La Vara, J. L. de; Ali, R.; Dalpiaz, F.; Sanchez, J. & Giorgini, P. (2010). Business Process Contextualisation via Context Analysis. In: *Proceedings of the 29th International Conference on Conceptual Modeling*, pp. 471–476. DOI: 10.1007/978-3-642-16373-9_37.
Bucchiarone, A.; Marconi, A.; Pistore, M. & Sirbu, A. (2011). A Context-Aware Framework for Business Processes Evolution. In: *15th IEEE International EDOC Conference Workshops.* Helsinki, Finland, pp. 146–154. DOI: 10.1109/EDOCW.2011.47.
Koç, H.; Timm, F.; Espana, S.; González, T. & Sandkuhl, K. (2016). A method for context modelling in capability management. In: *Research Papers*. 43.
Hallerbach, A.; Bauer, T. & Reichert, M. (2007). Managing Process Variants in the Process Life Cycle. In: CTIT Technical Report Series; No. Supplement/TR-CTIT-07-87. Centre for Telematics and Information Technology (CTIT), University of Twente. Enschede, The Netherlands. *(more recent publications in this line of work have been subsequently identified and further used: Hallerbach et al. (2010) and Hallerbach (2009))*

A1.2.4 Review: Variability modeling (PE-Rogger, 2018)

The literature review focused on identifying approaches related to variability modeling, which can be used to design processes which are subsequently tailorable. The keyword matrix to generate search strings is presented in Table A-14.

Table A-14: Keyword matrix – variability modeling

	Topical aspects (AND-relationship)		
Synonyms in English (OR-relationship)	Process variability	Reference process	Approach
	Business process	Standard Process	Methodology
	Process variants	Basic Process	Model
		Customizable Process	Design
		Customization	Developing
			Mapping
			Modeling
Synonyms in German (OR-relationship	Variantenreiche Prozesse	Referenzprozess	Vorgehen
	Variabilität in Geschäftsprozessen	Standardprozess	Methodik
	Prozessvarianten	Basisprozess	Modell
		Anpassbarer Prozess	
		Anpassung	
		Konfiguration	

The keyword matrix has been used to derived search strings using Boolean operators as indicated (Table A-15). *Google Scholar*, *SCOPUS*, and *ScienceDirect* have been used as search databases. As additional criteria, only publications between the years 2000 and 2017 have been regarded, and patents and citations have been excluded in *Google Scholar*. Only *Google Scholar* was used to identify German results. Identified results have been analyzed to identify further relevant references (backward reference search)

Table A-15: Search strings and number of results per database

Database	Search string (German)	Search string (English)	Results
Google Scholar	(Variantenreiche Prozesse OR Variabilität in Geschäftsprozessen OR Prozessvarianten) AND (Referenzprozess OR Standardprozess OR Basisprozess OR Anpassbarer Prozess OR Anpassung OR Konfiguration) AND (Vorgehen OR Methodik OR Modell)	("process variability" OR process variants) AND ("reference process" OR "standard process" OR "basic process" OR customizable process) AND (approach OR design OR developing OR modeling)	German: 198 English: 993
Science Direct		pub-date > 1999 and ("process variability" OR "business process" OR "process variants") AND ("reference process" OR "standard process" OR "basic process" OR "customizable process" OR customization) AND (approach OR methodology OR model OR design OR developing OR mapping OR modeling)[All Sources(Business, Management and Accounting,Computer Science,Decision Sciences,Economics, Econometrics and Finance,Engineering,Social Sciences)].	1213
SCOPUS		TITLE-ABS-KEY (("process variability" OR process AND variants) AND ("reference process" OR "standard process" OR "basic process" OR customizable AND process) AND (approach OR design OR developing OR modeling)) AND PUBYEAR > 1999	70
			Sum: 2474

After the results have been exported from the search databases, using the criteria in Table A-16.the results were filtered and reduced to a final set of relevant results, as presented in Table A-16.

Table A-16: Inclusion and exclusion criteria for selection of relevant results

Inclusion	Reference describes process variability in organizations and includes an approach to define and elicit variant-rich processes
	Reference describes process variability in organizations and includes an approach to document/visualize process variants
Exclusion	Reference does not address process variability
	Reference is not accessible
	Reference describes modeling languages and their extensions
	Reference describes process mining techniques for constructing process models
	Reference does not describe methods for eliciting or documenting variant-rich processes
	Study solely compares approaches

Table A-17 Reduction of search results

Reduction steps (no. of references removed due to)						
Results	**Duplicates**	**Access rights**	**Title**	**Abstract**	**Content**	**Relevant hits**
2474	82	33	2094	127	111	27

The relevant results are presented in Table A-18. The full citation is given in case a reference is not otherwise quoted within this thesis. It has to be noted, that La Rosa et al. (2017) has also been identified but is not listed due to its nature as review paper (cf. section 2.5.4).

Table A-18: Results for variability modeling

Method	**References**
Bi-directional procedure model	Zellner, P.; Laumann, M. & Appelfeller, W. (2015). Towards Managing Business Process Variants within Organizations--An Action Research Study. In: Bui, T. & Sprague, R. (Eds.) *48th Hawaii International Conference on System Sciences (HICSS)*, Kauai, Hawaii, pp. 4130–4139.
Process decomposition	Milani et al., 2016 Milani, 2015
Multi-perspective approach	Saidani, O. & Nurcan, S. (2014). Business process modeling: a multi-perspective approach integrating variability. In: *Enterprise, Business-Process and Information Systems Modeling*. Springer, pp. 169–183.
Feature-based modeling	Asadi, M. (2014). *Developing and Validating Customizable Process Models*. PhD Thesis. Vancouver, Canada: Communication, Art & Technology: School of Interactive Arts and Technology, Simon Frasier University. Asadi, M.; Mohabbati, B.; Gröner, G. & Gasevic, D. (2014). Development and validation of customized process models. In: *Journal of Systems and Software (96)*, pp. 73–92.
Questionnaire model	La Rosa, M. (2009). *Managing variability in process-aware information systems.* PhD Thesis: Faculty of Science and Technology, Queensland University of Technology. La Rosa et al., 2009 La Rosa & Dumas, 2008

Method	References
	La Rosa, M.; Dumas, M. & Ter Hofstede, A. H. (2008). *Modelling business process variability*, IDEA Group. La Rosa, M.; Dumas, M.; Ter Hofstede, A. H. & Mendling, J. (2011). Configurable multi-perspective business process models. In: *Information Systems (36)*, pp. 313–340. Schaidt, S.; Santos, E. A.; Vieira, A. D. & Loures, Eduardo de Freitas Rocha (2017). Dealing with Variability: A Control-Based Configuration of Process Variants. In: Álvaro Rocha; Ana Maria R. Correia; Hojjat Adeli; Luis Paulo Reis & Sandra Costanzo (Eds.), *Recent Advances in Information Systems and Technologies - Volume 1*, Porto Santo Island, Madeira, Portugal, pp. 416–425. DOI: 10.1007/978-3-319-56535-4_42.
Provop (Process variants by options)	Hallerbach, a.; Bauer, T. & Reichert, M. (2008). Managing process variants in the process life cycle. In: Proceedings of the 10th International Conference on Enterprise Information Systems (ICEIS 2008), pp. 154–161. Hallerbach, A.; Bauer, T. & Reichert, M. (2008). Context-based configuration of process variants. In: *3rd International Workshop on Technologies for Context-Aware Business Process Management (TCoB 2008)*, Barcelona, Spain. Hallerbach, 2009 Hallerbach, A.; Bauer, T. & Reichert, M. (2009). Issues in modeling process variants with provop. In: Aalst, W.; Ardagna, D.; Mecella, M.; Mylopoulos, J.; Sadeh, N.; Shaw, M.; Szyperski, C. & Yang, J. (Eds.) *Business Process Management Workshops. BPM 2008 International Workshops*, Milano, Italy, September 1-4, 2008. Revised Papers, pp. 56–67. Hallerbach, A.; Bauer, T. & Reichert, M. (2009). Guaranteeing soundness of configurable process variants in Provop. In: Hofreiter, B. (Ed.), *IEEE Conference on Commerce and Enterprise Computing (CEC '09*), Vienna, Austria, pp. 98–105. Hallerbach, A.; Bauer, T. & Reichert, M. (2009). *Correct configuration of process variants in PROVOP*, Faculty of Electrical Engineering and Computer Science, University of Ulm. Ulm. Hallerbach, A.; Bauer, T. & Reichert, M. (2010). Capturing variability in business process models: The Provop approach. In: *Journal of Software Maintenance and Evolution (22)*, pp. 519–546. DOI: 10.1002/smr.491. Hallerbach, A.; Bauer, T. & Reichert, M. (2010). Configuration and management of process variants. In: *Handbook on Business Process Management 1*: Springer, pp. 237–255. Hallerbach et al., 2010 Reichert, M.; Hallerbach, A. & Bauer, T. (2015). Lifecycle management of business process variants. In: Vom Brocke, J. & Rosemann, M. (Eds.) *Handbook on Business Process Management 1*. Berlin, Heidelberg, s.l.: Springer Berlin Heidelberg, pp. 251–278.
Process materialization	Kumar, A. & Yao, W. (2009). Process Materialization Using Templates and Rules to Design Flexible Process Models. In: Governatori, G.; Hall, J. & Paschke, A. (Eds.) *Rule interchange and applications. International symposium, RuleML*, Las Vegas, Nevada, USA, pp. 122–136. DOI: 10.1007/978-3-642-04985-9_13. Kumar, A. & Yao, W. (2012). Design and management of flexible process variants using templates and rules. In: *Computers in Industry (63)*, pp. 112–130. Yao, W.; Basu, S.; Li, J. & Stephenson, B. (2012). Modeling and configuration of process variants for on-boarding customers to IT outsourcing. In: Moser, L. (Eds.) *IEEE Ninth International Conference on Services Computing (SCC)*, 2012. 24 - 29 June 2012, Honolulu, Hawaii, USA, pp. 415–422.
Goal modeling	Asadi, M.; Mohabbati, B.; Gröner, G. & Gasevic, D. (2014). Development and validation of customized process models. In: *Journal of Systems and Software (96)*, pp. 73–92.

Method	**References**
	Lapouchnian, A.; Yu, Y. & Mylopoulos, J. (2007). Requirements-Driven Design and Configuration Management of Business Processes. In: Alonso, G.; Dadam, P. & Rosemann, M. (Eds.) *Business process management. 5th international conference (BPM 2007*), Brisbane, Australia, pp. 246–261. DOI: 10.1007/978-3-540-75183-0_18.
Declarative configurable process specification	Rychkova, I. & Nurcan, S. (2011). Towards adaptability and control for knowledge-intensive business processes: Declarative configurable process specifications. In: Sprague, R. (Ed.) *44th Hawaii International Conference on System Sciences. (HICSS)*, Koloa, Kauai, Hawaii, pp. 1–10.
Mereological graph	Meerkamm, S. & Jablonski, S. (2011). Configurable process models: experiences from a medical and an administrative case study. In: *International Conference on Service-Oriented Computing*, Helsinki, Finland, p. 33.

A1.2.5 Review: Analysis of tailoring knowledge (PE-Kölsch, 2018)

The literature review focused on identifying approaches related to analysing tailoring-knowledge. *Google Scholar* and *SCOPUS* have been used as search databases. Patents and citations were excluded in *Google Scholar*. Due to the lack of results, several iterations have been conducted, with successively expanding scope by abstracting the search terms used.

Graph-based analysis of tailoring knowledge (Iteration 1)

They keyword matrix for the first search iteration is depicted in Table A-19.

Table A-19: Keyword matrix – graph-based analysis of tailoring knowledge

	Topical aspects (AND-relationship)			
Synonyms in English (OR-relationship)	Tailoring	Analysis	Graph	Complexity
	Process variability	Investigation		Network
	Process customization	Examination		Dependency
	Process adaptation			connectivity
Synonyms in German (OR-relationship	Tailoring	Analyse	Graph	Komplexität
	Prozess-Variabilität	Untersuchung		Vernetzung
	Prozessanpassung	Überprüfung		Abhängigkeit
				Zusammenhang

As the derived search string did not yield results, additional iterations have been conducted, with successively expanding scope by abstracting the used search terms.

Graph-based analysis of rule-based knowledge (Iteration 2)

They keyword matrix for the second search iteration is depicted in Table A-20.

Table A-20: Keyword matrix – graph-based analysis of rule-based knowledge

	Topical aspects (AND-relationship)			
Synonyms in English (OR-relationship)	Knowledge	Analysis	Graph	Complexity
	Rule-based	Investigation		Network
	Logical connection	examination		Dependency
	If-then relation			connectivity
Synonyms in German (OR-relationship	Wissen	Analyse	Graph	Komplexität
	Regelbasiert	Untersuchung		Vernetzung
	Logische Verknüpfung	Überprüfung		Abhängigkeit
	Wenn-Dann Beziehung			Zusammenhang

The conducted search yielded 43 results, which have been subsequently reduced by removing duplicates and analysing the abstract. The final two results are listed in Table A-21. Both citations do not fulfill the proposed relevance criteria. The full citation is given in case a reference is not otherwise quoted within this thesis.

Table A-21: Results for graph-based analysis of rule-based knowledge

Reference	**Criteria**	
Struik, T. (2014). *A Network Analysis of Knowledge Production in Transportation: Exploring Co-evolution of Path- and Place-dependency*. Master thesis. Universität Utrecht.	○	●
Takahashi, D. & Xiao, Y. (2008). Complexity analysis of retrieving knowledge from auditing log files for computer and network forensics and accountability. In: *IEEE International Conference on Communications (ICC'08).* IEEE, 1474–1478.	○	○
Criterion: Rule-based knowledge (● fulfilled; ○ not fulfilled)		
Criterion: Graph-based analysis (● fulfilled; ○ not fulfilled)		

Analysis of rule-based knowledge (Iteration 3)

The second search iteration focused on identifying approaches for the graph-based analysis of rule-based knowledge. They keyword matrix is depicted in Table A-22.

Table A-22: Keyword matrix –analysis of rule-based knowledge

	Topical aspects (AND-relationship)		
Synonyms in English (OR-relationship)	Knowledge	Analysis	Complexity
	Rule-based	Investigation	Network
	Logical connection	Examination	Dependency
	If-then relation		connectivity
Synonyms in German (OR-relationship	Wissen	Analyse	Komplexität
	Regelbasiert	Untersuchung	Vernetzung
	Logische Verknüpfung	Überprüfung	Abhängigkeit
	Wenn-Dann Beziehung		Zusammenhang

The conducted searches resulted in 956 results, which have been reduced to 25 results after removing duplicate, irrelevant (based on the abstract), and inaccessible results. From these 25, only 12 provided a description of analysis approaches (cf. Table A-23). The full citation is given in case a reference is not otherwise quoted within this thesis. Interestingly, all 12 results are based on graph- or network theory and use corresponding metrics.

Table A-23: Results for analysis of rule-based knowledge

Reference	Focus	Centrality	Density	Clustering	Cliques	Distance	Cohesion	Path Length	Size
Busch, P., & Richards, D. (2005). The application of social network analysis to knowledge management. In B. Campbell, D. Bunker, & J. Underwood (Eds.), *16th Australasian Conference on Information Systems (ACIS 2005)*, Sydney, Australia:	Knowledge management	●	●		●				
Busch, P. (2010). Business process management, social network analysis and knowledge management: a triangulation of sorts? https://aisel.aisnet.org/acis2010/59	Knowledge management, BPM	●				●			
Hu, C. & Racherla, P. (2008). Visual representation of knowledge networks: A social network analysis of hospitality research domain. *International Journal of Hospitality Management*, *27*(2), 302–312.	Knowledge networks within a research domain	●	●		●				

Reference	Focus	Centrality	Density	Clustering	Cliques	Distance	Cohesion	Path Length	Size
Lei, G. & Xin, G. (2011). Social network analysis on knowledge sharing of scientific groups. *Journal of System and Management Sciences, 1*(3), 79–89.	Knowledge-sharing of scientific groups	●							
Liebowitz, J. (2005). Linking social network analysis with the analytic hierarchy process for knowledge mapping in organizations. *Journal of knowledge management, 9*(1), 76–86.	Knowledge mapping in organizations	●			●				
Mueller, C., Gronau, N. & Lembcke, R. (2008). Application of Social Network Analysis in Knowledge Processes. In: *ECIS 2008 Proceedings.*	Knowledge processes	●	●			●			
Müller-Prothmann (2007)	Knowledge sharing	●							●
Muyun (2017)	Organizational knowledge transfer					●			
Parise, S. (2007). Knowledge management and human resource development: An application in social network analysis methods. In: *Advances in Developing Human Resources, 9*(3).	Knowledge management and human resource development	●	●				●		
Zappa, P. & Lomi, A. (2016). Knowledge sharing in organizations: A multilevel network analysis. In: Lazega, E.; Snijders, T. A. B. (Eds.) *Multilevel Network Analysis for the Social Sciences*. Springer, Cham, pp. 333–353.	Knowledge sharing in organizations	●	●						
Zhiyang & Lu, 2009	Knowledge cooperation networks	●		●				●	
Zhu, W., Shao, L. & Huang, Z. (2007). Social network analysis application in tacit knowledge management. In: *Workshop on Intelligent Information Technology Application*. IEEE.	Management of tacit knowledge	●	●	●		●			

A1.2.6 Review: Tailoring workshops (PE-Rast, 2018)

The literature review focused on identifying workshop-based approaches to support process tailoring. The keyword matrix to generate search strings is presented in Table A-24.

Table A-24: Keyword matrix – workshop based tailoring support

	Topical aspects (AND-relationship)					
Synonyms (OR-relationship)	Product	Develop-ment	Process	Tailoring	Implemen-tation	Workshops
	Project	Planning		Adaptation	Application	

The keyword matrix has been used to derived search strings using Boolean operators as indicated (Table A-25). The search has been limited to the years 1997 to 2017.

Table A-25: Search strings and results – workshop based tailoring support

		Number of results				
	Search string	**Google Scholar**	**IEEE xplore**	**Scopus**	**Web of Science**	**Sum**
1	"process tailoring" OR "process adaptation") AND (application OR implementation) AND "product development"	997	201	42		1240
2.1	"project planning" AND workshops AND ("process tailoring" OR "process adaptation")	301	39	12	127	479
2.2	"project planning" AND (implementation OR application) AND ("process tailoring" OR "process adaptation")	572	21	14	476	1083
2.3	"project planning" AND "tailoring workshop"	14	0	0		14

After the results have been exported from the search databases, using the criteria in Table A-26 the results were filtered and reduced to a final set of relevant results, as presented in Table A-27. The final results are listed in Table A-28.

Table A-26: Inclusion and exclusion criteria for selection of relevant results

Inclusion	Reference provides description of implementation (in the form of workshops)
	Reference describes a tailoring approach
Exclusion	Reference addresses level 1 tailoring

Table A-27: Reduction of search results

	Reduction steps (no. of references removed due to…)								
	Sum	**Duplicates**	**Citations**	**Patents**	**Language**	**Not relevant (title)**	**Access rights**	**Not relevant (abstract)**	**Relevant hits**
1	1240	47	16	3	18	513	41	560	2
2.1	479	141	6	0	4	88	19	181	5
2.2	1083	465	2		7	307	1	195	3
2.3	14	0	0	0	0	2	1	11	0
	Final number of relevant results from keyword search (without duplicates):								**10**

Table A-28: Results – workshop-based process tailoring

Reference
Uikey, N. & Suman, U. (2016). Tailoring for agile methodologies: A framework for sustaining quality and productivity. In: *IJBIS (23)*, pp. 432-455. DOI: 10.1504/IJBIS.2016.080216.
Pikkarainen, M.; Salo, O. & Still, J. (2005). Deploying Agile Practices in Organizations: A Case Study. In: Hutchison, D.; Kanade, T.; Kittler, J.; Kleinberg, J.; Mattern, F.; Mitchell, J.; Naor, M.; Nierstrasz, O.; Pandu Rangan, C.; Steffen, B.; Sudan, M.; Terzopoulos, D.; Tygar, D.; Vardi, M.; Weikum, G.; Richardson, I.; Abrahamsson, P. & Messnarz, R. (Eds.), *Software Process Improvement*. Berlin, Heidelberg: Springer Berlin Heidelberg, pp. 16–27. DOI: 10.1007/11586012_3.
Magdaleno, A. M.; Nunes, V. T.; Araujo, R. M. & Borges, M. R. (2007). Flexible Organizational Process Deployment. In: Shen, W.; Luo, J.; Lin, Z.; Barthès, J.-P. & Hao, Q. (Eds.), *Computer Supported Cooperative Work in Design III*. Berlin, Heidelberg: Springer, pp. 679–688. DOI: 10.1007/978-3-540-72863-4_69.
Magdaleno, A.; Nunes, V.; Araujo, R. & Borges, M. (2006). Increasing Flexibility in Process Deployment with the Process Beans Composer. In: *10th International Conference on Computer Supported Cooperative Work in Design*, Nanjing, China, pp. 1–6. DOI: 10.1109/CSCWD.2006.253152.
Menolli, A.; Reinehr, S. & Malucelli, A. (2013). Organizational learning applied to software engineering: a systematic review. In: *Int. J. Soft. Eng. Knowl. Eng. (23)*, pp. 1153–1175. DOI: 10.1142/S0218194013500356.
Pikkarainen, M.; Salo, O.; Kuusela, R. & Abrahamsson, P. (2012). Strengths and barriers behind the successful agile deployment—insights from the three software intensive companies in Finland. In: *Empir Software Eng (17)*, pp. 675–702. DOI: 10.1007/s10664-011-9185-5.
Jalote, P. (2002). *Software project management in practice*. Boston, London, Sebastopol, CA: Addison-Wesley; Safari Books Online.
Pollack, J. (2016). It's not the plan, it's the process of planning. In: *2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, Bali, Indonesia, pp. 1790–1794. DOI: 10.1109/IEEM.2016.7798186.
Dvir, D. & Lechler, T. (2004). Plans are nothing, changing plans is everything: The impact of changes on project success. In: *Research Policy (33)*, pp. 1–15. DOI: 10.1016/j.respol.2003.04.001.
Nash, Z.; Childe, S. & Maull, R. (2001). Factors affecting the implementation of process based change. In: *IJTM (22)*, p. 55. DOI: 10.1504/IJTM.2001.002954.

A1.3 Classification of process variability modeling approaches

Table A-29 lists the evaluation criteria for the evaluation of approaches to model process model variability.

Table A-29: Evaluation criteria for approaches to capture process model variability (La Rosa et al., 2017)

Category	Characteristic	Value	Description
Scope	Process perspective	Control-flow	Ability of a customizable model to capture variability of activities and gateways.
		Resources	Ability of a customizable model to capture variability in (non)human resources
		Objects	Ability of a customizable model to capture variability in physical and data objects
	Process Type	Conceptual	Approach is designed to support conceptual process models only
		Executable	Approach is designed to make customized model executable (resolving inconsistencies)
Customization Type		Restriction	Approach supports variability by restriction
		Extension	Approach supports variability by extension
Supporting techniques	Decision Type	Abstraction	Users can customize model without directly interacting with the process model (use of a context model)
		Guidance	Guidance for customization is available (e.g. recommendations for selecting options or to avoid inconsistent customizations)
	Correctness Support	Structural	Ability to ensure correct structure, e.g. avoiding disconnected nodes
		Behavioral	Ability to ensure correct behavior, avoiding anomalies such as deadlocks or livelocks
Extra functional		Formalization	Provision of formal definitions (mathematical notations, algorithms) instead of just concepts
		Implementation	Full implementation in tool form
		Validation	Tested on models not created by authors and results verified by domain experts

A1.4 Requirements for tailoring approaches

Table A-30 lists requirements for tailoring support as derived by Martinez-Ruiz et al. (2012)

Table A-30:Requirements for tailoring approaches and notations (cf. Martinez-Ruiz et al., 2012)

ID	Requirement	Further explanation (optional)
Requirements for process model element variation support		
Q1.1	Variability in activities/tasks	-
Q1.2	Variability in artifacts	-
Q1.3	Variability in resources	-
Q1.4	Variability in control flow	-
Q1.5	Variability in product flow	-
Requirements for types of supported variation		
Q2.1	Optional variation	Allow inclusion/removal of elements
Q2.2	Alternative variation in a point	Allow selection from element alternatives
Q2.3	Alternative points of a variation	Allow placement of elements at different points
Q2.4	Mandatory variation elements	Some elements may be mandatory for all processes
Q2.5	Mandatory variation places	Some elements may be at mandatory places
Q2.6	Evolution of variants	Allow addition of new variants
Consistency assurance among variants by means of restriction models		
Q2.7	Constraints	Enable constraints to ensure consistency
Q2.8	Dependencies	Variations might affect other ones which depend on them
Q2.9	Variations across contained elements	Variations might affect lower levels of decomposition
Q1.6	Variations realized because of others	Primary variations can cause secondary ones, especially in large operations (e.g. task change causes role changes)
Q2.10	Variability propagation	e.g. variations in an activity can imply variations for roles
Requirements for usability support for the variation mechanisms		
Q1.7	Extensive variations (Crosscutting)	Enable tailoring of a high percentage of process elements; ensure compatibility with detailed variations
Q1.8	Detailed variations (Single/On-Point)	Modify individual entities
Q4.1	Relations between variants and base process	Variant elements must be associated with the base process
Q4.2	Variability transformation/Tailoring	Variability mechanisms must allow tailoring
Q4.3	Default variations	Notation should allow definition of default elements
Q3.2	Variability standardization	Variability notation must be as generic as possible to allow implementation in any modeling notation
Requirements for documentation and reuse of knowledge		
Q4.4	Documentation of elements	Description of creation, behavior, and tailoring operations
Q4.5	Rationale of the use of elements	Notation must allow to document rationale for var. selection
Q3.1	Differentiate common and variable parts	Notation must differentiate between parts common to all processes and variable parts

A2 Supplementary material: TailoringSystemModel metamodel

A2.1 TailoringSystemModel metamodel derivation

This section provides supplementary material regarding the development and description of the TSM metamodel.

A2.1.1 Existing metamodels for derivation of TSM metamodel

Table A-31 lists the pre-existing metamodels identified and described in related approaches, which served as the basis for the development of the TSM metamodel. For each metamodel, the table indicates the covered domains.

Table A-31: Existing metamodels serving as basis for the development of the TSM metamodel

		Domains			
Reference	**Name of approach/contained metamodel**	**C**	**R**	**P**	**O**
Kreimeyer, 2010	Aggregated process metamodel			●	●
Heimberger, 2017	Metamodel for analysis of emerging, product-induced communication and coordination needs among project team			●	●
Browning, 2014b	Process architecture framework (PAF), activity dependencies and attributes			●	
Lévárdy & Browning, 2009	Activity modes, activity dependencies and attributes			●	
Hurtado Alegria, 2012 (subsumes earlier publications)	Software Process Context Metamodel (SPCM) Process Feature Meta model (PFMM), Software Process Scope Meta Model (SPSMM) Software and Systems Process Engineering Meta Model (SPEM 2.0)	●	●	●	
Kalus, 2013	Simplified metamodel for feature-based tailoring	●	●	●	
Park et al., 2006	Conceptual rules to document context-process impacts	●	●	●	
Hallerbach, 2009	Provop	●	●	●	
La Rosa et al., 2009	Questionnaire model	●			
Graviss et al., 2016	Matrix-based documentation of tailoring rules	●	●		
Pillat et al., 2015	BPMNt – Tailoring extension for BPMN			●	
Lorenz et al., 2014	Metamodel for tailoring process	●		●	
He et al., 2008	Metamodel of reusable tailoring knowledge	●	●	●	

Key: *C = Context, R = Rules, P = Process, O = Organization*

A2.1.2 Decomposition of conceptual relationships to metamodel elements

Table A-32 represents an extended version of Table 5-4, detailing the decomposition of conceptual relationships to metamodel elements.

Table A-32: Decomposition of conceptual relationships into modeling constructs and element types

Name	**Description**	**Type**	**Node types**	**Edge types**
Context-Process relationships				
Process Tailoring Rule (PTR)	Documenting tailoring decisions based on selected context values and corresponding process impacts	R	**PTR** (r) (s) **ContextValue** (c) (t) **ProcessElement** (i) (t)	hasImpact hasCondition
Generic Impact (GI)	Not yet further specified impact of a context variable on process element(s) (for documentation purposes,)	D	**ContextVariable** (s) **ProcessElement** (t)	Generic Impact
Generic Impact (GI)	Not yet further specified impact of a context value on process element(s) (for documentation purposes)	D	**ContextValue** (s) **ProcessElement** (t)	Generic Impact
Intra-ContextRelationships				
Local Context Constraint (LCC)	Affiliation of a context value to its parent context variable	D	**ContextVariable** (s) **ContextValue** (t)	Local Constraint
Global Constraint Rule (GCR)	Requirement or exclusion of a context value based on the selecton of other context values	R	**GCR** (r) (s) **ContextValue** (c) (t) **ContextValue** (i) (t)	hasImpact hasCondition
Context Constraint	Hierarchical decomposition of context variables. (May be temporary and concretized into DTC or GCR)	D	**ContextVariable** (s) **ContextVariable** (t)	Context Constraint
Intra-Process Relationships				
Decision Tree Constraint (DTC)	Signifies the required evaluation of a context variable based on a selected value of another context variable	D	**ContextValue (s)** **ContextVariable (t)**	Decision Tree Constraint
Process Constraint Rule	In- or exclusion of process elements or activity modes depending on the existence of other process elements (Analog to GCR)	R	**PCR** (r) (s) **ProcessElement** (c) (t) **ProcessElement** (i) (t)	hasImpact hasCondition

Key:
R = Rule; D = Dependency; (r) = Rule Node; (c) = Cause; (i) = Impact; (s) = Source Node; (t) = Target Node

A2.2 TSM metamodel description

The following figures and tables provide a comprehensive description of the TSM metamodel. Figure A-2 and Figure A-3 depict the hierarchical structure and modeling rules in MDM notation.

Node types

Table A-33 presents an overview of the metamodel node types, including a short description and their corresponding attributes. Attributes are only described once at root level and inherited as depticted in Figure A-2. For each attribute, the data type is given

Edge types

Table A-34 presents an overview of the metamodel edge types. For each edge type, its direction, whether it is analytical (i.e. calculated during the analysis), the node types it connects, a short description, and its corresponding attributes are given. In case an edge type can connect multiple node types, the root node type is given in square brackets, e.g. [*PNode*] signifies all node types inheriting from *ProcessNode*, such as *Activity* and *GenericImpact* can be connected to the *GenericImpact* edge type.

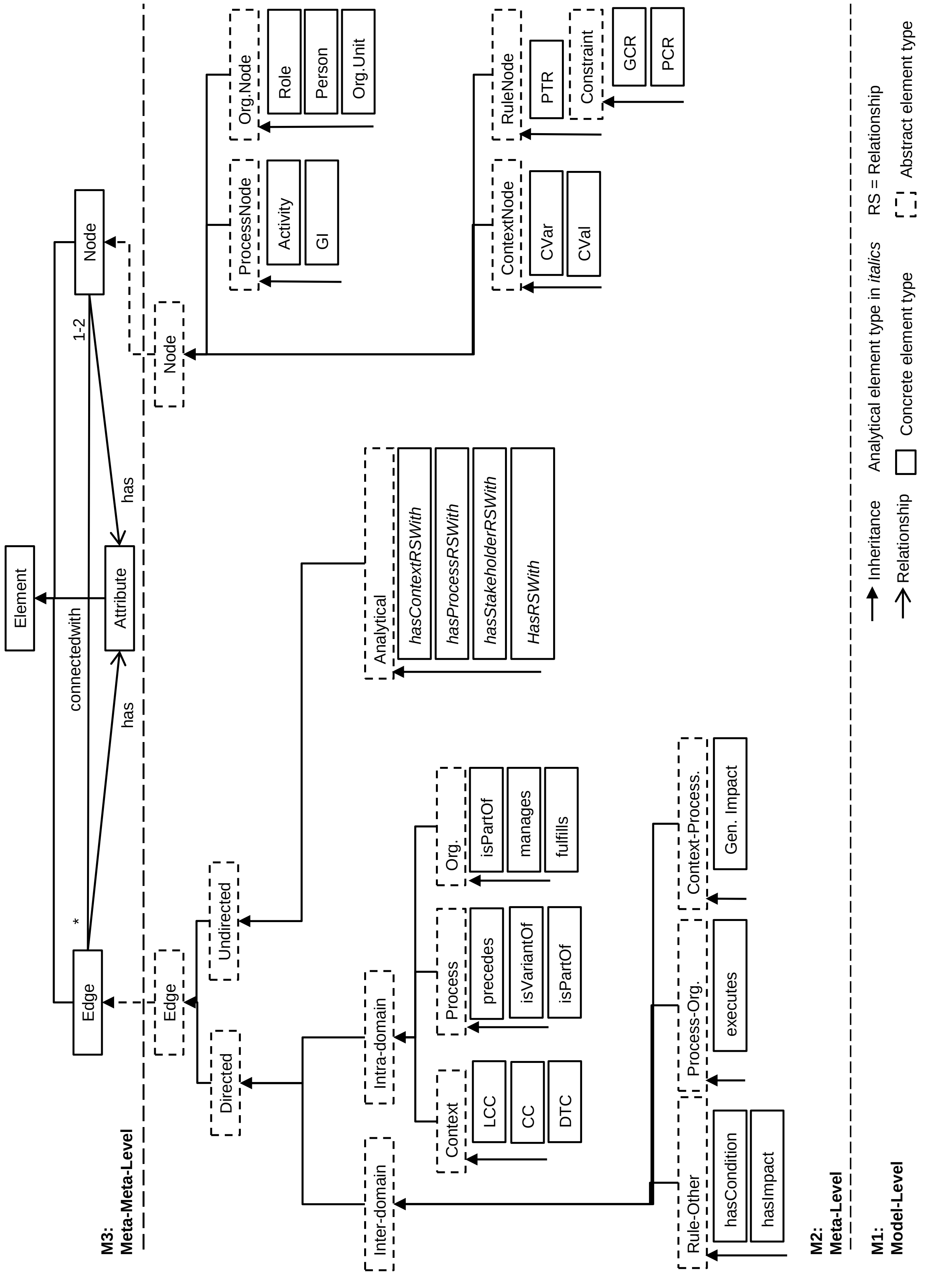


Figure A-2: Overview of full TSM metamodel hierarchy

Node types			Cvar	Cval	PTR	GCR	PCR	Activity	GI	Role	Person	OU
ContextNode		Cvar	CC	LCC				Generic Impact				
		Cval	DTC					Generic Impact	Generic Impact			
Rule Node		PTR		hasCond.	hasCRSW hasPRSW hasSHRSW			Generic Impact	Generic Impact			
	Constraint	GCR		hasCond. hasImpact								
		PCR						hasCond. hasImpact				
ProcessNode		Activity						precedes isPartOf IsVariantOf				
		General Impact (GI)										
OrganizationalNode		Role						executes		hasRSwith		isPartOf
		Person						executes		fulfills	Manages hasRSwith	isPartOf
		Org. Unit (OU)						executes				isPartOf hasRSwith

Figure A-3: Overview of TSM modeling rules in MDM notation

Node types

Table A-33: Node types of the TSM metamodel

Node type	Node Description	Attributes/Datatype	Attribute description
{Node}	Root node type, defines basic attributes.	id: int	Identification number of each node
		name: string	Name of each node
		description: string	Description of node, if applicable
Help	Helper node type to reimport cluster ID (not depicted)	clusterID: int	Cluster ID per stakeholder from application of stakeholder clustering
{ProcessNode} (PNode)	Abstract node type grouping process-related node types	Cr: array <int>	Element criticality and auxiliary data (active/passive sum).
		SBF: array <int>	Element Snowball Factor and auxiliary data (height/width of hierarchy).
		CB: double	Element betweenness centrality.
		responsibleStakeholder: string	Contains the name of the responsible stakeholder.
		connectedRules: array <string>	Contains the ids for PTRs connected to the element.
		numberOfVariants: int	Contains the number of variants associated with the element.
		previousActivities: array <string>	Contains ids of directly preceding activities
		followingActivities: array <string>	Contains ids of directly following activities
Activity	Task, step, or activity within the process to be tailored (baseline or variant)	isVariant: bool	Indicates whether the node represents a process element variant.
		isOptional: bool	Indicates whether the process element variant can be deleted.
		isDefault: bool	Indicates default activity mode
GenericImpact (GI)	Container node for documentation of general tailoring impacts, which are to be specified in further interviews	status: string	Description of status, e.g. whether the GenericImpact is currently being analyzed
{OrganizationalNode}	Abstract node type grouping	clusterID: int	Assigned Cluster ID of an organizational element

Node type	**Node Description**	**Attributes/Datatype**	**Attribute description**
(ONode)	organization-related node types	numberOfPTRs: int	Number of PTRs an organizational element is dependent of
		responsibleActivities: int	Number of activities an organizational element is responsible for
Role	Role specified within the process to be tailored, e.g. designer, planner, test engineer etc.		
Person	Individual associated with a particular organizational unit and executing specific roles		
OrganizationalUnit (OU)	Team, department or other specified unit within the organizational domain		
{ContextNode} (CNode)	Abstract node type grouping context-related node types	connectedPTR: array <int>	Contains the ids of PTRs connected to a particular context node
		acquisitionScope: array <string>	Scope/System boundary within which CVar or CVal has been acquired
ContextVariable (CVar)	Specified property used to characterize projects for tailoring	Operator: string	Defines exclusive (XOR), arbitrary (OR) or combined (AND) selection of values
		Question: string	Question format describing the context factor
		instantiationType: string	Indicates whether a tailoring rule is applied once or multiple times (e.g. for each component within a project)
		evaluationBasis: string	Describes the grounds for evaluation (project objective, component list, etc.)
ContextValue (CVal)	One or several values which can be assumed by a context variable.	Selected: bool	Indicates whether the context value is active for a particular project instance.
		isDefault: bool	Indicates the default selection
{RuleNode} (RNode)	Abstract node type grouping rule-related node types		
ProcessTailoringRule (PTR)	Node type representing a tailoring rule, which	numberOf dependentStakeholders: int	Indicates the number of stakeholders impacted by a PTR

Node type	Node Description	Attributes/Datatype	Attribute description
	can have one or several conditions (CVal) and impacts (Activity)	numberOfActivities: int	Indicates the number of activities impacted by a rule node
		meanCr: double	Mean Criticality of all impacted process elements
		meanSBF: double	Mean SnowballFactor of all impacted process elements
		meanCB: double	Mean Centrality of all impacted process elements
		conflict: bool	Indicates whether the node is part of a conflict pattern
		tailoringPoint: string	Indicates the defined tailoring point when the tailoring rule is to be evaluated and applied (e.g. a particular milestone)
{Constraint}	Abstract node type grouping constraint-related node types		
GlobalContext ConstraintRule (GCR)	Represents cross-tree constraint		
ProcessConstraintRule (PCR)	Represents process constraint		

Key: *{} = abstract; () = Abbreviation; Int = Integer; bool = Boolean*

Edge types

Table A-34: Edge types of the TSM metamodel

Name	Connects	Description	Attributes
{Edge}			id: int
{Directed}		Directed edges (native)	
{Undirected}		Undirected edges (for analytical purposes)	
{Inter-domain}		*Groups edge types which connect nodes within the same domain.*	
{Rule-Other}		*Groups edge types originating from the rule domain and ending at nodes within the context and/or process domain.*	
hasCondition (hasCond)	*PTR → CVal;* *GCR → CVal;* *PCR → [PNode];*	Indicates the conditional (if) side of a rule node; the type of rule node determines the node types the edge points to: PTR/context, GCR/context, PCR/process.	
hasImpact	*PTR → [PNode]* *GCR → CVal* *PCR → [PNode]*	Indicates the impacts of a rule node; the type of rule node determines the node types the edge points to: PTR/process, GCR/context, PCR/process).	topDelete: bool; topSelect: bool; topMove = bool; topModify = bool; descrMod = string; requires: bool; excludes: bool; status: string;
{Process-Organization}		*Used to group process-organization inter-domain edge types*	
executes	*[ONode] → Activity*	Used to indicate the execution of an activity by a particular role (most common), individual, or OU	RACI: string;
{Context-Process}		*Used to group context-process inter-domain edge types*	
GenericImpact (GI)	*CVar → [PNode]* *CVal → [PNode]* *PTR → [PNode]*	Indicates a generic, not closer specified impact from a context variable or value to a process element. For documentation purposes only, not included in analysis.	
{Intra-domain}		*Groups edge types which connect nodes within the same domain.*	
{Context}		*Groups dependencies within the context domain.*	
LocalContext Constraint (LCC)	*CVar → CVal*	Connects context values to their respective variable.	

Name	Connects	Description	Attributes
Context Constraint (CC)	*CVar → CVar*	Indicates the hierarchical decomposition of a context variable into more concrete variables.	isTemporary: bool
DecisionTree Constraint (DTC)	*CVal → CVar*	Indicates whether a particular context variable needs to be evaluated due to the selected value of another variable.	
{Organization}		*Groups dependencies within the organization domain.*	
isPartOf	*OU → OU* *Person → OU*	Used to model the hierarchical structure of organizational units and affiliation of Individuals.	
manages	*Person → Person*	Used to model hierarchical dependencies between individuals, without using the OrganizationalUnit node type.	
fulfills	*Person → Role*	Indicates an individual carrying out a particular role.	
{Process}		*Groups edge types within the process domain.*	
isPartOf	*Activity → Activity*	Indicates hierarchical decomposition between activities.	
isVariantOf	*Activity → Activity*	Assigns process element variants to a particular baseline activity.	
Precedes	*Activity → Activity*	Indicates temporal precedence dependencies between activities; used to calculate structural metrics.	
{Analytical}		*Groups edge types generated during analysis*	numberOf Elements: int
hasRelationship With (hasRSw)	*[ONode] – [ONode]*	Indicates, whether two tailoring stakeholders (roles, individuals, organizational units) have a communication need. Used to calculate and represent the need for communication between two tailoring stakeholders. (Analytical)	Alignment: double; organizationalDistance: int;
hasContext RelationshipWith (hasCRSw)	*PTR – PTR*	Used to identify whether two PTR nodes share a common context value or variable (Analytical)	(*numberOfElements* indicates number of common PTRs)
hasProcess RelationshipWith (hasPRSw)	*PTR – PTR*	Used to identify whether two PTR nodes share a common process element. (Analytical)	(*numberOfElements* indicates number of common activities)
hasStakeholder RelationshipWith (hasSHRSw)	*PTR – PTR*	Used to identify whether two PTR nodes share a common process stakeholder. (Analytical)	(*numberOfElements* indicates number of common stakeholders)

Key: *– undirected; → directed; {} = Abstract; () = Abbreviation; int = Integer; bool = Boolean*

A3 Supplementary material: Tailoring methodology

Appendix A3 provides supplementary material concerning the tailoring methodology.

Overviews

The following overviews are presented:

- **Extended overview** of the tailoring methodology in DSM notation, dependencies between steps, iterations (cycles), and role involvement **(Appendix A3.1)**.
- Overview and description of the individual **iterations (Appendix A3.2)**.

Supplementary material for individual phases

The overviews are followed by the following supplementary material for the individual phases:

- **Phase 1:** Preparation **(Appendix A3.3)**
    - Checklist of questions to reflect the initial situation
- **Phase 2:** Information acquisition **(Appendix A3.4)**
    - Activity interface catalog
    - Information acquisition methods
    - Categories of information acquisition strategies
    - References for existing context factor categorization schemes
    - Generic information acquisition interview guideline
- **Phase 4:** Analysis framework **(Appendix A3.5)**
    - Source code for data import (Soley)
    - Source code for rule conflict identification (Soley)
    - Algorithm and source code for activity metric calculation (Soley)
    - Source code for calculation of alignment metric (Soley)
    - Ssource code for stakeholder clustering (Matlab, Soley)
    - Exported data for generation of tailoring analysis reports
    - Overview of analysis result content per report type
    - Tailoring analysis report templates
- **Phase 5:** Operationalization & review **(Appendix A3.6)**
    - Tailoring workshop requirements
    - Tailoring workshop checklist and heuristics

Developed artifacts

Table A-35 presents an overview of the core artifacts created during the development of the tailoring methodology.

Table A-35: Constituent tailoring methodology elements and describing artifacts

Methodology element	Artifact	Documented in
Procedure	Textual description	7
	DSM overview	A3.1
Tailoring Role Model	Textual description	7.1.4
	RAM	A3.1
TSM Metamodel	Textual description/Illustrations	6
	Node/Edge type class diagram	A2.2
	Modeling rules (MDM)	A2.2
	Node type list	A2.2
	Edge type list	A2.2
	Soley software demonstrator	PE-Kölsch, 2018; 7.5.2
Acquisition methods	Short descriptions of ten information acquisition methods	7.3; A3.4.2
	Generic information acquisition strategies	A3.4.3
	Generic information acquisition interview guideline	7.3.4; A3.4.5
	Context acquisition grid	7.3.2
Analysis framework	GQM Framework	7.5.1
	Textual description of submethodology	7.5.2
	Metric formulas and analysis algorithms	7.5.4; A3.5
	Software demonstrator (Soley, Matlab, Excel)	7.5
	Report templates	7.5.6; A3.6
Workshop Concept	Textual description (preparation/execution)	7.6.2; 7.6.3
	Question and heuristics checklist	A3.7.2
Extension – Process variants	Concept	7.7; PE-Sapundziev, 2018
	Software demonstrator (Soley)	7.7; PE-Sapundziev, 2018
Extension – Process modularization	Modularization procedure	7.7; PE-Thomas, 2018
	Modularization software demonstrator (Excel)	7.7; PE-Thomas, 2018

A3.1 Extended overview of the tailoring methodology

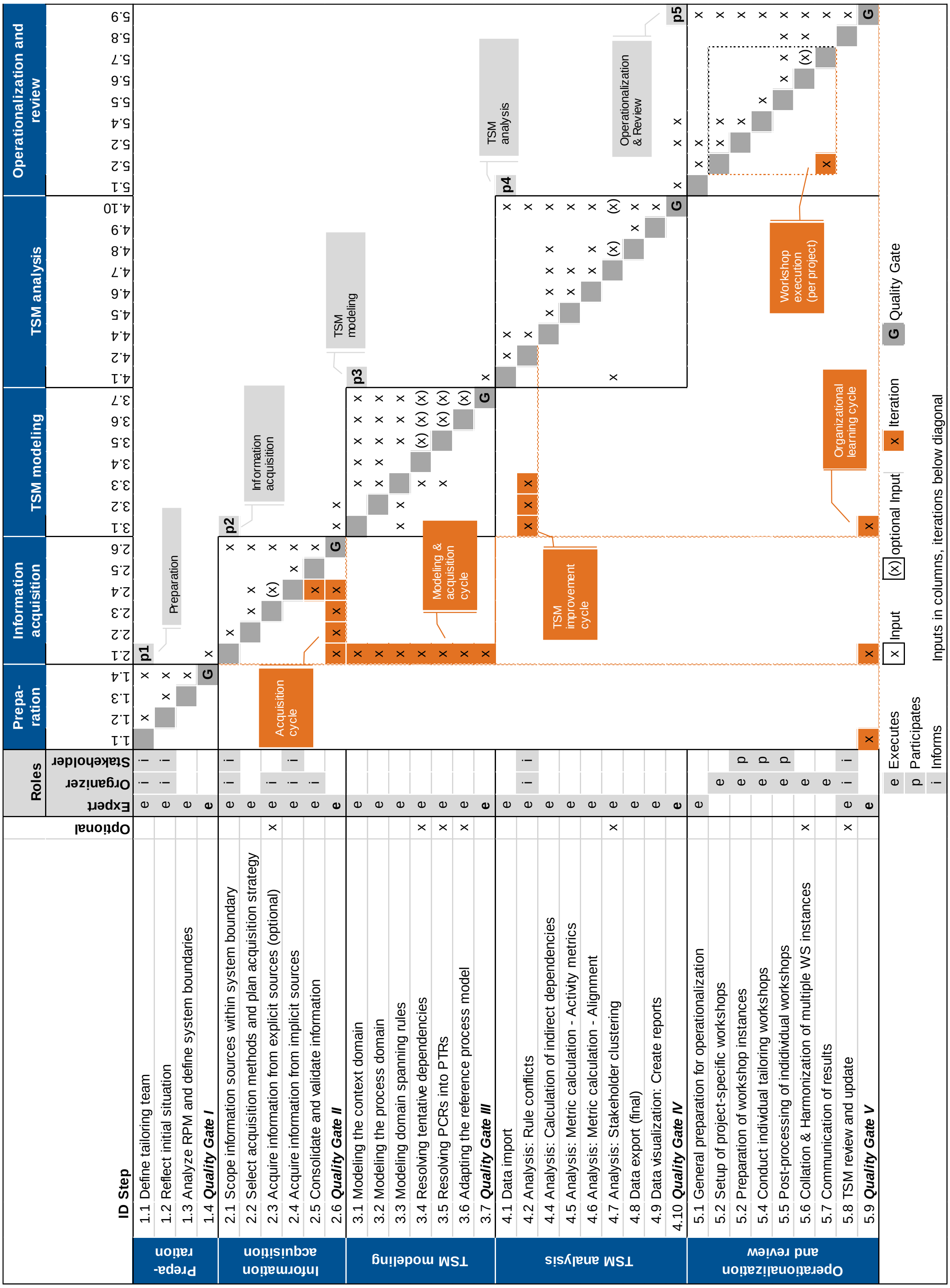


Figure A-4: DSM model of the process tailoring methodology with role involvement

A3.2 Iterations within the tailoring methodology

Figure A-4 contains a number of possible iterations within the tailoring methodology. The iterations represent intra- and cross-phase feedback loops. In total, five purposeful iterations have been identified:

- **Acquisition cycle**: Iteration of information acquisition activities within a given system boundary before proceeding to the modeling phase, in order to extend and cross-validate information acquisition. Iterations can represent **repetitions** (conducting information acquisition activities on the same level of detail) and **recursions** (conducting information acquisition activities on a more detailed level, e.g. decomposed activities).
- **Modeling & acquisition cycle**: Modeling activities trigger further information acquisition activities due to additional information needs identified during modeling (e.g. unclear specification or decomposition of activities, unclear role assignments, concretization of tentative dependencies). Acquisition and modeling activities can be expected to be subject to frequent iterations as they are co-dependent activities.
- **TSM improvement cycle**: Identified rule conflicts and model inconsistencies can trigger further modeling as well as information acquisition activities.
- **Workshop execution (per project)**: The execution of tailoring workshops for project instances is embedded in phase 5. The indicated activities are to be carried out separately for each project instance where workshop-based tailoring is to be applied, subsequently feeding into the review and update activity.
- **Organizational learning cycle**: Identification of new knowledge during TSM reviews or schedule reviews can trigger additional information acquisition and modeling activities. This cycle represents the iterative application of the methodology in parallel to PD project execution.

A3.3 Phase 1: Preparation

Table A-36 presents the checklist of reflective questions supporting the analysis of the initial situation as conducted in phase 1 of the tailoring methodology

Table A-36: Checklist of reflective questions for analysis of initial situation

Category	ID	Question
PDP context	1	Is the context of the PDP more static (e.g. mature company) or dynamic (e.g. start-up; major changes in environment or process/corporate strategy)? *(gives an indication regarding the reliability and stability of acquired context information)*
RPM	2	Is a PDP RPM defined?
	3	Does the PDP RPM accurately reflect tasks, dependencies, and other information from PD projects? Is there a basic continuity and consistency between PDP RPM and PD-specific processes?
	4	In which representations/documents/repositories/systems is the RPM or individual aspects (partial models) defined?
	5	Are the activities detailed enough to allow the formulation of meaningful tailoring rules?
	6	Are there discernible hierarchical levels within the RPM, describing the decomposition of the process? If yes, which hierarchical levels can be identified? Are precedence-dependencies between activities limited to a single decompositional level? Are decomposed activities connected on all levels of decomposition? (cf. section 7.5.4 for analysis-related requirements regarding the decomposition of activity dependencies) *(for modeling isPartOf-Dependencies)*
	7	Which node types does the RPM contain in general? *(Potential adaptation of the metamodel)*
	8	Does the RPM contain activity-type elements? *(For formulation of activity modes and tailoring rules)*
	9	Does the RPM contain roles and/or organizational units (departments etc.)? *(for identification of tailoring-affected stakeholders)*
	10	Does the RPM contain mandatory elements (e.g. for regulatory reasons)? *(identification/limitation of activity modes)*
	11	Does the RPM already contain alternative/optional activities? *(identification of activity modes)*
	12	Does the RPM contain subprocesses recurring in different positions (Master/Shadow)? *(starting points for variance analysis)*
	13	Which dependency types does the RPM contain in general?
	14	Does the RPM contain precedence dependencies between activities and how are these defined (cf. Appendix A3.4.1)? *(for calculation of structural metrics in order to assess tailoring rule impact)*
	15	Does the RPM contain flows with conditional branching (OR-operators) *(Input for activity mode definition)*
	16	What are the objectives of individual subprocesses or activities? *(To facilitate context factor identification, cf. section 7.3)*

Category	ID	Question
Organi-zational structure	17	Are models/data of the hierarchical organizational structure associated with the PDP available? *(Modeling of organizational structure)*
	18	How is the organizational hierarchy structured? (*modeling of organizational hierarchy, definition of organizational node and edge types*)
	19	Are roles or organizational units assigned to activities in the RPM? *(identification of affected tailoring stakeholders)*
Projects	20	How are PD projects currently organized?
	21	Are PD projects clearly defined? *(To facilitate characterization and context factor identification)*
	22	Are PD project-management roles defined? *(Potential role owners and workshop participants)*
	23	Does the PD project organization contain multiple levels of hierarchy? *(Potential role owners and workshop participants)*
	24	How many team members do PD projects consist of (minimum, maximum, average)?
	25	Is the PDP RPM currently used as a basis for managing PD projects (continuity)? *(Familiarity of tailoring stakeholders with RPM)*
	26	Are project stakeholders familiar with the PDP RPM, i.e. do they know the activities they are familiar with? *(for information acquisition)*
	27	How and where are project plans currently documented? *(for information acquisition)*
	28	Which projects are currently planned? *(PD project roadmap for information acquisition and initial application/validation)*

A3.4 Phase 2: Information acquisition

A3.4.1 Activity interface catalog

Figure A-5 presents a catalog of possible inputs for the creation of precedence relationships within the baseline RPM/TSM. The catalog is intended as a tool to guide information acquisition by structuring possible dependencies regarding four categories (without claiming completeness or relevance in every case): Collaboration, Communication, Information, and Organization.

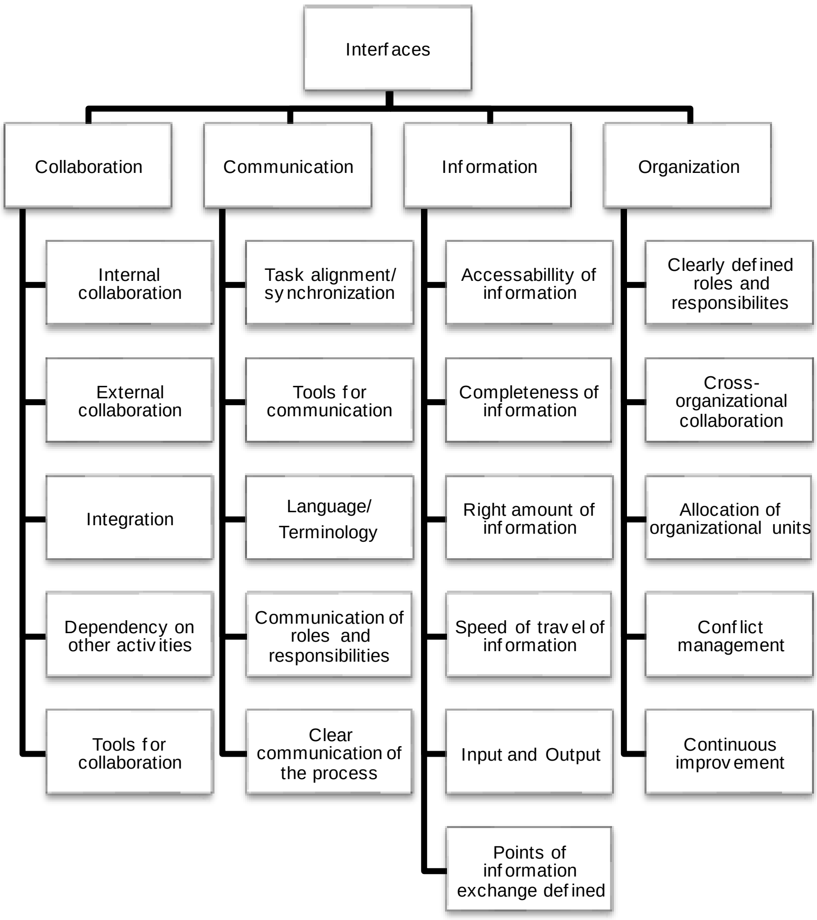


Figure A-5: Catalog of possible inputs for creation of precedence relationships in baseline RPM and TSM (PE-Thomas, 2018)

A3.4.2 Information acquisition methods

Table A-37 presents a collated list of the information acquisition methods developed and applied within the scope of this thesis. For each method, possible information sources, a short description, and the resulting information are given.

Table A-37: Collated empirically derived information acquisition methods

Method	Possible Sources	Description and resulting information
Literature-based		
Adaptation of generic context factors	Context factor catalogs and generic context models	• Initial acquisition of generic context variables from literature. • Starting points and initial input for interviews, workshops, etc., (esp. in the absence of further explicit information sources) • Adaptation of generic context variables to concrete situation
Explicit information		
Document analysis	RPM; Process handbook; Product portfolio; etc.	• Identification of baseline RPM and RPM/subprocess variants • Identification of candidate context factors from general documents (project characterization etc.)
RPM variant comparison	RPM variants	• (Manual) Comparison of different process variants (delta analysis) • Using pre-existing or exemplary process variants (created during information acquisition, e.g. as part of participative observation) • Identification of differences between process variants resulting from a fixed context variable and different values • Identification of optional and variant process elements
Project data analysis	Documented project records (plans, requirements specifications…)	• Comparison and (statistical) analysis of project records • Usage of a potentially large number of process instances • Documented process contents for specific projects (project plans) • Identification of process and context variances possible • Identification of correlations between process element occurrences
Tailoring data analysis	Pre-existing tailoring data	• Analysis of historical tailoring decisions (analog to project records) • Identification of variance and rationale (frequency) • E.g. from milestone documents or dedicated tailoring documents
Implicit information - Observation		
Participative	Project team members	• Participation in project-specific process instance • Only suitable for small enough system boundary
Project planning procedures	Project planners (Planning guidelines)	• Observation of project planning practices/procedures • Passive: Observation of project planners without interference • Active: Discussion and process modeling of planning procedure and important decision points • Combination with interviews with project planners regarding personal planning practices • Analysis whether recurring assumptions/premises relevant for tailoring are made
Workshops	Project kick-off meetings, (preliminary)	• Conduct and observe/record workshops where process is collaboratively tailored by a team of stakeholders from different disciplines and/or departments (cf. phase 5, section 7.6)

Method	Possible Sources	Description and resulting information
	tailoring workshops (Project planners, project managers)	• Analyze observations regarding tailoring decisions, assumptions and impacts on the process • Corresponding workshops can be pre-established at organizations as project kick-off meetings • Recurring workshops are beneficial for iterative and redundant data acquisition • Workshops can serve as sources for data validation when preliminary results are presented as input.
Implicit information – Interviews		
Context-oriented	Management roles, e.g. Project managers, etc.	• Acquisition/validation of context factors and affected process elements • Best suited for interview partners with project (portfolio) overview (managing roles, project leaders, planners, …
Process-oriented	Executing roles, e.g. engineers, designers, etc.	• Acquisition/validation of process variances and rationale • Best suited for interview partners with in-depth process knowledge (executing roles, engineers, designers, etc.)

A3.4.3 Categories of information acquisition strategies

Table A-38 lists four generic information acquisition strategies depending on the availability of information regarding RPM and project instances in a particular application case.

Table A-38: Generic information acquisition strategies depending on information availability

		RPM	
		High *(RPM extensively documented, contains specific activities)*	**Low** *(RPM not or poorly documented, e.g. generic activities)*
Project instances	**High** *(data regarding characterization, conducted activities, milestones, resources, outcomes, etc.)*	• Analyze project plans (activity frequency) • Analyze project documentation to identify tentative context factors • Prepare interview guideline with RPM, identified process variance and context factors • Conduct interviews	• Analyze project documentation • Derive RPM (commonalities) and variances from documented project instances • Derive initial context factor information from project documentation
	Low *(documented poorly or not at all)*	• Derive interview guideline based on RPM • Conduct preliminary cross-functional tailoring workshops based on RPM for incremental information acquisition	• Create initial RPM • Adapt literature-based context factors • Conduct preliminary cross-functional tailoring workshops based on initial RPM for incremental information acquisition

A3.4.4 Existing categorization schemes for context factors

Table A-39 lists context factor categorization schemes used to develop the context factor acquisition grid (cf. PE-Langner, 2018, p. 56).

Table A-39: Existing context factor categorization schemes

Existing context categorization schemes		
• Antunes et al., 2010 • Vom Brocke et al., 2016 • Cesare et al., 2008 • Clarke & O'Connor, 2012 • Badke-Schaub & Frankenberger, 2004 • Gericke et al., 2013 • Guertler, 2016	• Hales & Gooch, 2004 • Kang et al., 2008 • Khan et al., 2014 • Maffin, 1998 • Martinez-Ruiz et al., 2012 • Meißner et al., 2005 • Nieberding, 2010 • Du Preez et al., 2009	• Park et al., 2006 • Saidani et al., 2015 • Skalak et al., 1997 • Vasconcelos et al., 2013 • Xu & Ramesh, 2007 • Xu & Ramesh, 2008b • Zakaria et al., 2015b

A3.4.5 Generic information acquisition interview guideline

Table A-40 contains a generic guideline for information acquisition interviews, valid for context- as well as process-oriented interviews, with question items structured along four groups.

Table A-40: Generic guideline for information acquisition interviews

Group	Question	CO	PO	Ref.
Warm Up	*(Explain process tailoring, the methodology, and the definitions of context factors, process variances, tailoring rules, and tailoring operators)*	●	●	
	Please explain your role within the PDP and your responsibilities (activities).	●	●	
	Please explain the position of your role and your activities within the overall hierarchy of the PDP.	●	●	
	Which of the activities you carry out in the PDP are most important and which are supporting activities?		●	
Process	Which deliverables does the investigated process produce?	●	●	M
	What are the objectives of the process?	●	●	
Context factors	How is the portfolio of projects under your supervision characterized? Which differences in project characteristics exist?	●		
	Which decisions can you think of which lead to a change in the PDP for a specific project?	●		
	Which characteristics of a project influence the course of the PDP?	●		
	Which (recurring) tailoring decisions have come up in the past during project planning?	●		
	Which project characteristics have been part of the tailoring decisions?	●		
	Which project characteristics/factors influence your particular activities within the PDP?		●	

Group	Question	CO	PO	Ref.
	What are the specific values of these context factors?	●	●	
	What can characterize the success or failure of a project?	●		R
	Who can make a certain decision? Are there any alternatives?	●		R
	Are there any external circumstances that require a different (sub-) process/different activities for meeting the specific needs, and if so, when?	●	●	M
Process variances	Who are customers/consumers of the (internal) process deliverables?	●	●	M
	Where are the deliverables distributed?	●	●	M
	How are theses deliverables produced? Which methods are used?	●	●	M
	Which activities are required/recommended/optional in order to achieve a particular result?		●	R
	What (data) artifacts are mandatory for each task? What are the alternatives?		●	R
	What are available solution patterns for a specific task/to produce a specific result?		●	R
	Do multiple instances of your subprocesses/activities occur at different positions within the superordinate process/PDP? Are these instances governed by differing boundary conditions/context values?		●	
	Which activities carried out in projects are optional, i.e. do not have to be executed in every instance?		●	
	Is activity XYZ optional, i.e. is it required only under certain circumstances? What are these circumstances?		●	
	Which of the activities carried out do have different modes, i.e. are carried out in different ways, e.g. using different methods, tools, systems? Can you imagine a situation where the activities are carried out differently? What causes the selection of a particular mode?		●	
	Are there any activities carried out only under particular circumstances and not currently documented in the reference process model?		●	
	How do your activities change in response to the listed context factors and their values (*requires prepared context factors*)?		●	

Key: *CO = Context-oriented interview; PO = Process-oriented interview; X = Proposed question focus; Ref. = Reference; R = Rychkova & Nurcan (2011) M = Milani (2015)*

A3.5 Phase 4: Analysis Framework

The following subsections contain the algorithms and implementation (Soley and Matlab Code) for the data import, identification of rule conflicts, calculation of structural metrics, and stakeholder clustering.

A3.5.1 Data import

Soley code for data import (PE-Kölsch, 2018)

```
sequence importAll{
   importAllNodes | importAllEdges | deleteUnconnectedElements
}
//Import aller Knoten, die sich in der Datei "Daten_Import_Test_Case" befinden
sequence importAllNodes{
   ImportNodeList(
   "..//..//Data//Daten_Import_Test_Case - Example.xls", 1, 1, -1, -1, "nodes", "")
}
//Import aller Kanten, die sich in der Datei "Daten_Import_Test_Case" befinden
sequence importAllEdges{
   ImportEdgeList(
   "..//..//Data//Daten_Import_Test_Case - Example.xls", 2, 1, -1, -1, "Edges", "", false)
}
//Löschen von "Waisen"
sequence deleteUnconnectedElements{
   [delteUnconnectedContextVaraibles] | delteUnconnectedNodes*
}
//Identifikation von Kontextvariablen, die keinen Vernetzung mit PTR haben
function findUnconnectedContextVariables(cV:ContextVariable):boolean{
   def var unconnected:boolean=true;
      for (ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
         if (isReachable(cV,ptr)==true){
            unconnected=false;
         }
      }
   return(unconnected);
}
rule delteUnconnectedContextVaraibles{
   cV:ContextVariable;
   if {findUnconnectedContextVariables(cV)==true;}
   modify{
      delete(cV);
   }
}
```

A3.5.2 Rule conflict identification

Soley code for identification of rule conflict patterns (PE-Kölsch, 2018)

```
sequence identifyConflicts{
  [identifyConflicts1] | [identifyConflicts2]
}
  //Varainte wird von einer PTR ausgewählt und gleichzeitg von einer anderen PTR exkludiert
  rule identifyConflicts1{
    ptr1:ProcessTailoringRule;
    ptr2:ProcessTailoringRule;
    a:Activity;
    ptr1 -e1:hasImpact-> a <-e2 :hasImpact-ptr2;
    modify{
      eval{
        if(e1.operatorDelete==true && e2.operatorSelect==true){
          ptr1.conflict=true;
          ptr2.conflict=true;
        }
      }
    }
  }

  //Varainte wird ausgewählt obwol übergeordnetes Element gelöscht wird
  rule identifyConflicts2{
    ptr1:ProcessTailoringRule;
    ptr2:ProcessTailoringRule;
    a1:Activity;
    a2:Activity;
    ptr1 -e1:hasImpact-> a1 -:isVariantOf-> a2 <-e2 :hasImpact-ptr2;
    modify{
      eval{
        if(e1.operatorDelete==true && e2.operatorSelect==true){
          ptr1.conflict=true;
          ptr2.conflict=true;
        }
      }
    }
  }
```

A3.5.3 Structural metric: Criticality

The calculation of the Criticality metric is illustrated in Figure A-6. Subsequently, the original code for the graph-based calculation is presented (PE-Kölsch, 2018).

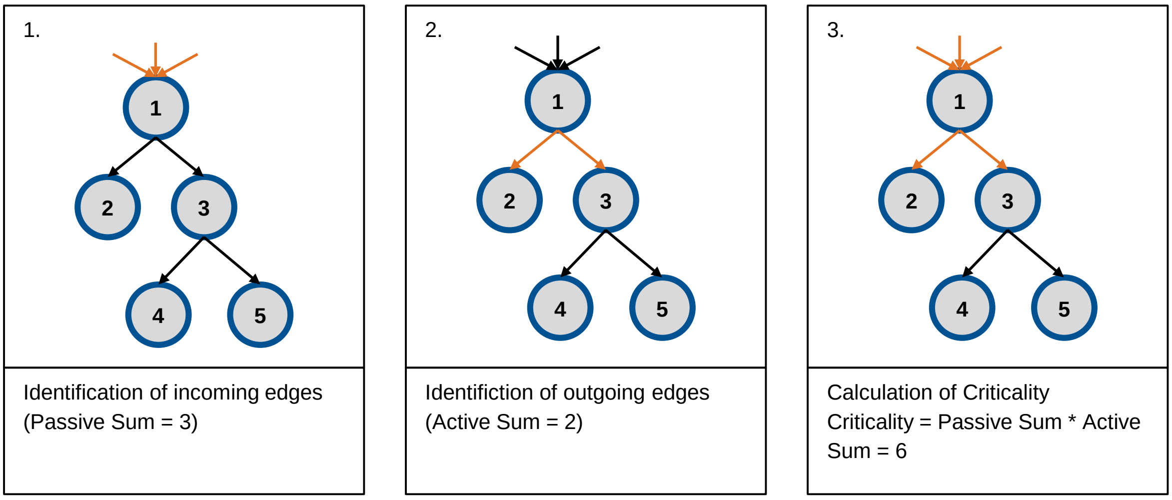


Figure A-6: Illustration of algorithm for calculation of Criticality (based on PE-Kölsch, 2018)

```
//Berechnung der Criticality für jeden Knoten der Knoten-Klasse "Activity" und Berechnung der
durchschnittlichen Criticality für jeden Knoten der Knoten-Klasse "ProcessTailoringRule"
sequence criticality{
   [computeCriticality] | [computeChildCriticality] | [computeMeanCriticality]
}
   //Berechnung der Criticality
   function criticalityOfNode(Activity:Node): array<int>
   {
      def var activeSum:int;
      def var passiveSum:int;
      def var cri:int;
      def ref Criticality:array<int> = array<int>[];
      activeSum = countOutgoing(Activity, precedes);
      passiveSum = countIncoming(Activity, precedes);
      cri = activeSum*passiveSum;
      //Array - 1. Wert: active sum -> [0]
      Criticality.add(activeSum);
      //Array - 2. Wert: passive sum -> [1]
      Criticality.add(passiveSum);
      //Array 3. Wert: criticality -> [2]
      Criticality.add(cri);
      return(Criticality);
   }
   rule computeCriticality
   {
      a:Activity;
      modify{
         eval{
            a.criticality=criticalityOfNode(a);
         }
      }
   }
```

```
//Übertragen/Vererben der Criticality an Varianten
rule computeChildCriticality{
   a1:Activity;
   a2:Activity;
   a2-:isVariantOf-> a1;
   modify{
      eval{
         a2.criticality=a1.criticality;
      }
   }
}
//Berechnung der durchschnittlichen Criticality je PTR
function meanCriticality(domain1:Node):double
{
   def var meanCriticality:double;
   def var iHilf:double;
   for(domain2:ProcessElement in nodes(ProcessElement)){
      if (isBoundedReachableOutgoing(domain1, domain2, 1, hasImpact)==true){
         meanCriticality=meanCriticality+domain2.criticality[2];
         iHilf=iHilf+1;
      }
   }
   if(iHilf > 0){
      meanCriticality=meanCriticality/iHilf;
   }
   else{
      meanCriticality=0;
   }
   return(meanCriticality);
}
   rule computeMeanCriticality{
   ptr:ProcessTailoringRule;
   modify{
      eval{
         ptr.meanCriticality=meanCriticality(ptr);
      }
   }
}
```

A3.5.4 Structural metric: Snowball factor

The source code for the calculation of the SBF has been developed in collaboration between PE-Kölsch (2018) and Knippenberg (2018), the latter of which has been published in Knippenberg et al. (2018).

The calculation of the Snowball Factor metric is illustrated in Figure A-7. Subsequently, the original code for the graph-based calculation is presented (based on PE-Kölsch, 2018).

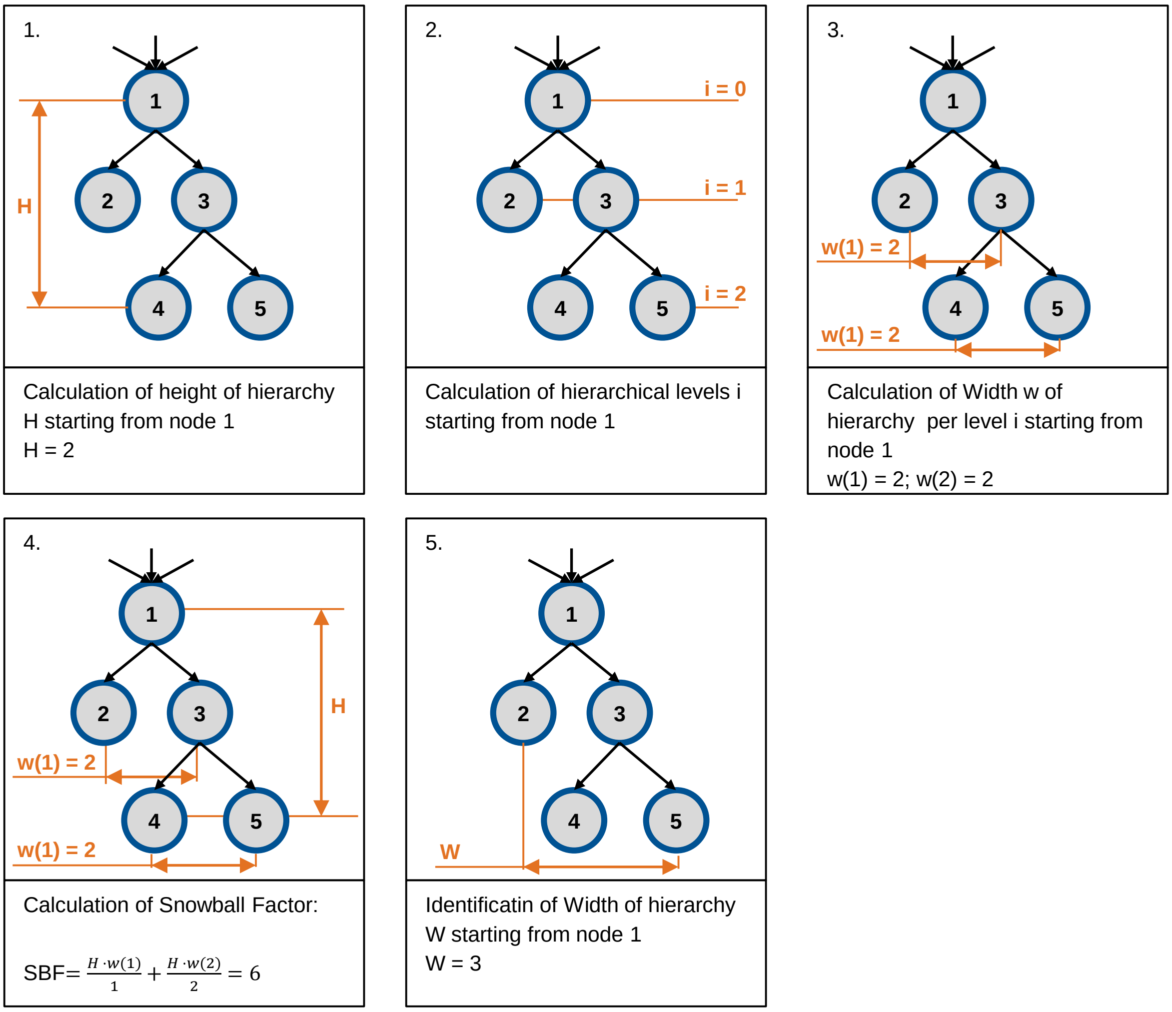


Figure A-7: Illustration of algorithm for calculation of Snowball Factor (based on PE-Kölsch, 2018)

```
//Berechnung des Snowball factors für jeden Knoten der Knoten-Klasse "Activity" und Berechnung des
durchschnittlichen Snowball factors für jeden Knoten der Knoten-Klasse "ProcessTailoringRule"
sequence snowballFactor{ [computeSnowballFactor] | [computeChildSnowballFactor] |
[computeMeanSnowballFactor] }

//Berechnung des Snowball factors
function snowballFactor(domain:Node): array<double>
{
   def ref sf:array<double> = array<double>[];
   //Tiefe der Hierarchie
  def var i:int;
   i=0;
```

```
   def var j:int;
   j=1;
   def var hOh:int;
   hOh=0;
   while(countBoundedReachableOutgoing(domain, i, precedes) != countBoundedReachableOutgoing(domain,
j, precedes)){
      i=i+1;
      j=j+1;
      hOh=hOh+1;
   }
   //Array - 1. Wert: Height -> [0]
   sf.add(hOh);
   //Breite der Hierarchie
   def var wOh:double;
   for(child:Node in reachable(domain)){
      if(isReachableOutgoing(domain,child, precedes)==true && countOutgoing(child, precedes)==0){
         wOh=wOh+1;
      }
   }
   //Array - 2. Wert: Width -> [1]
   sf.add(wOh);
   //Snowball Factor
   def var k:int = 1;
   def var width_i:int;
   def var SF_i:double;
   def var SF:double;
   while(k < hOh){
      width_i = countBoundedReachableOutgoing(domain, k, precedes) -
countBoundedReachableOutgoing(domain, k-1, precedes);
      SF_i = (hOh*width_i)/k;
      SF = SF + SF_i;
        k = k+1;
   }
   //Array - 3. Wert: Snowball factor -> [2]
   sf.add(SF);
   return(sf);
 }
rule computeSnowballFactor{
   domain:Activity;
   modify{
      eval{
         domain.snowballFactor=snowballFactor(domain);
      }
   }
}
//Übertragen/Vererben des Snowball factors an Varianten
rule computeChildSnowballFactor{
   a1:Activity;
   a2:Activity;
   a2-:isVariantOf-> a1;
   modify{
      eval{
         a2.snowballFactor[2]=a1.snowballFactor[2];
         a2.snowballFactor[1]=a1.snowballFactor[1];
         a2.snowballFactor[0]=a1.snowballFactor[0];
      }
   }
}
```

```
//Berechnung des durchschnittlichen SNowball factors je PTR
function meanSnowballFactor(domain1:Node):double{
    def var meanSnowballFactor:double;
    def var iHilf:int;
    for(domain2:Activity in nodes(ProcessElement)){
        if (isBoundedReachableOutgoing(domain1, domain2, 1, hasImpact)==true){
            meanSnowballFactor=meanSnowballFactor+domain2.snowballFactor[2];
            iHilf=iHilf+1;
        }
    }
    if(iHilf > 0){
        meanSnowballFactor=meanSnowballFactor/iHilf;
    }
    else{
        meanSnowballFactor=0;
    }
     return(meanSnowballFactor);
}
rule computeMeanSnowballFactor{
     ptr:ProcessTailoringRule;
     modify{
        eval{
            ptr.meanCriticality=meanCriticality(ptr);
            ptr.meanCentrality=meanCentrality(ptr);
             ptr.meanSnowballFactor=meanSnowballFactor(ptr);
         }
        }
    }
```

A3.5.5 Structural metric: Centrality

The calculation of the Snowball Factor metric is illustrated in Figure A-7. Subsequently, the original code for the graph-based calculation is presented (based on PE-Kölsch 2018).

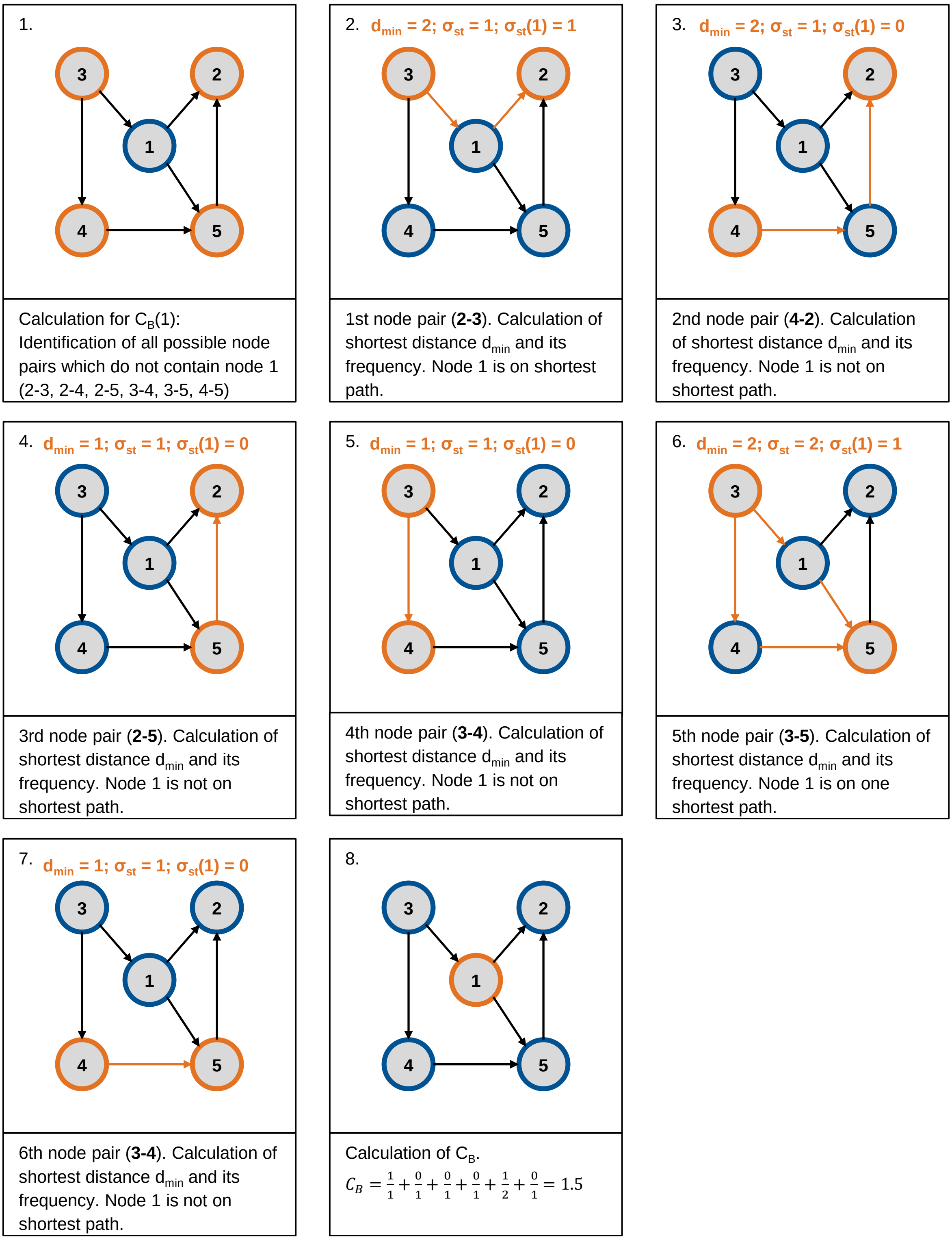


Figure A- 8: Illustration of algorithm for calculation of Betweenness Centrality (based on PE-Kölsch, 2018)

```
//Berechnung der Centrality für jeden Knoten der Knoten-Klasse "Activity" und Berechnung der
durchschnittlichen Centrality für jeden Knoten der Knoten-Klasse "ProcessTailoringRule"
sequence Centrality{  [computeCentrality] | [computeChildCentrality] | [computeMeanCentrality] }
    //Ermittlung der kürzesten Distanz zwischen zwei Knoten
function cDistance(node1:Node, node2:Node):int{
    def var distance:int;
    def var d:int;
    def var iHilf:int;
    iHilf=0;
    distance=0;
    d=0;
    if(isReachableOutgoing(node1, node2, precedes)==true){
        while(iHilf==0){
            if(isBoundedReachableOutgoing(node1, node2, d, precedes)==true){
               iHilf=1;
            }else{
                d=d+1;
            }
        }
    }
  distance = d;
    return(distance);

}
//Ermittlung der Anzahl kürzester Pfade zwischen zwei Knoten
function numberOfShortestPaths(node1:Node, node2:Node):int
{
    def var n:int = 0;
    def var n_Hilf:int = 0;
    def var k:int =0;
    def var d:int = 0;
    def var j:int;
    def var i:int;
    d = cDistance(node1,node2);
    i=1;
    j=d-i;
    while(j>0){
      n_Hilf=0;
      for(a:Activity in nodes(ProcessElement)){
          if(isBoundedReachableOutgoing(node1, a, i, precedes)==true && isBoundedReachableOutgoing(a,
node2, j, precedes)==true){
                n_Hilf=n_Hilf+1;
            }
      }
      i=i+1;
       j=d-i;
      if(n_Hilf>n){
          n=n_Hilf;
      }
   }
   return(n);
}
//Berechnung der Centrality
function centrality(a:Node):double {
   def var d:int;
   def var i:int;
   def var j:int;
   def var n:double = 0;
   def var c:double = 0;
```

```
def var c_1:int = 0;
def var c_2:int = 0;
def var c_Hilf:int=0;
def var cen:double=0;
def var k:int;
def var l:int;
for(a1:Activity in nodes(ProcessElement)){
  for(a2:Activity in nodes(ProcessElement)){
      if(isReachableOutgoing(a1, a2, precedes)==true){
         if(isReachableOutgoing(a1, a, precedes)==true && isReachableOutgoing(a, a2, precedes)==true){
            i=1;
            d=cDistance(a1, a2);
            j=d-i;
             while(j>0){
               if(isBoundedReachableOutgoing(a1, a, i, precedes)==true && isBoundedReachableOutgoing(a,
a2, j, precedes)==true){
                  n=numberOfShortestPaths(a1,a2);
                  k=1;
                  l=i-k;
                  while(l>0){
                     c_Hilf=0;
                     for(a3:Activity in nodes(ProcessElement)){
                         if(isBoundedReachableOutgoing(a1, a3, k, precedes)==true &&
isBoundedReachableOutgoing(a3, a, l, precedes)==true){
                         c_Hilf=c_Hilf+1;
                         }
                      }
                     k=k+1;
                     l=i-k;
                      if(c_Hilf>c_1){
                        c_1=c_Hilf;
                      }
                  }
                  k=1;
                  l=j-k;
                   while(l>0){
                     c_Hilf=0;
                      for(a4:Activity in nodes(ProcessElement)){
                         if(isBoundedReachableOutgoing(a, a4, k, precedes)==true &&
isBoundedReachableOutgoing(a4, a2, l, precedes)==true){
                         c_Hilf=c_Hilf+1;
                         }
                     }
                     k=k+1;
                      l=j-k;
                      if(c_Hilf>c_2){
                         c_2=c_Hilf;
                      }
                   }
                   if(i==1 && j==1){
                      c=1/n;
                   }
                   else{
                      c=(c_1 + c_2)/n;
                   }
                   cen=cen+c;
                   j=0;
                }
```

```
                else{
                    i=i+1;
                    j=d-i;
                }
              }
            }
          }
        }
    }
    return(cen);
}
rule computeCentrality{
    a:Activity;
    modify{
        eval{
            a.centrality=centrality(a);
        }
    }
}
//Übertragen/Vererben der Centrality an Varianten
rule computeChildCentrality{
    a1:Activity;
    a2:Activity;
    a2-:isVariantOf-> a1;
    modify{
        eval{
            a2.centrality=a1.centrality;
        }
    }
}
//Berechnung der durchschnittlichen Centrality je PTR
function meanCentrality(domain1:Node):double
{
    def var meanCentrality:double;
    def var iHilf:int;
    for(domain2:Activity in nodes(ProcessElement)){
        if (isBoundedReachableOutgoing(domain1, domain2, 1, hasImpact)==true){
            meanCentrality=meanCentrality+domain2.centrality;
            iHilf=iHilf+1;
        }
    }
    if(iHilf > 0){
        meanCentrality=meanCentrality/iHilf;
    }
    else{
        meanCentrality=0;
    }
    return(meanCentrality);
}
rule computeMeanCentrality{
    ptr:ProcessTailoringRule;
    modify{
        eval{
            ptr.meanCentrality=meanCentrality(ptr);
        }
    }
}
```

A3.5.6 Structural metric: Alignment

Soley code for the calculation of the alignment metric (PE-Kölsch, 2018)

```
sequence communicationAll{
  [computeRequirementOfCommunication]
}
  //Berechnung der maximalen durchschnittlichen Komplexitätsmetriken
  function maxMeanCriticality():double{
    def var maxMeanCriticality:double;
    def var meanCriticalityHilf:double;
    for(ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
      meanCriticalityHilf=ptr.meanCriticality;
      if(meanCriticalityHilf>maxMeanCriticality){
        maxMeanCriticality=meanCriticalityHilf;
      }
    }
    return(maxMeanCriticality);
  }
  //Berechnung der maximalen durchschnittlichen Komplexitätsmetriken
  function maxMeanSnowballFactor():double{
    def var maxMeanSF:double;
    def var meanSFHilf:double;
    for(ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
      meanSFHilf=ptr.meanSnowballFactor;
      if(meanSFHilf>maxMeanSF){
        maxMeanSF=meanSFHilf;
      }
    }
    return(maxMeanSF);
  }
  //Berechnung der maximalen durchschnittlichen Komplexitätsmetriken
  function maxMeanCentrality():double{
    def var maxMeanCentrality:double;
    def var meanCentralityHilf:double;
    for(ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
      meanCentralityHilf=ptr.meanCentrality;
      if(meanCentralityHilf>maxMeanCentrality){
        maxMeanCentrality=meanCentralityHilf;
      }
    }
    return(maxMeanCentrality);
  }

  //Berechnung des Kommunikationsbedarfs
  function requirementOfCommunication (p1:Node, p2:Node):double
  {
    //1. Organizational Distance
    def var distance:int;
    def var d:int;
    def var iHilf:int;
    iHilf=0;
    distance=0;
    d=0;
    if(isReachable(p1, p2, leads)==true){
      while(iHilf==0){
        if(isBoundedReachable(p1, p2, d, leads)==true){
          iHilf=1;
```

```
            }else{
               d=d+1;
            }
         }
      }
      distance = d;
      //2.Number of common Rules
      def var coordination:double;
      def var communication:double;
      def var c:int;
      def var ptrMean:double;
      c=0;
      for(ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
         if(isBoundedReachable(ptr,p1,3)==true && isBoundedReachable(ptr,p2,3)==true){
            c=c+1;
            ptrMean=ptrMean + (ptr.meanCriticality/maxMeanCriticality()) +
(ptr.meanSnowballFactor/maxMeanSnowballFactor()) + (ptr.meanCentrality/maxMeanCentrality());
         }
      }
      if(c>0){
         ptrMean=ptrMean/c;
      }
      //3. Requirement of Coordination
      coordination=ptrMean*c;
      //4. Requirement of Communication
      communication=coordination*d*d;
      return(communication);
   }

   function checkPTRConnection(p1:Node,p2:Node):int{
      def var c:int;
      c=0;
      for(ptr:ProcessTailoringRule in nodes(ProcessTailoringRule)){
         if(isBoundedReachable(ptr,p1,3)==true && isBoundedReachable(ptr,p2,3)==true &&
isBoundedReachable(p1,p2,1,hasRelationshipWith)==false){
            c=1;
         }
      }
      return(c);
   }
   rule computeRequirementOfCommunication{
      p1:Person;
      p2:Person;
      if{checkPTRConnection(p1,p2)>0;}
      modify{
            p1 -e1:hasRelationshipWith- p2;
         eval{
            e1.requirementOfCommunication=requirementOfCommunication (p1, p2);
         }
      }
   }
```

A3.5.7 Stakeholder clustering

Matlab code for stakeholder clustering (PE-Kölsch, 2018)

```
%% Import Data from .csv-file
    Kommunikationsbedarf=importfile('Kommunikationsbedarf.csv',2);
%% Create the distance matrix
    Data=computation_DistanceMatrix(Kommunikationsbedarf);
%% Delete all empty rows and columns from the distance matrix
    o=length(Data);
    q=o;
    p=1;
    %Start with the last row
    for i=o:-1:2
        x=0;
        %Check every column of the appropraite row wether the cell is empty or
        %not
        for j=q:-1:2
            if Data(i,j)>0
                x=1;
                j=2;
            end
        end
        %Delete the row and the column of the matrix if all cells are empty
        if x==0
            Data(:,i)=[];
            Data(i,:)=[];
            q=q-1;
        end
    end
    %Create a vector containing all remaining IDs
    id=Data(2:end,1);
    %Remove the header (IDs) from the matrix
    Data=Data(2:end,2:end);
%% Perform Clustering
    rows = length(Data);
    maxValue =  max(Data(:));
    k=1;
    h=2;
    %Transform the similarity matrix into a distance matrix
    for i=1:rows
        for j=h:rows
            distance=maxValue-Data(i,j);
        v(k)=distance;
        k=k+1;
        end
    h=h+1;
    end
    %Complete-Linkage-Algorithm
    Z=linkage(v, 'complete');
```

```
    g = cluster(Z,'maxclust',3);
%% Export Data
    %Create the headers of for the excel file
    for i=1:rows
        node_class(i)="Help";
    end
    group=[node_class',id,g];
    header={'node class' 'id' 'clusterID'};
    %Export the data
    filename = 'Cluster_Zuordnung.xls';
    xlswrite(filename, header, 1, 'A1');
    xlswrite(filename, group, 1, 'A2');
```

Matlab Code for data import (PE Kölsch, 2018)

```
function Abstimmungsbedarf = importfile(filename, startRow, endRow)
%IMPORTFILE Import numeric data from a text file as a matrix.
%   ABSTIMMUNGSBEDARF = IMPORTFILE(FILENAME) Reads data from text file
%   FILENAME for the default selection.
%
%   ABSTIMMUNGSBEDARF = IMPORTFILE(FILENAME, STARTROW, ENDROW) Reads data
%   from rows STARTROW through ENDROW of text file FILENAME.
%
% Example:
%   Abstimmungsbedarf = importfile('Abstimmungsbedarf.csv', 2, 609);
%
%    See also TEXTSCAN.

% Auto-generated by MATLAB on 2018/04/20 08:26:59

%% Initialize variables.
delimiter = ';';
if nargin<=2
    startRow = 2;
    endRow = inf;
end

%% Format for each line of text:
%   column1: double (%f)
%            column2: double (%f)
%   column3: double (%f)
%            column4: double (%f)
% For more information, see the TEXTSCAN documentation.
formatSpec = '%f%f%f%f%[^\n\r]';

%% Open the text file.
fileID = fopen(filename,'r');

%% Read columns of data according to the format.
% This call is based on the structure of the file used to generate this
% code. If an error occurs for a different file, try regenerating the code
% from the Import Tool.
dataArray = textscan(fileID, formatSpec, endRow(1)-startRow(1)+1, 'Delimiter', delimiter, 'TextType', 'string',
'EmptyValue', NaN, 'HeaderLines', startRow(1)-1, 'ReturnOnError', false, 'EndOfLine', '\r\n');
for block=2:length(startRow)
```

```
    frewind(fileID);
    dataArrayBlock = textscan(fileID, formatSpec, endRow(block)-startRow(block)+1, 'Delimiter', delimiter, 'TextType', 'string', 'EmptyValue', NaN, 'HeaderLines', startRow(block)-1, 'ReturnOnError', false, 'EndOfLine', '\r\n');
    for col=1:length(dataArray)
        dataArray{col} = [dataArray{col};dataArrayBlock{col}];
    end
end

%% Close the text file.
fclose(fileID);

%% Post processing for unimportable data.
% No unimportable data rules were applied during the import, so no post
% processing code is included. To generate code which works for
% unimportable data, select unimportable cells in a file and regenerate the
% script.

%% Create output variable
Abstimmungsbedarf = [dataArray{1:end-1}];
```

Matlab Code for calculation of Distance matrix (PE-Kölsch, 2018)

```
function [Distance_Matrix] = compute_Similarity_Matrix(Data_Matrix)
    %Create a vector with all IDs
    A=Data_Matrix;
    rows = length(A);
    j=1;
    for i=1:rows
        if A(i,1)>0
            a(j)=A(i,1);
            j=j+1;
        end
    end
    %Identify the highest and lowest ID
    max_id=max(a);
    min_id=min(a);
    columns=length(a');
    k=1;
    for j=min_id:max_id
        for i=1:columns
            if a(i)==j;
                id(k)=a(i);
                j=j+1;
                k=k+1;
            end
        end
    end
    id=sort(id);
    columns=length(id');
    for i=1:columns;
        j=i+1;
        D(j,1)=id(i);
        D(1,j)=id(i);
    end
    for i=1:columns
```

```
        for j=1:rows
            if A(j,2)==id(i)
                for k=1:columns
                    if A(j,3)==id(k)
                        m=i+1;
                        n=k+1;
                        D(m,n)= A(j,4);
                    end
                end
            end
        end
    end
    Distance_Matrix=D;
end
```

Soley code for reintegration of cluster IDs into the TSM:

```
//Import der Workshop-Cluster-ID
sequence workshopCluster{
    importCluster | [transferClusterID] | deleteHelp*
}
    //Import Data
    sequence importCluster{
        ImportTypedNodeListAttrMapping(
        "..//..//Data//Analyseergebnisse/Cluster_Zuordnung.xls", 1, 2, -1, -1, "", "", "Help",
        map<int, string>{
            1 -> "id",
            2 -> "clusterID"
        }
        )
    }
    //Transfer der Cluster-ID
    rule transferClusterID{
        h:Help;
        p:Person;
        if{h.id==p.id;}
        modify{
            eval{
                p.clusterID=h.clusterID;
            }
        }
    }
    //Löschen des Hilfs-Knotens
    rule deleteHelp{
        h:Help;
        modify{
            delete(h);
        }
    }
```

A3.6 Phase 4: Tailoring analysis reports

A3.6.1 Data export

The exported analysis results are listed in two formats: The absolute results (Table A-41) in the form of attributes and dependencies, and the results per export file, indicating the column structure of the individual export files (Table A-42). Due to the need for case-specific adaptation of the organizational domain, organizational units and individuals are not differentiated but summarily designated as “stakeholder”.

It has to be noted at this point that **cluster dependencies** are not contained within the TSM, as stakeholder clusters are not implemented as node types. Cluster IDs are instead assigned to individual organizational nodes. Cluster dependencies are therefore generated solely as functions of the export routines, by analyzing whether organizational nodes assigned to two clusters share a dependency via common PTRs, activities, or context variables.

Table A-41: Summary of exported analysis results per node type (attributes and dependencies)

Domain	Attributes	Dependencies
All	id; name; description;	–
Context variable	–	ContextVariable – – ContextValue ContextVariable – – ContextValue – –PTR ContextVariable – – ContextValue – –PTR – – ContextValue – – ContextVariable ContextVariable – – ContextValue – – ContextVariable
PTR	dependentActivities; numberOfdependent Stakeholders; meanCr; meanSBF; meanCB;	PTR – – ContextValue – – ContextVariable PTR – – Activity PTR – – ContextValue – – ContextVariable – – ContextValue – – PTR (*numberOfElements*) PTR – – Activity – – PTR (*numberOfElements*) PTR – – Activity – – Role – –Stakeholder – –Role – –Activity – – PTR (*numberOfElements*)
Activity	Cr; SBF; CB; responsibleStakeholder; connectedRules; numberOfVariants; previousActivities; followingActivities;	(previous and following activities are exported via array-attributes)
Org.	clusterID; numberOfPTRs; responsibleActivities;	Stakeholder – – Role – – Activity – – PTR Stakeholder– – Role – – Activity Stakeholder – – Role – – Activity – – PTR – – Activity – – Role – – Stakeholder (*hasRelationshipWith*) Stakeholder – – Role – – Activity – – Role – – Stakeholder

Table A-42: Structure and content of export files

Main node type of export file	Attributes per node type	Dependencies to other node types	Attributes per dependency
Organizational node	id; description; name; Cluster id; responsibleActivities; numberOfPTRs;	PTRs (affecting organizational node)	numberOfActivities; meanCr; meanSBF; meanCB;
		Dependent stakeholder (via PTR)	Stakeholder id, PTR id
		Activities (via PTR)	Cr; SBF; CB;
		OrganizationalNodes (affected via activities)	id
PTR	id; description; numberOfdependent Stakeholders;	Activity	id; Cr; Active Sum; Passive Sum; SBF; Width; Height; CB;
		ContextVariable:	id; name;
		ContextValue:	id; name;
Activity	id; Cr; Active Sum; PassiveSum; SBF; Height; Width; Cr; Description; Responsible Stakeholder; numberOfVariants; followingActivities; precedingActivities;		
Context variable	id; name; description;	ContextValue	id; name;
		Connected PTRs	id;
		Dependent ContextVariable (via PTR)	id; name;
Cluster	id	OrganizationalNodes per cluster:	id; name
		PTRs (per cluster)	id; meanCr; meanSBF; meanCB; numberOfActivities;
		Activity (per cluster)	id; Cr; SBF; CB;
		Cluster dependency via PTR	id (PTR)
		Cluster dependency via Activity	id (activity)
		Cluster dependency via Context Variable	id (ContextVariable)
PTR dependencies	id	Dependent PTRs (via Context) (*hasContextRelationshipWith*)	numberOfElements
		Dependent PTRs (via Stakeholders) (*hasStakeholderRelationshipWith*)	numberOfElements
		Dependent PTR (via activities) (*hasProcessRelationshipWith*)	numberOfElements
Communication	id (ONode)	Communication requirements (*hasRelationshipWith*)	Alignment

A3.6.2 Overview of analysis questions per report type

The following figure summarizes the information context of the individual tailoring reports in terms of addressed analysis questions. Question Q1.1 is answered via the PTR conflict analysis, which is not part of the tailoring reports.

		Analysis goals and questions																									
		G1	G2						G3	G4						G5							G6				
Level	**Report type**	Q1.1	Q2.1	Q2.2	Q2.3	Q2.4	Q2.5	Q2.6	Q3.1	Q4.1	Q4.2	Q4.3	Q4.4	Q4.5	Q4.6	Q5.1	Q5.2	Q5.3	Q5.4	Q5.5	Q5.6	Q5.7	Q6.1	Q6.2	Q6.3	Q6.4	Q6.5
Network	Process tailoring rule report		●	●			●	●																			
	Tailoring stakeholder report				●	●			●																		
Cluster	Workshop cluster report									●	●	●	●	●	●												
Node	Context variable report																							●			
	Process tailoring rule report																						●		●		●
	Activity report																									●	
	Tailoring stakeholder report															●	●	●	●	●	●	●					

Figure A-9: Answered analysis questions per report type

A3.6.3 Tailoring analysis report templates

Within this subsection, full-size templates for the individual tailoring reports are presented. The templates illustrate the general structure, selected metric visualizations and information context. As the intention is to convey the general concept, dummy data and blind text are used. In addition to the templates, their information content in terms of dependencies and attributes used is elaborated.47

The focus of the **network level** is to give an overview of a particular domain or node type. Based on the formulated analysis questions, two report types have been defined on this level of granularity, based on two node types: *Process tailoring rules* and *stakeholders*.

Network level: Process tailoring rule report

The network level PTR report contains an overview of all PTRs contained within the TSM and their associated information. The overview aids tailoring experts in identifying potential modeling errors and outliers (e.g. rules without impacts or with a particular high number of impacts), and answering questions related to the significance of tailoring rules, which influence many activities and/or stakeholders (Q2.1, Q2.2) and thus have a large influence on the process, via a large number of impacts and high mean activity metrics (Q2.1, Q2.6.). The report is concluded by an overview of indirect dependencies between PTRs via common *ContextVariables*, *Activities*, and *Stakeholders*. This information can be used to group PTRs for discussion in workshops and identify side-effects between PTRs.

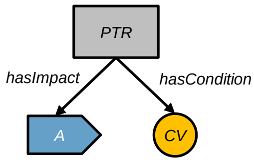
In order to drill down to further details, node-level reports can be used.

Table A-43: Information content of network level PTR report

ID	Dependency	Attribute	Vis.
Q2.1	*PTR – – Activity*	*numberOfActivities*	T, P
Q2.6	*PTR – – Activity*	*meanCr; meanSBF; meanCB (Activity)*	T, P
Q2.2	*PTR – – Activity – – Role – – Stakeholder*	*numberOfDependentStakeholders*	T, P
Q2.5	*PTR – – ContextValue – – ContextVariable– – ContextValue – – PTR*	*numberOfElements (hasCRSw)*	M
	PTR – – Activity – – PTR	*numberOfElements (hasPRSw)*	
	PTR – – Activity – – Role – – Stakeholder – – Role – – Activity – – PTR	*numberOfElements (hasSHRSw)*	

Key: *T = Table: P = Portfolio; M = Matrix*

Process tailoring rules (network level)



Description

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed lobortis, mauris sed fringilla luctus, diam dolor interdum tellus, at efficitur neque est sit amet leo. Sed eu urna at ex interdum congue quis id lectus.

General information

Number of nodes:

n-times

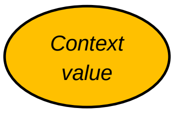
Number of edges:

y-times

Context-based analysis

Number of connected nodes:

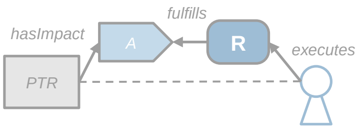
n-times



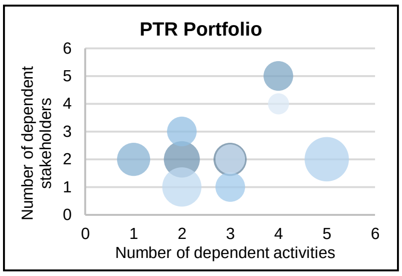
Number of connected edges:

y-times

Process-based analysis



PTR	Level	Number of Activities	Number of Stakeholders	ØCriticality (Cri)	ØSnowball factor (Cen)	ØCentrality (Cri)	Cri+SF+Cen
1	HMS	2	2	1	3	2	6
	UMS	2	2	3	2	2	7
	Task	3	1	4	2	-	6
2	HMS	2	1	2	2	3	7
	UMS	-	-	-	-	-	-
	Task	2	5	5	6	2	13
3	HMS	-	-	-	-	-	-
	UMS	4	5	7	5	2	14
	Task	3	2	2	1	3	6



PTR Dependencies

Number of common Context Variables														
ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		2		4		1	1		2	2				
2	2		3		3	4								
3		3		2	2					6				
4	4		2		1	2								
5		3	2	1		3			3					3
6	1	4		2	3						2	2		1
7	1							2			2			1
8							2		2	3				
9	2				3			2		1			1	
10	2		6					3	1		1	2		
11						2	2			1				
12						2				2			1	
13									1			1		
14					3	1	1							

Number of common Activities														
ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1				4		1			2					
2					3	4							1	
3								7		5		3		
4	4				1	2								
5		3		1		3			3					3
6	1	4		2	3									1
7								2			2			1
8			7				2		4	1				
9	2				3			4		1			3	
10			5					1	1		1	2		
11							2			1				
12			3							2			2	
13		1							3			2		1
14					3	1	1						1	

Number of common Stakeholders														
ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1		1		4		1			2					
2	1				3	2							1	
3				2				7		5		3		
4	4		2		1	2								
5		3		1		3			3					
6	1	2		2	3		5							
7						5		2			2			
8			7				2		7					
9	2				3			7		4			3	
10			5						4		1	2		
11							2			1				
12			3							2			2	
13		1							3			2		1
14													1	

Figure A-10: Network-level process tailoring rule report (template)

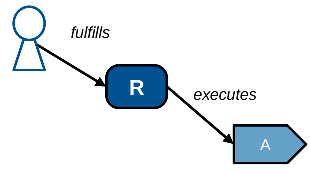
Network level: Tailoring stakeholder report

The involved process **stakeholders** participate in the tailoring workshops (cf. phase 5, section 7.6), discussing the individual tailoring rules and collectively making corresponding decisions. Therefore, the second report type on network level addresses the overview of the tailoring stakeholders within the process to be tailored. The report provides information to identify tailoring stakeholders impacted by a high number of PTRs (Q2.3), e.g. for training or with high relevancy for attendance during workshops. It furthermore allows the identification of stakeholders which are responsible for a high number of activities (Q2.4) and stakeholder dyads with a high need for communication regarding tailoring decisions via the alignment matrix (Q3.1).

Table A-44: Information content of network level stakeholder report

ID	Dependency	Attribute	Vis.
Q2.3	*Stakeholder – – Role – – Activity – – PTR*	*dependentRules*	H
Q2.4	*Stakeholder – – Role – – Activity*	*responsibleActivities*	H
Q3.1	*Stakeholder – – (OrganizationalNode) – – Stakeholder* *Stakeholder – – Role – – Activity – – PTR – – Activity – – Role – – Stakeholder*	*Alignment (hasRSw)* *clusterID (ONode)*	M
Key: *H = Histogram; M = Matrix*			

Stakeholder (network level)



Description

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed lobortis, mauris sed fringilla luctus, diam dolor interdum tellus, at efficitur neque est sit amet leo. Sed eu urna at ex interdum congue quis id lectus.

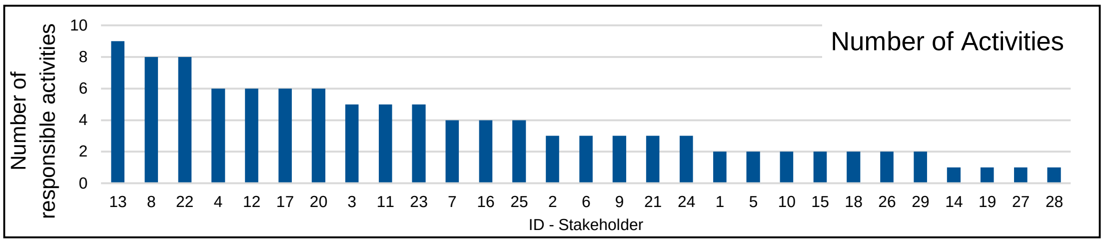
General information

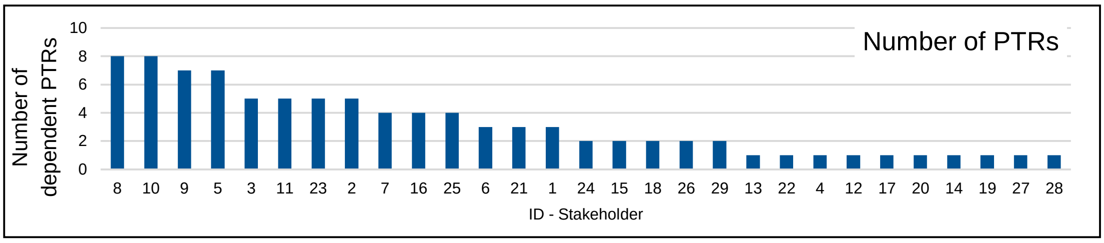
Number of nodes

n-times  *Individual*

Number of edges:

y-times *executes*





Requirement of communication

ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1			32	12		48	80		160	80		16		36	252	252	108	36	360	144	180	180	
2			12			32	32			16				108	108	108		108	144		36		
3	32	12					32		144	48	16	16		144	108	252		144	360	144	36	252	
4	12															108							
5														36					36				
6	48	32					44	4	48	80			48	72	432		324	36	396		108		
7	80	32	32			44		28	80	128			32		828	72	324	36	576	72	288	72	
8						4	28								144		36		36				
9	160		144			48	80			20				36	288	144	108	36	540	144	216	144	
10	80	16	48			80	128		20				32	144	396	108	180	36	396	72	108	72	
11			16																				
12	16		16													36			36			108	
13						48	32			32				36	108		72		108				
14	36	108	144		36	72			36	144			36		48	96		180	612	36	36	36	
15	252	108	108			432	828	144	288	396			108	48		96	288	72	720	108	540	108	72
16	252	108	252	108			72		144	108		36		96	96			144	360	144	36	144	
17	108					324	324	36	108	180			72		288				144		108		
18	36	108	144			36	36		36	36				180	72	144			144	36	72	36	
19	360	144	360		36	396	576	36	540	396		36	108	612	720	360	144	144		144	396	180	
20	144		144				72		144	72				36	108	144		36	144		16	64	
21	180	36	36			108	288		216	108				36	540	36	108	72	396	16		4	
22	180		252				72		144	72		108		36	108	144		36	180	64	4		
23															72								

Cluster 1

1; 5; 11; 16

Cluster2

12; 13; 14; 15; 17

Cluster 3

2; 3; 4; 9; 22; 23; 24

Cluster 4

18; 19; 28; 29; 30

Cluster 5

6; 7; 8; 10; 20; 21

Cluster 6

22; 23; 24; 25; 26; 27

Figure A-11: Network-level stakeholder report (template)

Cluster level: Workshop cluster report

On **cluster level**, information is grouped into reports relating to individual workshop groups as they result from the clustering step (cf. section 7.5.4). The clustering reports provide a propositional agenda for the individual workshops via *PTRs* prioritized according to activity metrics.

Each report provides an overview of cluster members (tailoring stakeholders), PTRs subject to the cluster, activities impacted by the PTRs within the cluster, and dependencies to other clusters (via *ContextVariables*, *PTRs* and *Activities*).

PTRs are prioritized according to mean activity metrics and list the stakeholders affected by the respective rule. In case the RPM includes different hierarchical levels, the respective level affected by the PTR is indicated.

Activities are listed sequentially, indicating the primary responsible stakeholder as well as further stakeholders dependent on a particular activity (e.g. to be informed). For each activity, the corresponding metrics are given.

Table A-45: Information content of cluster level workshop cluster report

ID	Dependency	Attribute	Vis.
Q4.1	*PTR – – Activity*	*numberOfActivities* *meanCr; meanSBF; meanCB (PTR)*	T, M
Q4.2	*Stakeholder – – Role – – Activity*	*Cr, SBF; CB (Activity)*	T, M
Q4.3	*Stakeholder – – Role – – Activity – – PTR*	*numberOfPTRs (ONode)*	T, M
Q4.4	*Stakeholder– – Role – – Activity*	*responsibleActivities (ONode)*	T, M
Q4.5	*Stakeholder – – Role – – Activity – – Activity – – Role – – Stakeholder*	-	T, M
Q4.6	*Stakeholder – – Activity – – Stakeholder* *Stakeholder – – Activity – – PTR – – Activity – – Stakeholder* *Stakeholder – – Activity – – PTR – – Context Value – – Context Variable – – ContextValue – – PTR – – Activity – – Stakeholder*	-	T, B
Key: *T = Table; P = Portfolio; B = Bar Chart*			

Cluster 3

Description

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Participants

Person 1	Person 6
Person 2	Person 7
Person 3	Person 8
Person 4	Person 9
Person 5	Person 10

Dependencies within the cluster

Process Tailoring Rules

Number of Acivities	ØCriticality	ØSnowball factor	ØCentrality	PTR (Level)	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
5				ID2	X	X		X	X	X	X	X		X
2	3,1	4,2	3,3	ID2 (HMS)	X	X		X	X	X		X		X
3	2,6	3,1	3,0	ID2 (UMS)	X	X			X	X	X			
3				ID8	X		X	X	X	X	X	X	X	
2	1,2	3,2	2,6	ID8 (HMS)	X		X	X	X			X	X	
1	2,0	3,0	3,5	ID8 (UMS)						X	X			
1				ID17	X			X		X	X	X		X
1	3,0	2,0	1,7	ID17 (Task)	X			X		X	X	X		X

Activities

X: Responsible Person X: Dependent Person

Criticality	Snowball factor	Centrality	Level	Activity	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
2	1	2	HMS	ID1	X				**X**					
2	3	3	HMS	ID3		**X**		X		X				X
3	2	1	HMS	ID4	X		**X**	X						
2	3	4	UMS	ID6	**X**	X	X							
3	4	4	UMS	ID11		X			X	**X**			X	
4	2	4	UMS	ID13	X							**X**		
2	3	1	UMS	ID19		X		**X**				X	**X**	
1	2	1	UMS	ID20	**X**			X						
4	3	3	Task	ID22	X	X	**X**			X		X	X	
2	3	2	Task	ID23	X	X			**X**					
4	3	3	Task	ID25						X			**X**	
2	3	3	Task	ID30				**X**				X	X	
3	3	2	Task	ID31		X	X	X						**X**
2	5	4	Task	ID32	X	X	X		X		**X**			X
4	3	2	Task	ID35	X					**X**			X	
1	2	2	Task	ID40				X			**X**			
5	4	5	Task	ID42		**X**					X		X	X

Dependencies with other clusters (CL)

Process Tailoring Rules				
CL 1	CL 2	CL 4	CL 5	CL 6
1; 5; 7; 12	3; 4; 6; 11	4; 2	3; 14	2; 5; 9; 11; 12
Activities				
CL 1	CL 2	CL 4	CL 5	CL 6
1; 5; 7; 12; 13	3; 4	4; 2; 7; 8; 11	3; 14	2; 5; 9
Context Variables				
CL 1	CL 2	CL 4	CL 5	CL 6
1; 5; 7; 12	3; 4; 6; 11	4; 5; 8; 10	3; 14; 17	2; 5; 9; 11; 12

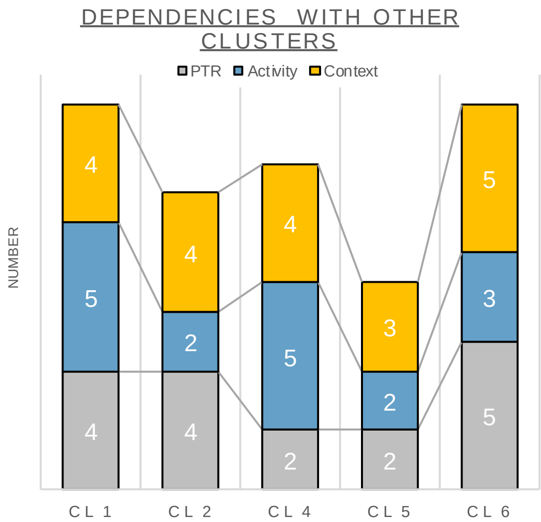

Figure A-12: Cluster report (template)

Node level: Context variable report

Besides the more global perspectives provided by network and cluster level reports, node level reports provide local perspectives. On the node level, reports regarding individual **Context Variables** are intended to support discussions in workshops by providing information on the properties of these variables (Q6.2). As no metrics are calculated for individual context variables, the report´s only contain information regarding variable dependencies.

The reports in particular provide information regarding *ContextValues* and related *PTRs*, as well as dependencies to other *ContextVariable* nodes via common PTRs.

Table A-46: Information content of node-level context variable report

ID	Dependency	Attribute	Vis.
Q6.2	*ContextVariable – – ContextValue – – PTR – – ContextValue – – ContextVariable*	-	T
	ContextVariable – – ContextValue – – ContextVariable		
	ContextVariable – – ContextValue		
	ContextVariable – – ContextValue – – PTR		

Key: *T = Table*

Context Variable

ID: 12

Context Variable

Description

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General Information

Context Variable (Name)	**Context Value (Name)**	**PTR (ID)**
Production location within project	Berlin	12; 16
	Stuttgart	11
	Munich	2
	Frankfurt	3; 7

Dependencies between Context Variables (via common PTR)

Context Variable (ID)	**Context Variable (Name)**	**PTR (ID)**
2	Project Volume	12
3	Strategic Relevance	16
4	Customer	11
8	Project Complexity	2
13	Cost	3
16	Components	7

Figure A-13: Node-level ContextVariable report (template)

Node level: Process tailoring rule report

In case of uncertainties regarding individual **tailoring rules**, additional information can be found within the respective reports, relating to the particular associated context factors (Q6.1), activities (Q6.3), and dependencies to other tailoring rules (Q6.5).

Each report lists the conditions for application of the PTR (ContextVariable and ContextValue). Furthermore, the affected activities are listed in table format with their respective activity metrics, as well as graphically using portfolios (Cr, SBF), and a histogram (C_B). Lastly, dependencies between the PTR depicted in a particular report and other PTRs via common *ContextVariables*, *Activites*, and *Stakeholders* are listed, in order to facilitate identification of strongly connected PTRs which potentially need to be discussed in combination.

Table A-47: Information content of node-level process tailoring rule report

ID	Dependency	Attribute	Vis.
Q6.1	*PTR – – ContextValue – – ContextVariable*	-	T
Q6.3	*PTR – – Activity*	*Cr; SBF; CB (Activity)*	T, P, H
Q6.5	*PTR – – ContextValue – – ContextVariable – – ContextValue – – PTR*	*numberOfElements (hasCRSw)*	T
	PTR – – Activity – – PTR	*numberOfElements (hasPRSw)*	
	PTR – – Activity – – Role – – Stakeholder – – Role – – Activity – – PTR	*numberOfElements (hasSHRw)*	
Key: *T = Table; P = Portfolio; H = Histogram*			

Process Tailoring Rule

ID: 42

PTR

Description

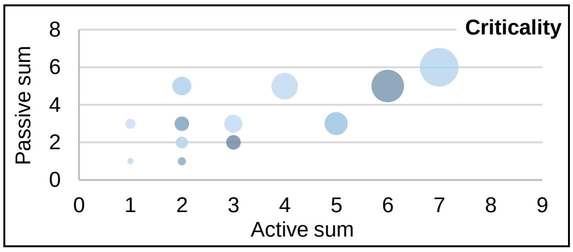
Lorem ipsum dolor sit amet, consectetur adipiscing elit. Sed lobortis, mauris sed fringilla luctus, diam dolor interdum tellus, at efficitur neque est sit amet leo. Sed eu urna at ex interdum congue quis id lectus.

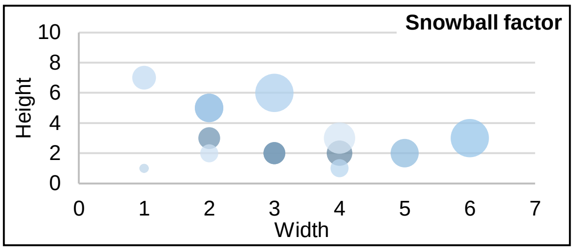
General Information

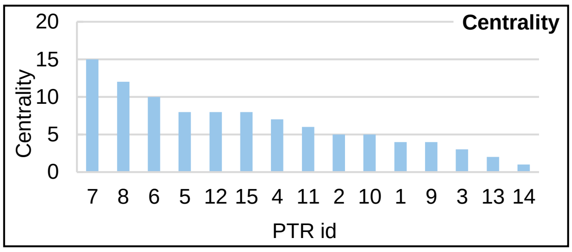
ID	Context Variable	Context Value
1	Project Volume	High
2	Strategic Relevance	Medium
3	Customer	Strategic customer
4	Project Complexity	High
5	Location of Production	Munich
6	Product Scope	Module

Process-based analysis

	Number of dependent Activities: 19			
Level	ID (Activity)	Criticality	Snowball factor	Centrality
HMS	1	2	3	4
HMS	2	2	4	1
HMS	3	5	4	3
HMS	4	2	2	3
HMS	5	2	1	1
UMS	6	1	2	2
UMS	7	4	3	4
UMS	8	2	3	4
UMS	9	4	3	2
UMS	10	2	5	4
UMS	11	5	3	4
UMS	12	2	1	1
UMS	13	3	5	3
Task	14	2	1	1
Task	15	1	5	2
Task	16	2	5	2
Task	17	2	2	2
Task	18	2	4	2
Task	19	5	2	3







Rule dependencies:

ID (PTR)	Common Context Variables	Common Activities	Common Stakeholder
1	2	2	4
2	1	2	3
5	3	0	0
11	0	2	2
23	2	5	5

Figure A-14: Node-level PTR report (template)

Node level: Activity report

In order to enable decision making within workshops regarding the impact of removing a particular activity or selecting an activity mode, the activity report contains information regarding the significance of individual **activities**.

Table A-48: Information content of node level activity report

ID	Dependency	Attribute	Vis.
Q6.4	*Activity – – Role – – Stakeholder*	*responsibleStakeholder (Activity)*	T, C
	Activity – – PTR	*connectedRules (Activity)*	
	Activity –precedes – Activity	*previousActivities; followingActivities; Cr; SBF; CB (Activity)*	
	Activity ←isVariantOf – Activity	*numberOfVariants (Activity)*	
Key: *T = Table; C = Colored Bar Chart*			

Activity

ID: 36

Description

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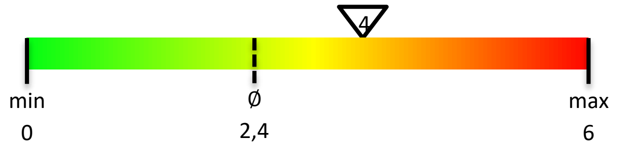
General Information

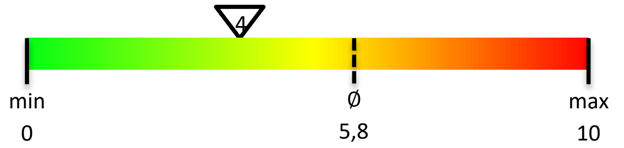
Responsible person:	Max Mustermann
Level:	Milestone
Preceding activities:	3; 4
Following activities:	11; 13
Connected PTRs:	3; 4
Number of Variants:	6

Metrics

Active Sum	Passive Sum
2	2
Criticality	
2	



Height	Width
1	3
Snowball factor	
4	



Centrality
9

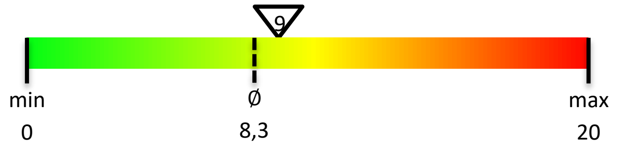


Figure A-15: Node-level activity report (template)

Node level: Tailoring stakeholder report

The tailoring stakeholder report on node level represents another local view and is generated for each modeled tailoring stakeholder (i.e. *OrganizationalUnit*, *Role*, *Individual*). Since tailoring is knowledge-intensive and dependent on individual project **stakeholders**, the final report describes the importance and dependencies within the tailoring activity regarding individual stakeholders.

General information contains the *name* and *id* of the respective stakeholder, the associated *clusterID*, and the number of *Activities*, the stakeholder is responsible for.

The stakeholder report summarizes the *PTRs* a particular stakeholder is responsible for and the corresponding dependent stakeholders, i.e. communication partners regarding a particular tailoring rule. *Activities* are similarly summarized, listing the respective metrics.

The report is concluded by the "requirement of communication", i.e. the values of the *Alignment* metric a respective stakeholder has with other stakeholders.

Table A-49: Information content of node-level stakeholder report

ID	Dependency	Attribute	Vis.
Q5.1	*Stakeholder – – Role – – Activity – – PTR*	*numberOfPTRs (ONode)*	T, M
Q5.2	*PTR – – Activity*	*meanCr; meanSBFr; meanCB* (PTR)	T, M
Q5.3	*Stakeholder – – Role – – Activity – – PTR – – Activity – – Role – – Stakeholder*	-	T, M
Q5.4	*Stakeholder – – Role – – Activity*	-	T, M
Q5.5	*Stakeholder – – Role – – Activity*	*Cr; SBF, CB (Activity)*	T, M
Q5.6	*Stakeholder – – Role – – Activity – – Role – – Stakeholder*	-	T, M
Q5.7	*Stakeholder – – Stakeholder* *Stakeholder – – Role – – Activity – – PTR – – Activity – – Role – – Stakeholder*	*Alignment (hasRSw); clusterID (Stakeholder)*	T
Key: *T = Table; M = Matrix*			

Stakeholder

ID: 22

Description

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General Information

Name:	Erika Musterfrau
Cluster-ID:	Cluster-ID 3
Number of dependent PTRs:	6
Number of responsible Activities	12

Dependent Process Tailoring Rules

Metrics				Dependent Stakeholders				
Number of Activities	**∅Criticality**	**∅Snowball factor**	**PTR (Level)**	**ID2**	**ID6**	**ID10**	**ID12**	**ID13**
4			**ID14**	X	X		X	
2	4	5	**ID14 (HMS)**	X	X		X	
2	3	5	**ID14 (UMS)**		X			
5			**ID27**		X	X	X	X
3	2	2	**ID27 (UMS)**			X	X	
2	1	3	**ID27 (Task)**		X			X

Responsible Activities

Metrics					Dependent Sakeholders							
Criticality	**Snowball factor**	**Centrality**	**Level**	**Activitiy**	**ID3**	**ID6**	**ID10**	**ID12**	**ID14**	**ID16**	**ID18**	**ID20**
3	2	2	**HMS**	**ID14**	X							
2	4	5	**HMS**	**ID15**		X		X				X
2	3	5	**UMS**	**ID26**		X						
3	2	5	**UMS**	**ID27**		X		X	X			
3	2	2	**UMS**	**ID29**			X					
2	1	3	**UMS**	**ID44**		X				X		
2	2	2	**Task**	**ID53**				X			X	
2	5	2	**Task**	**ID55**					X			X
2	2	2	**Task**	**ID57**							X	
3	1	3	**Task**	**ID59**		X					X	
2	1	4	**Task**	**ID71**						X		
1	6	2	**Task**	**ID73**			X					X

Requirement of communication

Stakeholder	Requirement of Communication
ID2	4
ID3	2
ID6	5
ID10	2
ID12	6
ID13	3
ID14	2
ID16	8
ID18	2
ID20	3

Figure A-16: Node-level stakeholder report (template)

A3.7 Phase 5: Tailoring workshop concept

A3.7.1 Requirements for tailoring workshops

Table A-50 lists the requirements which formed the basis for the development of the tailoring workshop concept. The requirements were derived based on literature and interviews.

Table A-50: Overview of tailoring workshop requirements (based on PE-Rast (2018, pp.59-62))

Category	Requirement
Participants	Relevant/Impacted departments and stakeholders
Preparation	Preparation on higher levels of project organization (e.g. subproject leaders or simultaneous engineering teams)
	Preparation on lower levels of project organization (e.g. designers carrying out PDP activities)
Moderation	Project-neutral moderator with in-depth PDP knowledge
	Cooperation between moderator and project lead
Point in time	Definition of mandatory and optional points of workshop execution within the PDP
Length	1.5 – 2 h per session
	Multiple sessions if necessary, depending on project complexity and size
Procedure	Team-/department-specific preparation of tailoring decisions
	Team-/department spanning workshops for decision making
Method usage	PDP RPM overview (print out)
	Visualization of activity dependencies (input-output-dependencies, information flow) to facilitate assessment of tailoring impacts
	Quantification of tailoring impacts via structural metrics
	Use of methods to enable workshop execution in a reactive, agile manner
	Templates for documentation of tailoring decisions
Documentation	Explicit documentation of tailoring decisions
	Mandatory justification of tailoring decisions via context factors

A3.7.2 Tailoring workshop checklist and heuristics

Table A-51 presents the checklist structuring the activities required for preparing and conducting individual tailoring workshop instances (based on PE-Rast 2018). For each checklist item, its characteristic as guiding question (Q) or heuristic (H) is indicated. Questions are open-ended and are reflective, while heuristics do affect the way tailoring workshops are carried out, e.g. which PTRs are relevant within a given workshop. Further, the applicability of tailoring reports (R) to support a checklist item is given.

Table A-51: Overview of checklist for preparing and executing tailoring workshops (based on PE-Rast 2018)

Group	Type	ID	Item	R
Situation and objective	Q	1	What is the goal of process tailoring in the current project and what is the contribution of process tailoring to the project goals	
	Q	2	What is the current tailoring point?	●
	Q	3	Which process section is subject to the tailoring workshop?	●
	Q	4	Which context factors are subject of the current tailoring workshop?	●
	H	5	How is the project organization structured (hierarchical levels) in the current project and which hierarchy level is selected for the workshop participants? *Consideration of project organization levels for participant selection*	
	Q	6	How can goal conflicts between stakeholders be minimized?	
Budget and time	Q	7	What budget is available for tailoring workshops?	
	Q	8	What time is allocated for tailoring workshops?	
	Q	9	What is the planned duration for tailoring workshops?	
	Q	10	How many workshops are required in regard to the projects' complexity and number of team members (single/multiple)?	●
Participants	Q	11	Who moderates the tailoring workshops?	
	Q	12	Who is the client/customer of the tailoring workshop? (e.g. the project leader, manager, or an external stakeholder)	
	Q	13	Who are the relevant workshop participants in relation to the project organization, the selected process section, and the selected context factors?	●
	Q	14	Who is required for decision making?	
	Q	15	Who has subject-matter knowledge?	
Venue	Q	16	Where are the workshops conducted?	
	Q	17	What equipment does the venue offer?	
	Q	18	Is a flexible set-up possible (e.g. for visualizations)?	
Workshop preparation	H	19	Is department-internal preparation of tailoring decisions necessary? *Department-internal pre-workshops in case tailoring rules have inter-departmental communication needs*	●
	Q	20	What is included in the workshop invitation?	
	Q	21	Which information is necessary for participants a priori?	●
	Q	22	What are preparatory tasks for the workshop?	●
	Q	23	Do all prospective participants have up to date analysis reports?	

Group	Type	ID	Item	R
Preparation of media and methods	Q	24	Which materials are used within the workshop?	
	Q	25	Which materials have to be prepared for the workshops (e.g. analysis reports, process overviews, input-output dependencies, documentation templates, pinboard for tracking of decisions and progress…)?	
Setting up the workshop	Q	26	Which materials are supplied in the workshop?	
	Q	27	Process overview available?	
	Q	28	Analysis reports generated and prepared?	●
	Q	29	Input-output dependencies visualized?	●
	Q	30	Documentation templates prepared?	
	Q	31	Pinboard for workshop tracking prepared?	
Introduction	Q	32	What is the current project situation?	
	Q	33	Which goals are to be achieved during the tailoring workshop?	
	Q	34	Which process section/subprocesses are subject to the workshop?	●
	Q	35	What is the procedure/agenda for the specific workshop?	●
Decision making	H	36	Does the tailoring decision have inter-departmental impacts and require inter-departmental communication and collaboration? *Decision discussed in inter-departmental workshop, otherwise decision making in department-specific workshops*	●
	Q	37	What is the tailoring decision?	●
	Q	38	What is the reason for the tailoring decision?	●
	Q	39	Is the activity removed or does an activity mode have to be selected?	●
	Q	40	Who is impacted by the tailoring decision?	●
	Q	41	Are there further impacts not documented in the analysis reports??	●
	Q	42	Do dependencies to other clusters need to be taken into account?	●
	Q	43	Have all participants had the chance to give their opinion?	●
	Q	44	Who needs to be further consulted or informed (e.g. due to absence)?	●
	Q	45	Can the tailoring decision be accepted (tailoring), is it rejected (no tailoring) in this project instance or is it postponed?	
Feedback	Q	46	What was beneficial for process tailoring?	
	Q	47	Where is potential for improvement?	
	Q	48	What are the main insights?	
	H	49	Have new context factors or tailoring operations been identified? *Expanding knowledge regarding context factors, triggering information acquisition and/or TSM adaptation*	

Key: *Q = Question; H = Heuristic; R = Analysis report*

A4 Supplementary material: Application and evaluation

A4.1 Case study overviews

Chronological overview

Figure A-17 lists a chronological overview of the conducted case studies (begin and end date).

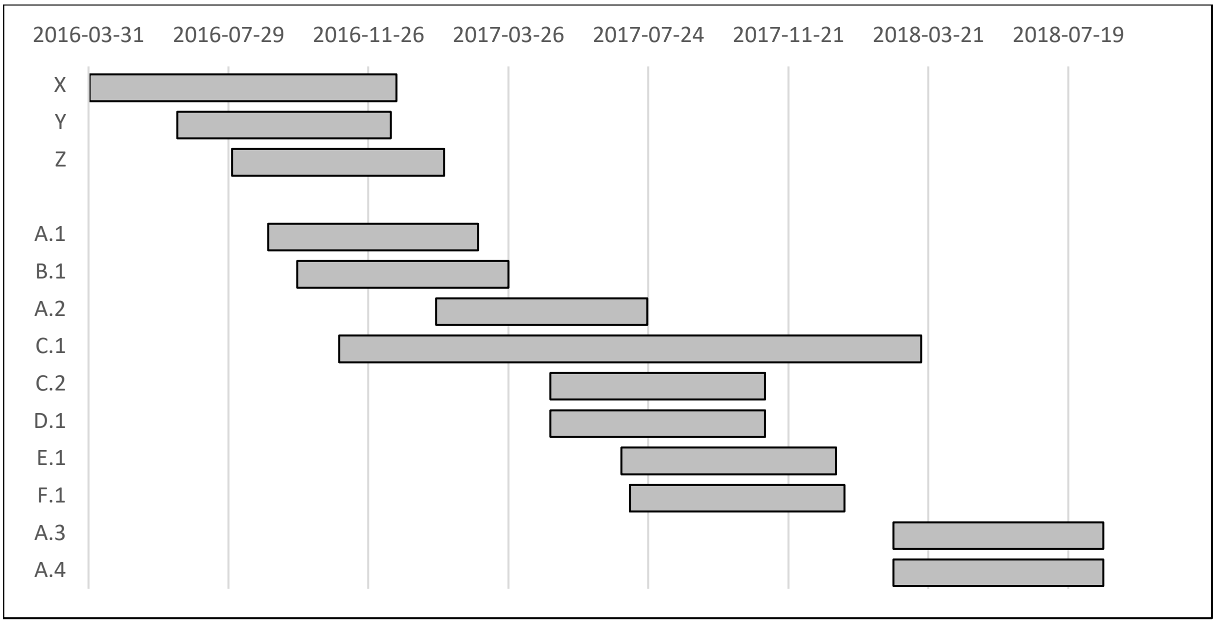


Figure A-17: Chronological overview of conducted case studies

Overview of case study characteristics and insights

Table A-52 gives an overview and short description of the application case studies (cf. also section 8.1, Table 8-1). In addition, the exploratory case studies X, Y, and Z are listed here. These have been conducted before the development of the initial tailoring support.

Table A-52: Characteristics of further case studies

ID	Reference	Description
X	PE-Höhn, 2016; Höhn et al., 2018	• Exploratory case study concerning a student design team (academic) • Interview- and questionnaire-based identification of generic context factors affecting the use of use phase data as input for PD • Description of process context possible
Y	PE-Spath, 2016	• Exploratory case study (academic) • Identification of project classes in an academic example (TUfast racing team) • Questionnaire-based identification of context factors • Design of RPM for two different project classes (new development and design adaptation) • Context description allows identification of two project classes (development of new vehicle architecture vs. adaptation of existing architecture)
Z	PE-Ralser, 2017	• Exploratory case study • Comparison of two different contexts for deployed processes (regular and strategic PD projects) • Identification of differences in context • Differences in context allow identification of context-appropriate measures for design of RPM (e.g. integration of methods)
A.1	PE-Frisch, 2017a; Hollauer et al., 2018a	• Department-specific instances of the company’s PDP (engine control units) • Comparison of process variants in different subdepartments and identification of context factors for rationale for variances • Focus on information acquisition, no operationalization of tailoring • Identification of context factors feasible • Context factors describe rationale for differences in process variants • Only limited definition of tailoring rules
A.2	PE-Frisch, 2017b	• Process for release of product configurations (interface between development and production; mature PDP subprocess) • Identification and matrix-based modeling of context factors and process impacts • Elaboration and application of initial modeling approach • Limited scope and size of process facilitated information acquisition • Process well-structured with clear objective, therefore clear definition of tailoring rules possible • Context factors can facilitate identification of context-specific process weaknesses • Small, well-structured process might benefit more from tailoring automation

ID	Reference	Description
A.3	PE-Schwertlein, 2018	• Analysis of sensor-integration process for highly automated driving • Preliminary RPM available but of low maturity • RPM not yet completely applied within a single project instance • Identification of context factors possible but highly dynamic • identification of concrete process impacts difficult due to low process maturity combined with high process dynamic • Context factors give indications for future process detailing and elaboration • Application of analysis framework not feasible due to low process maturity
A.4	PE-Gisdakis, 2018	• Definition of a lessons learned process in quality management • Tailoring support applied to aid in defining the base process by identifying potential variants and to tailor the integration of lessons learned into PD • Context-oriented approach: Only generic RPM available, initial identification of context factors and derivation of influences on RPM • Identification of 178 process elements on five hierarchical levels, 45 activity variants • Main stakeholders (roles) vary depending on the selection of activity modes due to particular context factors
B.1	Pavlitzek, 2017; Hollauer et al., 2017	• Application on PDP subprocess: Styling design process • Mature RPM available • Identification and description of context factors increase understanding for complex dependencies and rationale for decisions in project planning • Identification of context factors and impact, Formulation of tailoring rules • Manual process modularization based on context factors • Automation not desirable, instead combination of tailoring rules with expert judgment • Tailoring closely connected to budgeting and scheduling (activity modes differ in budget and time required) • Formalization of core metamodel elements and dependencies • Planning of subsequent system integration
C.1	PE-Sowa, 2017; PE-Langner, 2017; PE-Rast, 2018; PE-Rogger, 2018; Hollauer et al., 2018c; Hollauer et al., 2018d	• Cf. section 8.2 • Acquisition of context factors and process impacts on subprocess level (Development of production and logistics concepts within the overall PDP); successive filtering and refinement • Elaboration and application of overall procedure • Derivation of process adaptation need due to tailoring • Definition of process tailoring rules • Structural complexity as challenge for performing tailoring operations • Refinement and application of workshop concept
C.2	PE-Akiner, 2017; Hollauer et al., 2018c	• Cf. section 8.2 • Acquisition of context factors and impacts on project-level • Context factors with wide-spanning impacts over process • Acquisition of information through comparison of process variants and observation of tailoring workshops • Identification of workshops as possible means to address communication-intensiveness of tailoring • Initial application of metamodel and identification of need to model complex tailoring rules

ID	Reference	Description
D.1	PE-Philipp, 2017	• Customer application process (varying degrees of development work done per project) • Mature RPM available • Focus on elaboration of metamodel: Development of rule modeling for metamodel and evaluation on acquired data set • Implementation as relational database for verification and information acquisition • Statistical analysis of documented project-specific process instances and use for subsequent interviews • Formalization of rule concept; derivation of modeling constructs from conceptual framework
E.1	PE-Saad, 2018; Hollauer et al., 2018d	• Cf. section 8.3 • Development of tentative PDP RPM for a start-up company • Application of tailoring support in parallel to initial RPM definition • Initial identification of context factors: Difficult for dynamic contexts and low process maturity/understanding • Initial development and evaluation of workshop concept in start-up
F.1	PE-Wankmiller, 2018	• Development of new PDP RPM for design subdepartment (pre-development of production plants for automotive OEMs) • Adaptation of pre-existing PDP RPM • Accompanying application of tailoring support • TSM can shorten time for project planning • Use of matrix-based documentation due to unfamiliarity with tools • User-friendly tool for documentation of TSM required

Extended overview of tailoring methodology element evaluation

Figure A-18 provides an overview of the elements of the tailoring methodology applied within the case studies. ● indicates an element has been a focal point of the study, ◐ indicates an element has been applied. ○ indicates an element has not been evaluated in the respective study. Marks do not convey significance regarding positive or negative evaluation outcomes.

○ not applied
◑ applied
● focus

Phase	Group	Tailoring Methodology Element	Case Study A.1	A.2	A.3	A.4	B.1	C.1	C.2	D.1	E.1	F.1	Demonstrator	Test case	Expert1Interviews
		Procedure (overall, activity definition and sequence)	◑	◑	◑	◑	◑	●	●	◑	◑	●	◑	◑	◑
Phase 1	*Activities*	Define tailoring team	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
		Reflect initial situation	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
		Analyze RPM and define system boundaries	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
		Tailoring roles	○	○	○	○	○	○	○	○	○	○	◑	◑	◑
Phase 2	*Activities*	Scope information sources within system boundary	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
		Select acquisition methods and plan acquisition strategy	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
		Acquire information from explicit sources	◑	◑	◑	◑	◑	●	◑	●	◑	◑	○	○	○
		Acquire information from implicit sources	◑	◑	◑	◑	◑	●	◑	●	◑	◑	○	○	○
		Consolidate and validate information	◑	◑	◑	◑	◑	◑	◑	◑	◑	◑	○	○	○
	Acquisition methods	Adaptation of generic context factors	○	○	○	◑	○	◑	○	○	◑	○	○	○	○
		Document analysis	●	●	●	●	●	●	●	●	◑	●	○	○	○
		RPM variant comparison	●	○	○	○	○	●	●	○	○	◑	○	○	○
		Project data analysis	○	○	○	○	○	○	○	●	○	○	○	○	○
		Tailoring data analysis	○	○	○	○	○	●	◑	○	○	○	○	○	○
		Participative observation	○	○	○	○	◑	◑	◑	○	●	●	○	○	○
		Project planning procedure observation	○	○	○	○	●	○	○	○	○	◑	○	○	○
		Preliminary tailoring workshop observation	○	○	○	○	○	○	●	○	○	○	○	○	○
		Process-oriented interviews	◑	◑	◑	◑	◑	◑	◑	●	●	◑	○	○	○
		Context-oriented interviews	◑	◑	◑	◑	◑	◑	◑	●	●	◑	○	○	○
Phase 3	*Activities*	Modeling the context domain	◑	●	◑	◑	◑	●	●	●	◑	●	○	○	○
		Modeling the process domain	◑	●	◑	◑	◑	●	●	●	◑	●	○	○	○
		Modeling domain spanning rules	◑	●	◑	◑	◑	●	●	●	◑	●	○	○	○
		Resolving tentative dependencies	○	○	○	○	○	○	○	◑	○	○	○	○	○
		Resolving PCRs into PTRs	○	○	○	○	○	○	○	◑	○	○	○	○	○
		Adapting the reference process model	◑	◑	◑	◑	◑	●	◑	○	●	◑	○	○	○
		Meta Model	○	◑	●	●	◑	●	●	●	◑	◑	◑	◑	◑
Phase 4	*Activities*	Data import	○	○	○	○	○	○	○	○	○	○	●	●	◑
		Analysis: Rule conflicts	○	○	○	○	○	○	○	○	○	○	●	●	◑
		Analysis: Calculation of indirect dependencies	○	○	○	○	○	○	○	○	○	○	●	●	●
		Analysis: Metric calculation - Activity metrics	○	○	○	○	○	○	○	○	○	○	●	●	●
		Analysis: Metric calculation - Alignment	○	○	○	○	○	○	○	○	○	○	●	●	●
		Analysis: Stakeholder clustering	○	○	○	○	○	○	○	○	○	○	●	●	●
		Data export (final)	○	○	○	○	○	○	○	○	○	○	●	●	◑
		Data visualization: Create reports	○	○	○	○	○	○	○	○	○	○	●	●	●
		Analysis Framework	○	○	○	○	○	○	○	○	○	○	●	●	●
Phase 5	*Activities*	General preparation for operationalization	○	○	○	○	○	●	○	○	●	○	○	○	○
		Setup of project specific workshops	○	○	○	○	○	●	○	○	●	○	○	○	○
		Preparation of workshop instances	○	○	○	○	○	●	○	○	●	○	○	○	○
		Conduct individual tailoring workshops	○	○	○	○	○	●	○	○	●	○	○	○	○
		Post processing of indidividual workshops	○	○	○	○	○	●	○	○	●	○	○	○	○
		Collation & Harmonization of multiple WS instances	○	○	○	○	○	●	○	○	●	○	○	○	○
		Communication of results	○	○	○	○	○	●	○	○	●	○	○	○	○
		TSM review and update	○	○	○	○	○	●	○	○	●	○	○	○	○
		Workshop Concept	○	○	○	○	○	●	○	○	●	○	○	○	◑

○ not applied ◑ applied/evaluated ● Focus

Figure A-18: Extended overview of applied tailoring methodology elements per case study

A4.2 Tailoring workshop evaluation

Workshop evaluation: Question items

Table A- 53 lists the question items used to evaluate the tailoring workshops conducted in case studies C.1 and E.1 (for results see appendices A4.3 and A4.4). Questions Q1 to Q6 assess the workshop quality and thus serve as controlling questions (Part I), while Q7 to Q19 assess the workshop benefits as perceived by the participants (Part II). Questions Q1 to Q19 used 5-step Likert scales to describe agreement to each statement (1 “completely agree” to 5 “completely disagree”). Question 10 is adapted in respect to the case study (OEM vs. startup company). Questions Q20 to Q22 assess the appropriateness of the workshop format. Q20 assesses length (too short, adequate, too long), Q21 difficulty (advanced, adequate, poor), and Q22 media use (Visualization, room, handouts, overall impression) on a 5-step scale from “excellent” to “poor”, with the possibility to abstain from answering the question. Q23 concludes the questionnaire by offering the possibility to give qualitative feedback.

Table A- 53: Question items used for tailoring workshop evaluation

ID	Question (German original)	Question (Englisch translation)
Q1	Der Workshop-Moderator wirkte fachlich kompetent.	The workshop moderator made a competent impression.
Q2	Der Workshop-Moderator verstand es, den Inhalt gut und interessant zu vermitteln.	The workshop moderator understood to convey the content well and in an interesting way.
Q3	Der Workshop-Moderator ging ausreichend auf die Teilnehmer ein (z.B. Nachfragen).	The workshop moderator listened and responded to participants (e.g. regarding questions).
Q4	Dem Moderator ist es gelungen, durch Impulse oder spezielle Fragen Diskussionen zu initiieren.	The moderator succeeded to initiate discussions through giving impulses or specific questions.
Q5	Die Atmosphäre innerhalb des Workshops war sehr angenehm.	The workshop atmosphere was comfortable.
Q6	Die Inhalte des Workshops waren klar und verständlich gegliedert.	The workshop content was structured in a clear and understandable way.
Q7	Tailoring-Workshops können in Zukunft von großem Nutzen für das Unternehmen sein.	Tailoring workshops can be of great use for the company in the future.
Q8	Ein Tailoring-Workshop hilft, dabei einen agileren und flexibleren Entwicklungsprozess zu gestalten.	A tailoring workshop aids in designing a more agile and flexible development process.
Q9	Ein Tailoring-Workshop hilft bei der Gestaltung von Schnittstellen und Verantwortungsverteilungen innerhalb des Entwicklungsprozesses.	A tailoring workshop aids in designing interfaces and distributing responsibilities within the development process.
Q10	Prozess-Tailoring und ein Tailoring-Workshop sind für ein Großunternehmen/startup sinnvoll.	Process tailoring and tailoring workshops make sense for large companies/startups.
Q11	Ein Tailoring-Workshop hilft den Mitarbeitern, sich besser zu strukturieren.	A tailoring workshop supports employees to structure themselves and their work.

ID	Question (German original)	Question (Englisch translation)
Q12	Ein Tailoring-Workshop trägt zur gemeinsamen Vision eines Entwicklungsprozesses bei.	A tailoring workshop contributes to creating a common vision of the development process.
Q13	Ein Tailoring-Workshop verbessert die Zusammenarbeit innerhalb des Entwicklungsteams.	A tailoring workshop improves collaboration within the development team.
Q14	Ein Tailoring-Workshop hilft dabei, die Arbeit der Kollegen besser zu verstehen.	A tailoring workshop aids in understanding the work/tasks of coworkers.
Q15	Durch Prozess-Tailoring und den Workshop kann der Prozess und der Workflow effizienter gestaltet werden.	Through process tailoring and tailoring workshops, the process and workflow can be made more efficient
Q16	Durch Prozess-Tailoring und den Workshop können in Zukunft Dokumentationen von Retrospektiven effizient gestaltet und eingesetzt werden.	Through process tailoring and tailoring workshops, documentation of retrospectives can be made and applied efficiently.
Q17	Die Einbringung von methodischem Vorgehen und Denken führt zu einer schnelleren und effizienteren Zielerreichung.	The introduction of methodical procedure and thinking leads to faster and more efficient goal achievement.
Q18	Ich wäre daran interessiert in Zukunft an mehreren erweiterten Workshops zu diesem Thema teilzunehmen.	I would be interested to participate in multiple extended workshops in the future regarding this topic
Q19	Prozess-Tailoring kann effektiv die Arbeit des Projektleiters unterstützen.	Process tailoring can effectively support the work of the project leader.
Q20	Angesichts dieses Themas war dieser Workshop (zu kurz / angemessen / zu lang)	In light of the topic this workshop was: (too short / adequate/ too long)
Q21	Ihrer Meinung nach war dieser Workshop: (fortgeschritten/angemessen/schwach)	In your opinion, this workshop was: (advanced/adequate/poor)
Q22	Bitte bewerten Sie die folgenden Punkte: Visualisierung, Meetingraum, Handouts, Eindruck gesamt (exzellent, sehr gut, gut, angemessen, schwach, keine Angabe)	Please rate the following: Visualization, Meeting room, Handouts, Overall impression (excellent, very good, good, adequate, poor, no response)
Q23	Was war gelungen/nicht gelungen? Welche Dinge würden Sie ändern? Zusätzliche Anmerkungen.	What was particularly good/bad? Which aspects would you change? Additional remarks.

Comparison of workshop evaluation from C.1 and E.1

Figure A-19 combines the results for the tailoring workshop evaluations in case studies C.1 and E.1 to enable comparison.

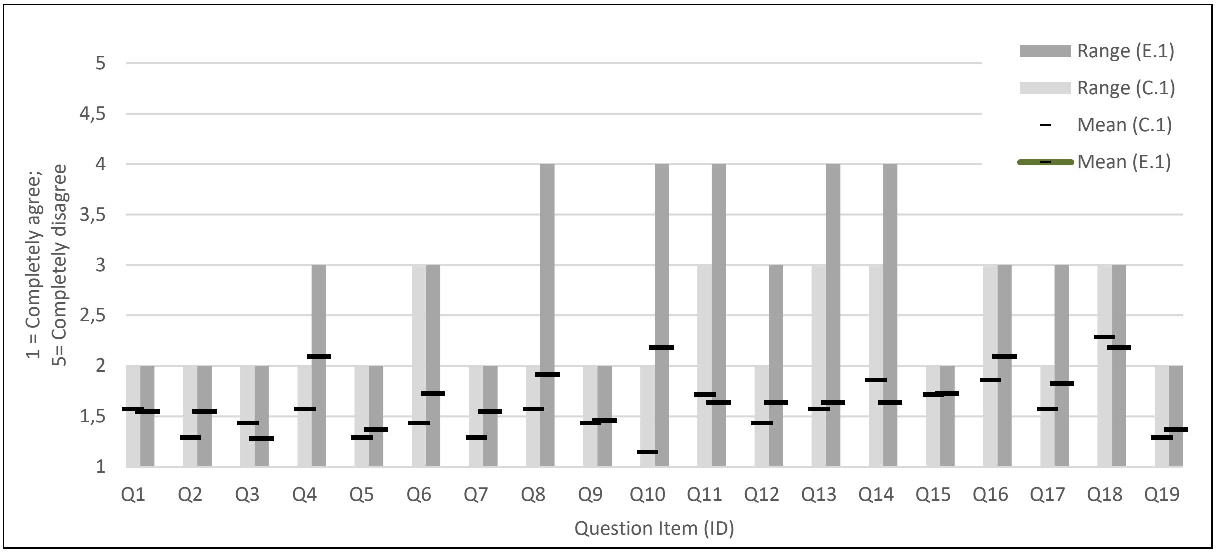


Figure A-19: Comparison of answer range and mean values from workshop evaluation in case studies C.1 and E.1

A4.3 Case study C supplementary data

A4.3.1 Context factors C.1

Table A-54 presents an overview of the context factor identified in UoA C.1 which were selected for the formulation of tailoring rules. The context factors are subsequently presented with their values in feature model notation.

Table A-54: Overview of final context factors for rule formulation (C.1, PE-Rogger, 2018)

ID	Context variable	Description	Values	TP
1.1.0	Project type and characteristics	Groups context factors directly related to project characteristics	(none)	PI
1.1.1	Cancellation	Project adresses supplier cancellation	yes/no	PI
1.1.2	Software	Project includes software development	yes/no	PI
1.1.3	Documentation change	Project only addresses change of documentation	yes/no	PI
1.1.4	Material change	Project only addresses change of material	yes/no	PI
1.1.5	Customer-specific request	Project includes already assembled customer-specific request	yes/no	PI
1.2.0	Production sites	Groups context factors related to production sites	(none)	PI
1.2.1	Number of production sites	Project includes one or multiple production sites	1/>1	PI
1.2.2	Production site abroad	Project includes production site abroad	yes/no	PI
1.2.3	Change of current production sites	Project includes new production sites	yes/no	PI
1.2.4	CKD relevant	Project affects CKD supply (completely knock-down)	yes/no	PI
1.3.0	Production concept	Groups context factors related to production concept	(none)	CD
1.3.1	Change of current production concept	Project requires change of current production concept	yes/no	CD
1.3.2	Floor layout	Project content requires change of current floor layout	yes/no	CD
1.3.3	Station layout/material flow	Project requires change of current station layout and material flow	yes/no	CD
1.3.4	Assembly & production process	Project requires change of current assembly & production process	yes/no	CD
1.3.5	Modularization concept	Project requires change of modularization concept	yes/no	CD
1.3.6	Testing concept	Project requires change of testing concept	yes/no	CD
1.4.0	Investments	Groups context factors related to investments	(none)	CD
1.4.1	New investments	Project requires investments for new facility, manufacturing, or testing equipment	yes/no	CD
1.4.2	New facility	Project requires new facility for pre-series or series assembly line	yes/no	CD
1.4.3	Location of new facilities	Location where new facilities are required	Pre-series/ series line	CD

ID	Context variable	Description	Values	TP
1.4.4	New manufacturing equipment	Project requires new manufacturing equipment for pre-series or series assembly line	yes/no	CD
1.4.5	Location of new manufacturing equipment	Location where new manufacturing equipment is required	Pre-series/ series line	CD
1.4.6	New testing equipment	Project requires new testing equipment for pre-series or series assembly line	yes/no	CD
1.4.7	Location of new testing equipment	Location where new testing equipment is required	Pre-series/ series line	CD
1.5.0	Virtual validation	Groups context factors related to virtual validation	(none)	CD
1.5.1	DMU	Project requires virtual validation using digital mock-ups	yes/no	CD
1.6.0	Physical validation	Groups context factors related to physical validation	(none)	CD
1.6.1	Build prototype in pre-series center	Project requires production validation by building a prototype	yes/no	CD
1.6.2	Build physical mockup	Project requires production validation by building a physical mock-up	yes/no	CD
1.6.3	Build pre-series release vehicle	Project requires production validation by building a pre-series vehicle	yes/no	CD
1.6.4	Location pre-series release vehicle	Location where the pre-series release vehicle is/are built	Pre-series/ series line	CD
1.6.5	Build production test run	Project requires production validation by building a production test run	yes/no	CD
1.6.6	Build 0-Series	Project requires production validation by building a 0-series	yes/no	CD
1.7.0	Training	Groups context factors related to worker training	(none)	CD
1.7.1	Worker training	Project requires training of pre-series/series assembly workers	yes/no	CD
1.7.2	Training location	Location where assembly worker training is required	Pre-series/ series line	CD

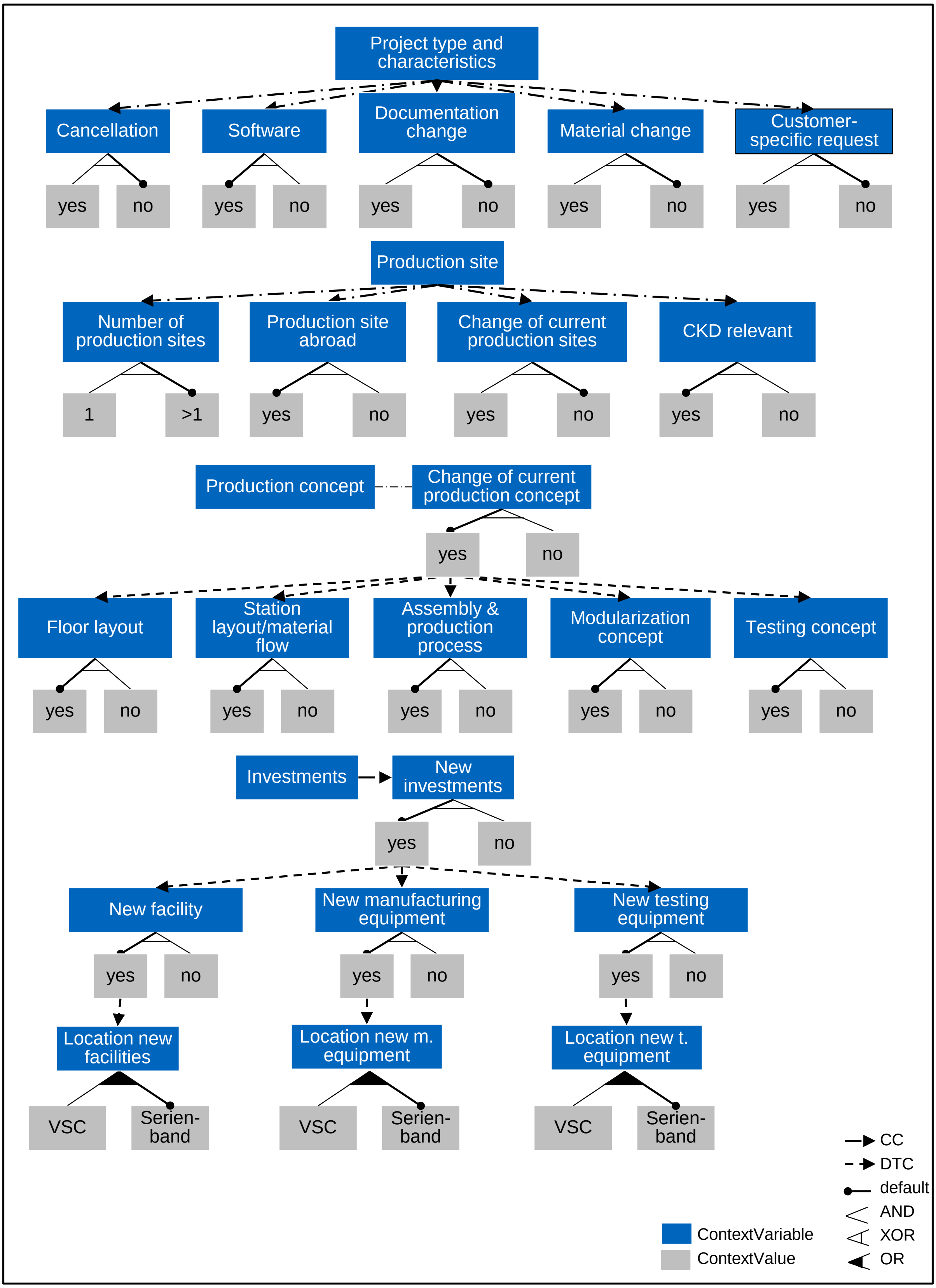


Figure A-20: C.1 - Context factors in feature model representation (part 1)

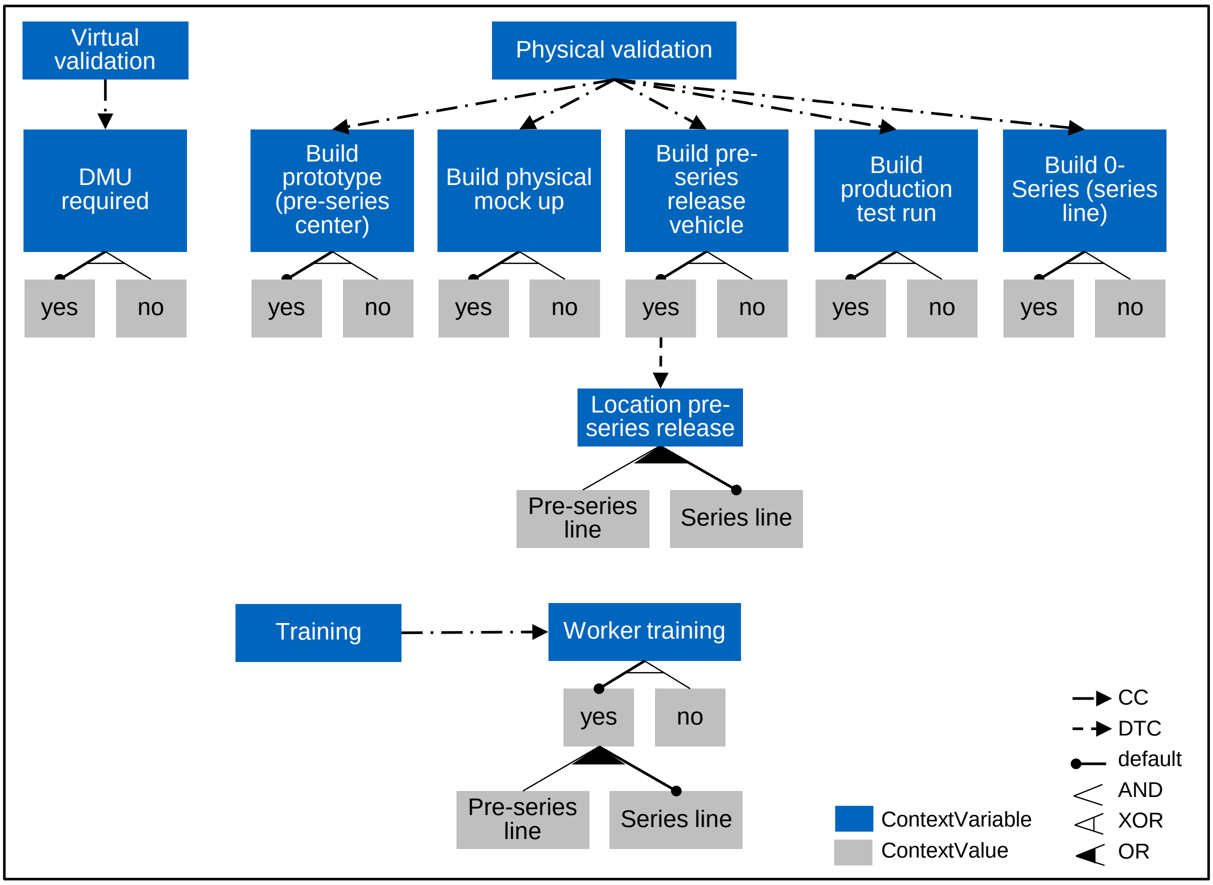


Figure A-21: C.1 - Context factors in feature model representation (part 2)

A4.3.2 Context factors C.2

Table A-55 lists context factors from C.2. Context factors in this case are not grouped. Context factor 1 introduces 41 new activities into the OEM PDP RPM, which are subsequently tailored for non-group (i.e. regular) projects. No further analysis on subprocess level was made. Context factor 3 was included in response to context factor 2. Context factors 8, 9, 10 were not further used in the formulation of tailoring rules.

Table A-55: Context factors from UoA C.2 including complex rule (PE-Akiner, 2017)

				Impact			
ID	**Variable**	**Description**	**Values**	**A**	**SP**	**P**	**D**
1	Group Project	Is the project carried out in collaboration with other subsidiaries of the corporate group?	yes/no	41			m
2	Variant development	Are variants to be developed in the project?	yes/no	31	20		m
3	Number of developed variants	How many variants are to be developed?	few/many				m
4	Project lead time	How long is the project lead time in comparison to the defined benchmarks?	Above/below benchmark	39	6		m
5	Lot size	How many products are expected to be produced?	high/low			2	m
6	Intended product maturity	To what maturity is the vehicle or product to be developed? (5 maturity levels)	Concept				m
			Prototype				
			Pre-series release			2	
			Production test run			1	
			0-Series				
7	Component classification	Which types of components are not included in the project? (7 classes, OR-relationship)	A	10	6		m
			B	11	7		
			C	6	4		
			D	6	4		
			E	4	3		
			F	1	1		
			G	1	1		
8	Amount of carryover parts	How many components are reused vs. developed from scratch?	(none)				m
9	Modularity	How modular is the product to be developed?	(none)				m
10	Industrialization	Do vehicles of lower maturity require homologation?	(none)				m
11	HMI concept	Is a human-machine interface developed?	yes/no	45	20		m
12	Pre-development project	Is a pre-development project available?	yes/no	7	4		m
13	Defense project	Is the project a military/defense project?	yes/no	9	8		me
14	Styling relevant	Does the project include styling aspects?	yes/no	59	31		m
15	Concept alternatives	Are concept alternatives required?	yes/no	r:11 fl:3	2		m
16	Virtual validation	Is virtual verification performed? (Digital Mock-Ups)	yes/no	4	4		m
17	Trade barriers	Are trade barriers to be expected, e.g. due to new production sites?	yes/no	1	1		s
18	Concept development	How is concept development performed?	inhouse/ external	2	1		s

				Impact			
ID	**Variable**	**Description**	**Values**	**A**	**SP**	**P**	**D**
19	New functions	Are new vehicle functions developed?	yes/no	2	1		s
20	3D cutouts	Are 3D cutouts required?	yes/no	5	4		s
21	(complex rule)	Short lead time, no variant development, small lot size				10	m
r = remove; fl = frontloading							
Number of impacts per level (A = Activity level, SP = Subprocess/Subgate level, P = Phase/Gate level)							
Impacted departments per PTR (s = single, m = multiple)							

A4.3.3 Tailoring workshop evaluation data C.1

Table A-56 to Table A-59 contain the aggregated responses of workshop participants from case study C.1 (PE-Rast 2018).

Table A-56: Data from parts I and IIa of the tailoring workshop evaluation (C.1)

ID	Question (Englisch translation)	1	2	3	4	5	mean	Most frequent	Sum
Q1	The workshop moderator made a competent impression.	3	4	0	0	0	1,57	2	7
Q2	The workshop moderator understood to convey the content well and in an interesting way.	5	2	0	0	0	1,29	2	7
Q3	The workshop moderator listened and responded to participants (e.g. regarding questions).	4	3	0	0	0	1,43	1	7
Q4	The moderator succeeded to initiate discussions through giving impulses or specific questions.	3	4	0	0	0	1,57	2, 3	7
Q5	The workshop atmosphere was comfortable.	5	2	0	0	0	1,29	1	7
Q6	The workshop content was structured in a clear and understandable way.	5	1	1	0	0	1,43	2	7
Q7	Tailoring workshops can be of great use for the company in the future.	5	2	0	0	0	1,29	2	7
Q8	A tailoring workshop aids in designing a more agile and flexible development process.	3	4	0	0	0	1,57	2	7
Q9	A tailoring workshop aids in designing interfaces and distributing responsibilities within the development process.	4	3	0	0	0	1,43	1	7
Q10	Process tailoring and tailoring workshops make sense for large companies.	6	1	0	0	0	1,14	1	7
Q11	A tailoring workshop supports employees to structure themselves and their work.	3	3	1	0	0	1,71	1,00	7
Q12	A tailoring workshop contributes to creating a common vision of the development process.	4	3	0	0	0	1,43	1, 2	7
Q13	A tailoring workshop improves collaboration within the development team.	4	2	1	0	0	1,57	1, 2	7

ID	Question (Englisch translation)	1	2	3	4	5	mean	Most frequent	Sum
Q14	A tailoring workshop aids in understanding the work/tasks of coworkers.	3	2	2	0	0	1,86	1, 2	7
Q15	Through process tailoring and tailoring workshops, the process and workflow can be made more efficient	2	5	0	0	0	1,71	2	7
Q16	Through process tailoring and tailoring workshops, documentation of retrospectives can be made and applied efficiently.	2	4	1	0	0	1,86	2, 3	7
Q17	The introduction of methodical procedure and thinking leads to faster and more efficient goal achievement.	3	4	0	0	0	1,57	2	7
Q18	I would be interested to participate in multiple extended workshops in the future regarding this topic	1	3	3	0	0	2,29	3,00	7
Q19	Process tailoring can effectively support the work of the project leader.	5	2	0	0	0	1,29	1	7

Table A-57: Q20 of tailoring workshop evaluation (C.1)

ID	Question item	too short	adequate	too long	Most frequent	Sum
Q 20	In light of the topic this workshop was:	2	5	0	adequate	7

Table A-58: Q21 of tailoring workshop evaluation (C.1)

ID	Question item	advanced	adequate	poor	Most frequent	Sum
Q21	In your opinion, this workshop was:	3	4	0	adequate	7

Table A-59:Q22 of tailoring workshop evaluation (C.1)

ID	Question Item		excellent	very good	good	adequate	poor	no response	Most frequent	Sum
Q22	Please rate the following:	Visualization poster wall	1	4	2	0	0	0	very good	7
		Visualization slides	1	4	2	0	0	0	very good	7
		Meeting room	2	5	0	0	0	0	very good	7
		Handouts (PDP printout)	2	5	0	0	0	0	very good	7
		Overall impression	1	3	2	0	0	1	very good	7

A4.4 Case study E.1 supplementary data

Context factors E.1

Table A-60 lists the context factors identified in case study E.1 (PE-Saad, 2018).

Table A-60: Context factors case study E.1

Category	Context Factor	Value
Team	Size	n/a
	Roles	n/a
	Skills	n/a
	Organization	Simple
Project	Medical certification required?	**n/a** (Yes/No)
	Project type	**New development** Customer application Adaptation Variant development
	Dependency on other projects	**Yes**/No
	Prototype manufacturable in-house	**Yes**/No
	Knowledge regarding applied fabrication technologies	Available
	In-house development of modules	n/a
	Validation by simulation	**Not possible**/possible
	Resources available?	**Yes**/No
Product	All functions of the prototype clearly defined?	Yes/**No**
	All functions of the design clearly defined?	Yes/**No**
	Requirements stable?	Yes/**No**

Key: *The selected value for the workshop is indicated in* **bold;** *n/a = unknown at time of tailoring workshop*

Tailoring workshop evaluation data E.1

Table A-61 to Table A-64 contain the aggregated responses of workshop participants from case study C.1 (PE-Saad, 2018).

Table A-61: Data from parts I and IIa of the tailoring workshop evaluation (E.1)

ID	Question (Englisch translation)	1	2	3	4	5	Mean	Most frequent	Sum
Q1	The workshop moderator made a competent impression.	5	6	0	0	0	1,55	4	11
Q2	The workshop moderator understood to convey the content well and in an interesting way.	5	6	0	0	0	1,55	4	11
Q3	The workshop moderator listened and responded to participants (e.g. regarding questions).	8	3	0	0	0	1,27	5	11
Q4	The moderator succeeded to initiate discussions through giving impulses or specific questions.	3	4	4	0	0	2,09	4, 3	11
Q5	The workshop atmosphere was comfortable.	7	4	0	0	0	1,36	5	11
Q6	The workshop content was structured in a clear and understandable way.	4	6	1	0	0	1,73	4	11
Q7	Tailoring workshops can be of great use for the company in the future.	5	6	0	0	0	1,55	4	11
Q8	A tailoring workshop aids in designing a more agile and flexible development process.	4	5	1	1	0	1,91	4	11
Q9	A tailoring workshop aids in designing interfaces and distributing responsibilities within the development process.	6	5	0	0	0	1,45	5	11
Q10	Process tailoring and tailoring workshops make sense for startup companies.	4	3	2	2	0	2,18	5	11
Q11	A tailoring workshop supports employees to structure themselves and their work.	6	4	0	1	0	1,64	5,00	11
Q12	A tailoring workshop contributes to creating a common vision of the development process.	5	5	1	0	0	1,64	5, 4	11
Q13	A tailoring workshop improves collaboration within the development team.	5	5	1	0	0	1,64	5, 4	11
Q14	A tailoring workshop aids in understanding the work/tasks of coworkers.	5	5	1	0	0	1,64	5, 4	11
Q15	Through process tailoring and tailoring workshops, the process and workflow can be made more efficient	3	8	0	0	0	1,73	4	11
Q16	Through process tailoring and tailoring workshops, documentation of retrospectives can be made and applied efficiently.	3	4	4	0	0	2,09	4, 3	11
Q17	The introduction of methodical procedure and thinking leads to faster and more efficient goal achievement.	4	5	2	0	0	1,82	4	11
Q18	I would be interested to participate in multiple extended workshops in the future regarding this topic	3	3	5	0	0	2,18	3,00	11
Q19	Process tailoring can effectively support the work of the project leader.	7	4	0	0	0	1,36	5	11

Table A-62: Q20 of tailoring workshop evaluation (E.1)

ID	Question item	too short	adequate	too long	Most frequent	Sum
Q20	In light of the topic this workshop was:	0	10	1	adequate	11

Table A-63: Q21 of tailoring workshop evaluation (E.1)

ID	Question item	advanced	adequate	poor	Most frequent	Sum
Q21	In your opinion, this workshop was:	1	10	0	adequate	11

Table A-64: Q22 of tailoring workshop evaluation (E.1)

ID	Question item		excellent	very good	good	adequate	poor	no response	Most frequent	Sum
Q22	Please rate the following:	Visualization	4	4	3	0	0	0	very good	11
		Meeting room	0	4	6	1	0	0	very good	11
		Handouts (PDP printout)	4	7	0	0	0	0	very good	11
		Overall impression	3	7	1	0	0	0	very good	11

A4.5 Application and evaluation of the analysis framework

Adapted metamodel for test case

Due to the particularities of the data used for the test case and the nature of the base metamodel, the adapted metamodel is illustrated in the following figures. As can be inferred from the figures, no organizational units were modeled, using direct dependencies between managers and team members (i.e. stakeholders) instead. The graph analysis rules were adapted accordingly, and the analysis otherwise executed as described in section 7.5.

	Context Variable	ContextValue	PTR	Activity	Role	Individual (Stakeholder)
Context Variable						
ContextValue	isValueOf					
PTR		hasCondition		hasImpact		
Activity				precedes isPartOf		
Role				Executes		
Individual (Stakeholder)					isResponsible For	manages

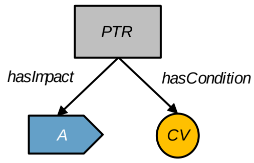
Modified element/dependency — Additional element/dependency

Figure A-22: Adapted metamodel for test case (MDM)

Test Case: Tailoring analysis reports

This section contains excerpts of the tailoring reports generated as part of the test case, structured according to network, cluster, and node level. Due to the number of elements contained in the respective TSM, not all reports are reproduced in full. Instead, pages are omitted if they contain additional information but do not contribute to understanding.

Process Tailoring Rules
Overview



Description:

General Information:

Number of Nodes:

127 - times PTR

Number of Edges:

137 - times hasImpact

Context-based Analysis:

Number of connected Nodes:

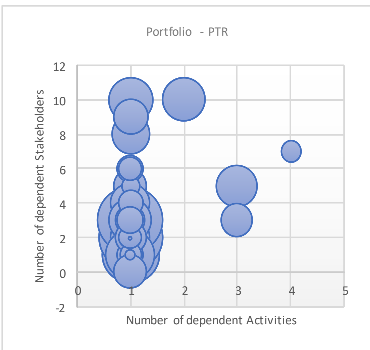
17 - times Context value

Number of connected Edges:

26 - times hasCondition

Process-based Analysis:

PTR	Number of Activities	Number of Stakeholders	Criticality :Cri	Snowball factor:SF	Centrality: Cen	Cri+SF+Cen
1	1	2	1	61	200	262
2	1	3	3	83	212	298
3	1	2	4	26	523	553
4	1	1	1	12	75	88
5	1	3	2	41	66	109
6	1	2	2	54	103	159
7	1	5	1	7	12	20
36	1	4	6	34	27	67
37	1	0	0	27	0	27
38	1	0	1	26	17	44
39	1	0	0	0	0	0
40	1	8	1	65	137	203
41	1	7	0	0	0	0
42	1	10	1	31	241	273
43	1	1	2	35	404	441
44	1	2	0	75	0	75
45	1	2	1	61	200	262
46	1	3	3	69	295	367
47	1	2	1	28	84	113
48	1	0	1	28	96	125
51	1	3	1	4	91	96



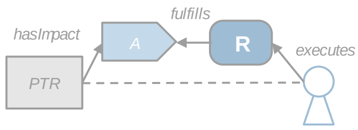
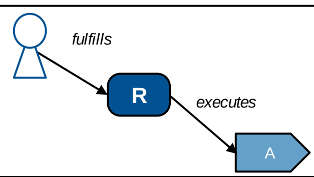


Figure A-23: Test case PTR report page 1 of 4 (Network level); pages 3 to 4 are omitted as they contain further rules described in the same manner)

Stakeholder



Description:

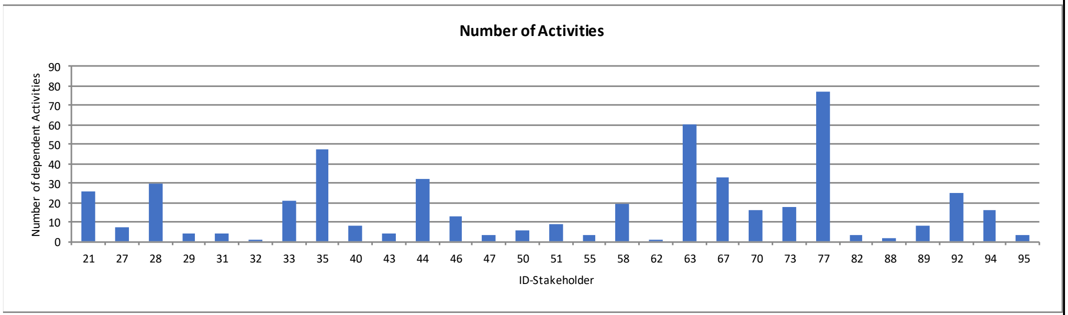
General Information:

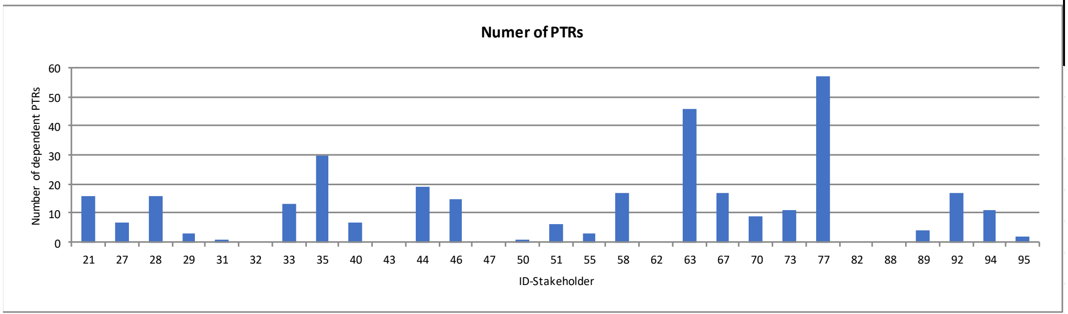
Number of Nodes:

99 - times *Individual*

Number of Edges:

499 - times *executes*





Clustering:

Cluster1:	ID51;

Cluster2:	ID21; ID27; ID28; ID29; ID31; ID40; ID44; ID50; ID55; ID58; ID67; ID73; ID77; ID89; ID94; ID95;

Cluster3:	ID33; ID35; ID46; ID63; ID70; ID92;

Figure A-24: Test case stakeholder report - page 1 (Network level)

ID	21	27	28	29	31	33	35	40	44	46	50	51	55	58	63	67	70	73	77	89	92	94	95
21			19	7		19	48		93	48		3		30	157	196	43	30	204	128	90	135	
27			7			41	41			7				65	101	65		65	86		20		
28	19	7					29		81	36	4	3		96	97	193		96	217	128	30	149	
29	7															68							
31														55					55				
33	19	41					30	2	19	19			3	16	240		183	8	200		43		
35	48	41	29			30		12	48	63			0		520	65	183	31	409	65	202	65	
40						2	12								50		23		23				
44	93		81			19	48			12				30	177	128	43	30	327	128	110	128	
46	48	7	36			19	63		12				0	56	143	82	43	16	166	65	43	65	
50			4																				
51	3		3													14			14			20	
55						3	0			0				8	8		0		8				
58	30	65	96		55	16			30	56			8		40	90		104	487	30	30	30	
63	157	101	97			240	520	50	177	143			8	40		48	130	39	470	97	345	97	4
67	196	65	193	68			65		128	82		14		90	48			96	315	128	30	128	
70	43					183	183	23	43	43			0		130				81		43		
73	30	65	96			8	31		30	16				104	39	96			127	30	62	30	
77	204	86	217		55	200	409	23	327	166		14	8	487	470	315	81	127		128	246	135	
89	128		128				65		128	65				30	97	128		30	128		13	56	
92	90	20	30			43	202		110	43				30	345	30	43	62	246	13		3	
94	135		149				65		128	65		20		30	97	128		30	135	56	3		
95															4								

Figure A-25: Test case stakeholder report - page 2; unclustered Alignment matrix (Network Level)

Cluster ID: 2

Description:

Participants:

21	Julia	27	Emma
28	Lulu	29	Klara
31	Bastian	40	Maxi
44	Maja	50	Steven
55	Doloris	58	Sandra
67	Kilian	73	Günther
77	Lucas	89	Frido
94	Leonie	95	Johanna

Dependencies within the Cluster:

Process Tailoring Rules:

Metrics					Dependent Stakeholders (ID)															
number of Activities	mean Criticality	mean Centrality	mean Snowball Factor	Rule (ID)	58	77	67	73	94	21	29	44	55	27	28	89	40	31	50	95
1	1	61	200	1	X	X														
1	3	83	212	2	X	X	X													
1	4	26	523	3		X		X												
1	1	12	75	4					X											
1	2	41	66	5			X			X	X									
1	2	54	103	6		X						X								
1	1	7	12	7	X	X							X							
1	6	34	27	36										X						
1	1	65	137	40		X	X		X	X		X			X	X				
1	0	0	0	41		X							X							
1	1	31	241	42	X	X	X	X	X	X		X			X	X				
1	2	35	404	43		X														
1	0	75	0	44													X			
1	1	61	200	45	X	X														
1	3	69	295	46	X	X												X		
1	1	28	84	47	X	X														
1	1	4	91	51	X	X														
1	1	12	75	52					X											
1	1	4	10	53					X	X					X					
1	2	41	66	54			X			X	X									
2	1	36	213	56		X	X		X	X		X			X	X				
2	1	36	213	57		X	X		X	X		X			X	X				
1	2	81	75	60		X														
1	1	6	8	61		X														
1	6	63	267	66		X														
1	0	0	0	67		X														
1	0	68	0	68		X														
1	2	35	404	69		X														

Figure A-26: Test case cluster report - page 1 of 7 (Cluster level) (page 2 is omitted as it only list further rules in the same manner)

Activities:

Metrics					Dependent Stakeholders (ID)															
Criticality	Centrality	Snowball Factor	Level	Activity (ID)	77	40	67	21	28	44	58	73	89	94	55	95	50	27	29	31
1	6	8		109	X															
4	78	125		107	X															
2	81	75		106	X															
4	84	30		105		X														
1	0	62		104		X														
21	19	432		101	X	X														
3	19	85		100	X															
3	19	31		99	X															
3	108	42		97	X															
3	102	115		96	X															
1	9	81		91			X													
3	13	146		90			X													
4	15	87		89	X		X	X	X	X	X	X	X	X						
4	15	87		88	X		X	X	X	X	X	X	X	X						
4	15	87		87			X													
3	35	186		86			X													
1	31	241		85	X		X	X	X	X	X	X	X	X						
1	33	277		84			X													
1	34	302		83			X													
8	57	335		82	X		X	X	X	X	X	X	X	X						
3	75	213		81			X													
0	0	0		79	X										X					
1	2	168		78	X			X		X										
3	35	10		77	X			X		X										
0	31	0		76												X				
0	0	0		73	X															
4	0	25		72													X			
1	65	137		71	X		X	X	X	X			X	X						
6	34	20		62														X		
1	6	6		34	X															
2	36	32		31	X	X														
4	45	23		30		X														
1	0	35		29		X														

Figure A-27: Test case cluster report - page 3 of 7 (Cluster level) (page 2 is omitted as it only list further rules in the same manner)

1	38	1		132	X			X																	
1	37	33		131										X											
4	42	385		130	X													X							
2	35	404		129	X																				
3	35	257		128	X																				
0	68	0		127	X																				
0	0	0		124	X																				
6	63	267		123	X																				

Dependencies with other Clusters:

Process Tailoring Rule

Cluster1:	Cluster3:
ID53;	ID7;
ID90;	ID36;
ID143;	ID40;
ID160;	ID41;
	ID42;
	ID44;
	ID51;
	ID56;
	ID57;
	ID60;
	ID61;
	ID70;
	ID71;
	ID72;
	ID74;
	ID75;
	ID83;
	ID86;
	ID92;
	ID94;
	ID95;
	ID97;
	ID98;
	ID99;
	ID101;
	ID102;
	ID105;
	ID107;
	ID117;
	ID130;
	ID131;
	ID132;

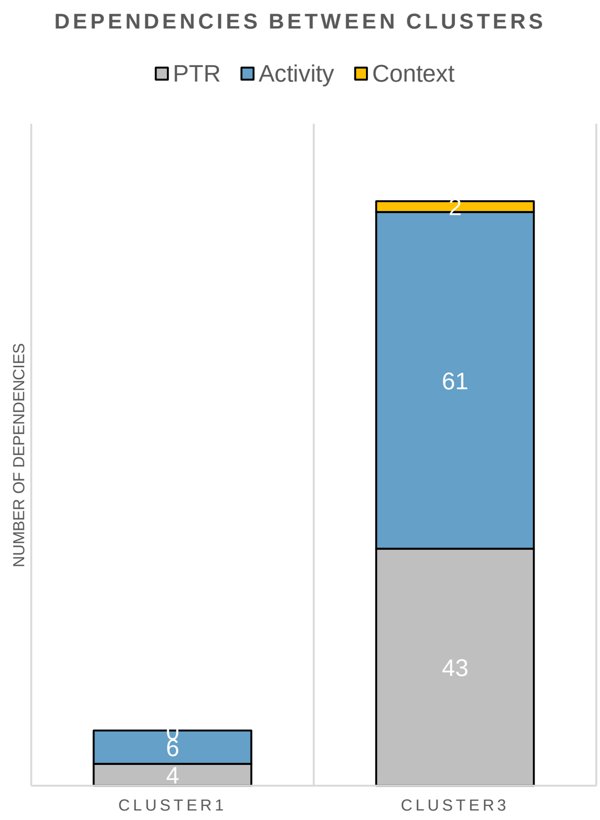


Figure A-28: Test case cluster report – page 5 of 7 (Cluster level) (pages 2 to 4 are omitted)

Activity

Cluster1:	Cluster3:
ID229;	ID109;
ID227;	ID107;
ID188;	ID106;
ID173;	ID105;
ID172;	ID104;
ID171;	ID101;
	ID100;
	ID99;
	ID97;
	ID96;
	ID89;
	ID88;
	ID85;
	ID82;
	ID79;
	ID78;
	ID77;
	ID76;
	ID73;
	ID72;
	ID71;
	ID62;
	ID34;
	ID31;
	ID30;
	ID29;
	ID23;
	ID22;
	ID21;
	ID19;
	ID18;
	ID17;

Context Variables

Cluster1:	Cluster3:
	ID2;
	ID25;

Figure A-29: Test case cluster report – page 6 of 7 (Cluster level) (pages 2 to 4 are omitted)

Process Tailoring Rule
ID: 72

Description:

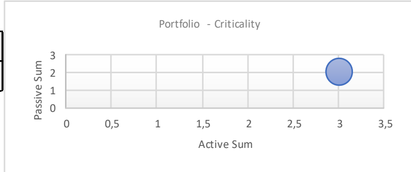
Context-based Analysis

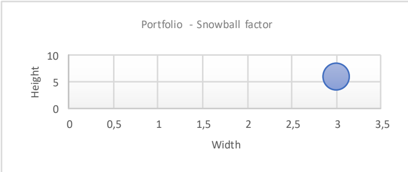
ID	Context Variable	Context Value
2	Projektklassifikation	gamma

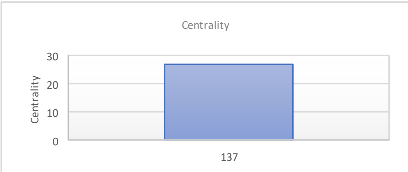
Process-based Analysis:

Number of dependent Activities: 1

ID	Criticality	Snowball factor	Centrality
137	6	34	27







PTR Dependencies:

ID	Common Context Variables	Common Activities	Common Stakeholders
71	1		1
63	1		
36	1	1	4
161			1
157			1
156			1
153			3
152			1
150			1
149			2

Figure A-30: Test case PTR report for PTR 72, page 1 of 2 (Node level)

Process Tailoring Rule
ID: 98

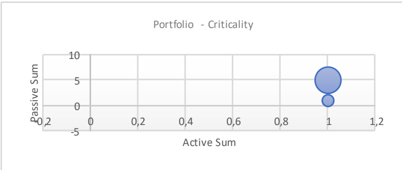
Description:

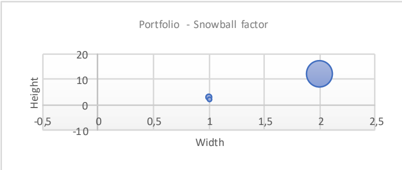
Context-based Analysis

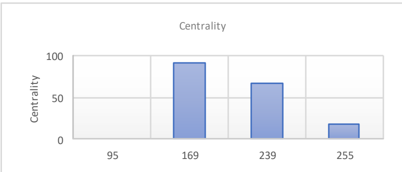
ID	Context Variable	Context Value

Process-based Analysis:

Number of dependent Activities:			4
ID	Criticality	Snowball factor	Centrality
95	0	0	0
169	1	4	91
239	5	2	66
255	1	45	18







PTR Dependencies:

ID	Common Context Variables	Common Activities	Common Stakeholders
159		1	3
142		1	3
126		1	2
119		1	6
51		1	3
156			1
155			1
153			2
150			2
148			1
145			1

Figure A-31: Test case PTR report for PTR 98, page 1 of 2 (Node level)

Activity

ID: 137

Description:

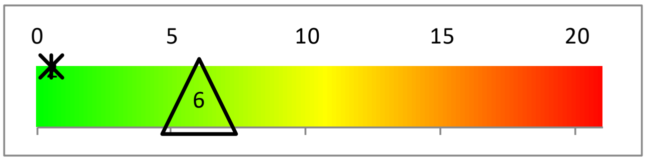
Pre-selection of functional material

General Information:

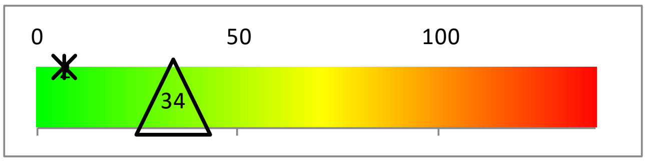
Responsible Person:	Emma
Number of Variants:	0
Previous Activities:	[70,108]
Following Activities:	[99,101,72]
Connected PTR:	[72,36]

Metrics:

Active Sum	Passive Sum
3	2
Criticality	
6	



Height	Width
6	3
Snowball factor	
34	



Centrality
27

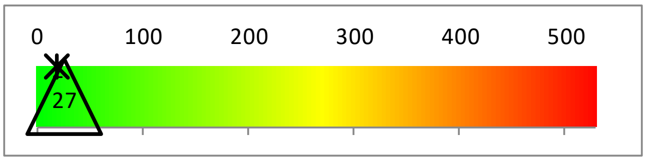


Figure A-32: Test case activity report for activity 137 (node level)

Context Variable
ID: 68

Description:

General Information:

Context Variable (Name)	Context Value (Name)	PTR (ID)
Projekttyp	Kopierprojekt	[161,37]
	Optionsprojekt	[161,37]
	Wartungsprojekt	[161]
	Überholungsprojekt	[161]
	Reparaturprojekt	[161]
	Modernisierungsprojekt	[161]
	Anpassungsprojekt	[161]
	Neuentwicklungsprojekt	[161,38]

Dependencies between Context Variables (Common PTR):

Context Variable (ID)	Context Variable (Name)	PTR (ID)

Figure A-33: Test case context report for context variable 68 (node level)

Stakeholder

ID: 21 Julia

Description:

General Information:

Person:	Julia
Cluster-ID:	2
Number of Responsible Activities:	26
Number of Connected Rules:	16

Dependent Process-Tailoring-Rules:

Metrics					Dependent Stakeholders (ID)															
number of Activities	mean Criticality	mean Centrality	mean Snowball Factor	Rule (ID)	29	67	28	44	63	77	89	94	58	73	92	51	35	46	33	70
1	2	66	41	5	X	X														
1	1	137	65	40		X	X	X	X	X	X	X								
1	1	241	31	42		X	X	X		X	X	X	X	X	X					
1	1	10	4	53			X					X				X				
1	2	66	41	54	X	X														
2	1	213	36	56		X	X	X	X	X	X	X					X	X		
2	1	213	36	57		X	X	X	X	X	X	X					X	X		
1	1	1	38	70					X	X					X					
1	1	26	7	88			X	X		X										
1	1	3	4	89			X	X		X										
1	1	4	7	94				X	X	X					X		X	X	X	X
1	2	5	7	108	X	X														
1	1	82	13	124																
1	1	80	38	127			X	X												
1	1	168	2	136				X	X	X					X		X	X	X	X
1	1	168	2	153				X	X	X					X		X	X	X	X

Responsible Activities:

Metrics					Dependent Stakeholders (ID)																
Criticality	Centrality	Snowball Factor	Level	Activity (ID)	28	44	58	67	73	77	89	92	94	33	35	46	63	70	29	43	51
4	87	15		89	X	X	X	X	X	X	X	X	X								
4	87	15		88	X	X	X	X	X	X	X	X	X								
1	241	31		85	X	X	X	X	X	X	X	X	X								
8	335	57		82	X	X	X	X	X	X	X	X	X								
1	168	2		78		X				X		X		X	X	X	X	X			
3	10	35		77		X				X		X		X	X	X	X	X			
1	137	65		71	X	X		X		X	X		X				X				

Figure A-34: Test case stakeholder report – page 1 (node level)

1	102	2		18		X				X		X		X	X	X	X	X									
1	4	7		17		X				X		X		X	X	X	X	X									
1	105	36		263	X	X																					
1	80	38		262	X	X																					
1	79	9		251						X									X	X							
1	82	13		250																							
3	143	40		241				X			X		X														
1	7	4		223	X	X				X																	
1	3	7		222	X	X				X																	
2	6	0		208				X												X							
2	5	7		206				X											X								
0	0	0		200		X				X		X			X		X										
1	6	0		191						X			X			X											
1	3	4		185	X	X				X																	
1	26	7		184	X	X				X																	
2	36	4		175	X			X											X								
2	66	41		174				X											X								
1	10	4		172	X								X								X						
1	1	38		132						X		X					X										

Requirement of Communication

Stakeholder (ID)	Requirement of Communication
28	19
29	7
33	19
35	48
44	93
46	48
51	3
58	30
63	157
67	196
70	43
73	30
77	204
89	128
92	90
94	135

Figure A-35: Test case stakeholder report – page 2 (node level)

A4.6 Evaluation of analysis framework: Questionnaire and results

Questionnaire

The question items and answer scales for the evaluation of the analysis framework are presented in Table A-65. Five-step Likert scales have been applied to rate agreement to particular statements (1 “completely agree”, 5 “completely disagree”), in combination with open questions and other scales (for descriptive questions). The question items are listed in the original German version and an English translation. Question items 1 – 4 represent descriptive questions to characterize the background of the interviewed experts (see section 8.4.2, Table 8-4), question items 5-10 (Section A) are intended to investigate the challenges associated with process tailoring and their severity as estimated by the interviewed experts, and question items 11 – 22 (Section B) aim at evaluating the estimated benefit of the analysis framework. (PE-Kölsch, 2018)

Table A-65: Question items of interview-based analysis framework evaluation

ID	German	English	Answer options
1	Welche Rolle(n) nehmen Sie in der Organisation Ihres Unternehmens ein?	What is your role within the organization of your company?	(open)
2	Wie viel Erfahrung haben Sie bereits mit dem Thema Prozessmanagement?	How much experience do you have in process management?	___ years
3	Wie viel Erfahrung haben Sie bereits mit dem Thema Projektmanagement?	How much experience do you have in project management?	___ years
4	Konnten Sie bereits Erfahrung zum Thema (Prozess-) Tailoring sammeln?	Have you been able to gather previous experience regarding (process-)tailoring?	yes/ no (___ years)
Section A) Assume, you are responsible for executing the tailoring activity in product development. How do you rate the following statements?			
5	Die Strukturierung des Vorgehens zur Durchführung des Tailoring-Prozesses stellt eine besondere Herausforderung dar.	Structuring the procedure for executing process tailoring poses a particular challenge.	Likert Scale
6	Die interne Abstimmung zwischen den involvierten Stakeholdern stellt eine besondere Herausforderung dar.	The internal coordination/communication between involved stakeholders poses a particular challenge	Likert Scale
7	Die Identifikation der einzelnen Abhängigkeiten der Stakeholder in Bezug auf den Tailoring-Prozess und des damit verbunden Kommunikationsbedarfs stellt eine besondere Herausforderung dar.	The identification of dependencies between stakeholders regarding the tailoring procedure and the associated communication needs poses a particular challenge	Likert Scale
8	Die Komplexität des Tailoring-Prozesses stellt eine besondere Herausforderung dar. Hierbei beinhaltet die Komplexität die Anzahl der betrachteten Elemente und deren Vernetzung.	The complexity of the tailoring procedure poses a particular challenge. Complexity includes the number of elements to be considered and their dependencies.	Likert Scale

ID	German	English	Answer options
9	Die Abschätzung der Auswirkung einer einzelnen Regelentscheidung auf den Prozess stellt eine besondere Herausforderung dar.	Estimating the effect of an individual tailoring rule/decision on the process poses a particular challenge	Likert Scale
10	Gibt es noch weitere Aspekte, die Sie bei der Umsetzung des Tailoring-Prozesses als herausfordernd erachten?	Are there further aspects which you consider challenging during the tailoring procedure?	(open)
Section B) In regard to the presented analysis concept: How do you rate the following statements?			
11	Die einzelnen Metriken (Criticality, Centrality und Snowball factor) können bereits in einer frühen Phase der Umsetzung des Tailoring-Prozesses Hinweise auf Unstimmigkeiten in der Prozessmodellierung.	The individual metrics (Criticality, Centrality, Snowball Factor) can indicate inconsistencies in process modeling during an early phase of tailoring implementation.	Likert Scale
12	Mit Hilfe der Analyse des internen Kommunikationsbedarfs bzgl. des Tailoring-Prozesses lassen sich geeignete Workshop-Gruppen ableiten	Using the analysis of internal communication needs regarding the tailoring procedure, adequate workshop groups can be derived.	Likert Scale
13	Die einzelnen Metriken (Criticality, Centrality und Snowball factor) helfen dabei, die Prozess-Tailoring-Regeln und Aktivitäten zu strukturieren und zu priorisieren.	The individual metrics (Criticality, Centrality, Snowball Factor) aid in structuring and prioritizing tailoring rules and process activities.	Likert Scale
14	Die einzelnen Reports unterstützen und dabei, den komplexen Tailoring-Prozess handhabbarer und übersichtlicher zu gestalten.	The individual reports aid in making the complex tailoring procedure more manageable and transparent.	Likert Scale
15	Die einzelnen Reports unterstützen und erleichtern die interne Kommunikation bzgl. des Tailoring-Prozesses.	The individual reports support and facilitate internal communication regarding the tailoring process.	Likert Scale
16	Die einzelnen Metriken (Criticality, Centrality und Snowball factor) innerhalb eines Clusters (Workshops) unterstützen bei der Ableitung einer möglichen Agenda	The individual metrics (Criticality, Centrality, Snowball Factor) within a cluster (workshop) support in deriving a possible agenda.	Likert Scale
17	Mit Hilfe der individuellen Reports können sich die Teilnehmer gezielt auf einen Tailoring-Workshop vorbereiten (wichtige Regeln, Aktivitäten & Schnittstellen).	Using the individual reports, tailoring workshop participants can prepare for a tailoring workshop in a targeted manner (important rules, activities, and interfaces).	Likert Scale
18	Die einzelnen Visualisierungen sind hilfreich und verständlich gestaltet.	The individual visualizations are designed in a helpful and understandable way.	Likert Scale
19	Bei welchen Visualisierungen sehen Sie noch Verbesserungsbedarf?	Regarding which visualizations do you see need for improvement?	(open)
20	Die für eine strukturierte Durchführung des Tailorings benötigten Informationen sind vorhanden.	The information required for a structured execution of tailoring is present [within in the reports]	Likert Scale
21	Welche Informationen fehlen Ihrer Meinung nach?	Which information is missing in your opinion?	(open)

ID	German	English	Answer options
22	Wo sehen Sie bei dem Analyse-Konzept noch generelles Verbesserungspotential?	Where do you see overall potential for improvement regarding the analysis concept?	(open)

Results

Table A-66 lists the responses from the individual questionnaires in response the descriptive question items (PE-Kölsch, 2018).

Table A-66: Responses for descriptive questions for analysis framework evaluation

	C1		C2			C3	C4	C5
ID	**E-1**	**E-2**	**E-3**	**E-4**	**E-5**	**E-6**	**E-7**	**E-8**
1	Working student	Quality engineer (responsible for PDP RPM)	Project manager	Head of Global Process Excellence	Project manager	Responsible for PDP RPM (Project Management Office)	Project manager	R&D, Implementation and development of processes
2	0.5	10	1.5	15	5	4	7	1
3	1.5	6	1.5	15	5	4+	12	15
4	0.5	3	No	No	No	2	2.5	No

Key: *I = Interview session (different company), E = Expert*

Table A-67 lists responses from the individual questionnaires in response the quantitative question items.

Table A-67: Responses for quantitative question items for analysis framework evaluation

	C1		C2			C3	C4	C5	
ID	**E-1**	**E-2**	**E-3**	**E-4**	**E-5**	**E-6**	**E-7**	**E-8**	**Mean**
5	2	2	1	2	3	4	1	2	**2,1**
6	1	2	1	1	3	2	2	2	**1,8**
7	3	2	2	2	3	1	1	1	**1,9**
8	1	1	2	3	3	1	1	1	**1,6**
9	1	1	1	3	3	2	1	2	**1,8**
11	3	3	2	2	3	1	-	2	**2,3**
12	2	2	1	2	3	2	1	2	**1,9**
13	1	2	1	2	3	2	1	2	**1,8**
14	1	3	3	3	3	4	1	3	**2,6**
15	2	2	1	3	3	4	2	2	**2,4**
16	1	3	2	3	3	1	2	3	**2,3**
17	1	3	3	4	3	3	1	2	**2,5**
18	1	3	2	5	4	2	2	3	**2,8**
20	3	4	3	3	3	1	1	2	**2,5**

Key: *I = Interview session (different company), E = Expert*

Table A-68 lists responses from the individual questionnaires in response the qualitative question items in the original German version.

Table A-68: Responses to qualitative question items

ID	**I**	**E**	**Statement**
10	I-1	E-1	-
		E-2	Erfassen der Prozesszusammenhänge, sodass ein logischer Verbund nach dem Tailoring vorhanden bleibt.
	I-2	E-3	Tiefe der vorliegenden Grunddaten vorhanden.
		E-4	-
		E-5	Aufwand - Nutzen muss in Relation stehen.
	I-3	E-6	Umsetzung; Hierarchie; Detaillierungsgrad; Templates
	I-4	E-7	-
	I-5	E-8	Keine, hier fehlt die Erfahrung.

ID	I	E	Statement
19	I-1	E-1	-
		E-2	3D-Darstellung von Graph-Kanten-Relationship Struktur. Visualisierungen sind nicht ohne Training nutzbar.
	I-2	E-3	-
		E-4	Visualisierungen müssen einfach erfassbar sein und verständlich. Fokus auf das Wesentliche.
		E-5	Bei allen vorgestellten Visualisierungen.
	I-3	E-6	Legende
	I-4	E-7	Die Visualisierungen sind gut, aber teilweise nicht einfach zu interpretieren. Ein Schulungs-aufwand zum Themenkomplex ist zwingend zu erarbeiten-konzeptionell zu ergänzen.
	I-5	E-8	Die Visualisierungen erfordern ein deutliches Maß an Vorkenntnis. Das beeinflusst die Zusammenstellung des Teams stark.
21	I-1	E-1	-
		E-2	Bei der Durchführung des Tailorings wird angenommen, dass der Prozess besteht. Analyse und Definition der Contextfactors und des Prozesses stellen eine besondere Herausforderung dar.
	I-2	E-3	-
		E-4	-
		E-5	Legende-Glossar zu den jeweiligen Abkürzungen nicht vorhanden. Für außenstehende Personen nicht verständlich.
	I-3	E-6	-
	I-4	E-7	-
	I-5	E-8	Keine Aussage aufgrund fehlender Erfahrung.
22	I-1	E-1	-
		E-2	Viel zu komplex. Die Frage ist, ob es in der Realität angewendet werden kann (Ressourcen, Kapazitäten,…)
	I-2	E-3	-
		E-4	Skalierbarkeit […] -> Ist recht klar, dass es Vorteile für große Projekte gibt, aber was ist mit mittleren + kleineren?
		E-5	Visuelle Aufbereitung, mit ausschließlich selbsterklärenden Grafiken.
	I-3	E-6	-
	I-4	E-7	Wenn zu viele Reports vorhanden, dann ggf. zusammenfassende Reports.
	I-5	E-8	Keine Aussage aufgrund fehlender Erfahrung.

Key: *I = Interview session (different company), E = Expert*

List of dissertations

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D1 COLLIN, H.:
Entwicklung eines Einwalzenkalanders nach einer systematischen Konstruktionsmethode. München: TU, Diss. 1969.

D2 OTT, J.:
Untersuchungen und Vorrichtungen zum Offen-End-Spinnen.
München: TU, Diss. 1971.

D3 STEINWACHS, H.:
Informationsgewinnung an bandförmigen Produkten für die Konstruktion der Produktmaschine.
München: TU, Diss. 1971.

D4 SCHMETTOW, D.:
Entwicklung eines Rehabilitationsgerätes für Schwerstkörperbehinderte.
München: TU, Diss. 1972.

D5 LUBITZSCH, W.:
Die Entwicklung eines Maschinensystems zur Verarbeitung von chemischen Endlosfasern.
München: TU, Diss. 1974.

D6 SCHEITENBERGER, H.:
Entwurf und Optimierung eines Getriebesystems für einen Rotationsquerschneider mit allgemeingültigen Methoden.
München: TU, Diss. 1974.

D7 BAUMGARTH, R.:
Die Vereinfachung von Geräten zur Konstanthaltung physikalischer Größen.
München: TU, Diss. 1976.

D8 MAUDERER, E.:
Beitrag zum konstruktionsmethodischen Vorgehen durchgeführt am Beispiel eines Hochleistungsschalter-Antriebs.
München: TU, Diss. 1976.

D9 SCHÄFER, J.:
Die Anwendung des methodischen Konstruierens auf verfahrenstechnische Aufgabenstellungen.
München: TU, Diss. 1977.

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Extruder mit Feststoffpumpe – Ein Beitrag zum Methodischen Konstruieren.
München: TU, Diss. 1978.

D11 HEISIG, R.:
Längencodierer mit Hilfsbewegung.
München: TU, Diss. 1979.

D12 KIEWERT, A.:
Systematische Erarbeitung von Hilfsmitteln zum kostenarmen Konstruieren.
München: TU, Diss. 1979.

D13 LINDEMANN, U.:
Systemtechnische Betrachtung des Konstruktionsprozesses unter besonderer Berücksichtigung der Herstellkostenbeeinflussung beim Festlegen der Gestalt.
Düsseldorf: VDI-Verlag 1980. (Fortschritt-Berichte der VDI-Zeitschriften Reihe 1, Nr. 60).
Zugl. München: TU, Diss. 1980.

D14 NJOYA, G.:
Untersuchungen zur Kinematik im Wälzlager bei synchron umlaufenden Innen- und Außenringen.
Hannover: Universität, Diss. 1980.

D15 HENKEL, G.:
Theoretische und experimentelle Untersuchungen ebener konzentrisch gewellter Kreisringmembranen.
Hannover: Universität, Diss. 1980.

D16 BALKEN, J.:
Systematische Entwicklung von Gleichlaufgelenken.
München: TU, Diss. 1981.

D17 PETRA, H.:
Systematik, Erweiterung und Einschränkung von Lastausgleichslösungen für Standgetriebe mit zwei Leistungswegen – Ein Beitrag zum methodischen Konstruieren.
München: TU, Diss. 1981.

D18 BAUMANN, G.:
Ein Kosteninformationssystem für die Gestaltungsphase im Betriebsmittelbau.
München: TU, Diss. 1982.

D19 FISCHER, D.:
Kostenanalyse von Stirnzahnrädern. Erarbeitung und Vergleich von Hilfsmitteln zur Kostenfrüherkennung.
München: TU, Diss. 1983.

D20 AUGUSTIN, W.:
Sicherheitstechnik und Konstruktionsmethodiken – Sicherheitsgerechtes Konstruieren.
Dortmund: Bundesanstalt für Arbeitsschutz 1985. Zugl. München: TU, Diss. 1984.

D21 RUTZ, A.:
Konstruieren als gedanklicher Prozess.
München: TU, Diss. 1985.

D22 SAUERMANN, H. J.:
Eine Produktkostenplanung für Unternehmen des Maschinenbaues.
München: TU, Diss. 1986.

D23 HAFNER, J.:
Entscheidungshilfen für das kostengünstige Konstruieren von Schweiß- und Gussgehäusen.
München: TU, Diss. 1987.

D24 JOHN, T.:
Systematische Entwicklung von homokinetischen Wellenkupplungen.
München: TU, Diss. 1987.

D25 FIGEL, K.:
Optimieren beim Konstruieren.
München: Hanser 1988. Zugl. München: TU, Diss. 1988 u. d. T.: Figel, K.: Integration automatisierter Optimierungsverfahren in den rechnerunterstützten Konstruktionsprozess.

Reihe Konstruktionstechnik München

D26 TROPSCHUH, P. F.:
Rechnerunterstützung für das Projektieren mit Hilfe eines wissensbasierten Systems.
München: Hanser 1989. (Konstruktionstechnik München, Band 1). Zugl. München: TU, Diss. 1988 u. d. T.: Tropschuh, P. F.: Rechnerunterstützung für das Projektieren am Beispiel Schiffsgetriebe.

D27 PICKEL, H.:
Kostenmodelle als Hilfsmittel zum Kostengünstigen Konstruieren.
München: Hanser 1989. (Konstruktionstechnik München, Band 2). Zugl. München: TU, Diss. 1988.

D28 KITTSTEINER, H.-J.:
Die Auswahl und Gestaltung von kostengünstigen Welle-Nabe-Verbindungen.
München: Hanser 1990. (Konstruktionstechnik München, Band 3). Zugl. München: TU, Diss. 1989.

D29 HILLEBRAND, A.:
Ein Kosteninformationssystem für die Neukonstruktion mit der Möglichkeit zum Anschluss an ein CAD-System.
München: Hanser 1991. (Konstruktionstechnik München, Band 4). Zugl. München: TU, Diss. 1990.

D30 DYLLA, N.:
Denk- und Handlungsabläufe beim Konstruieren.
München: Hanser 1991. (Konstruktionstechnik München, Band 5). Zugl. München: TU, Diss. 1990.

D31 MÜLLER, R.
Datenbankgestützte Teileverwaltung und Wiederholteilsuche.
München: Hanser 1991. (Konstruktionstechnik München, Band 6). Zugl. München: TU, Diss. 1990.

D32 NEESE, J.:
Methodik einer wissensbasierten Schadenanalyse am Beispiel Wälzlagerungen.
München: Hanser 1991. (Konstruktionstechnik München, Band 7). Zugl. München: TU, Diss. 1991.

D33 SCHAAL, S.:
Integrierte Wissensverarbeitung mit CAD – Am Beispiel der konstruktionsbegleitenden Kalkulation.
München: Hanser 1992. (Konstruktionstechnik München, Band 8). Zugl. München: TU, Diss. 1991.

D34 BRAUNSPERGER, M.:
Qualitätssicherung im Entwicklungsablauf – Konzept einer präventiven Qualitätssicherung für die Automobilindustrie.
München: Hanser 1993. (Konstruktionstechnik München, Band 9). Zugl. München: TU, Diss. 1992.

D35 FEICHTER, E.:
Systematischer Entwicklungsprozess am Beispiel von elastischen Radialversatzkupplungen.
München: Hanser 1994. (Konstruktionstechnik München, Band 10). Zugl. München: TU, Diss. 1992.

D36 WEINBRENNER, V.:
Produktlogik als Hilfsmittel zum Automatisieren von Varianten- und Anpassungskonstruktionen.
München: Hanser 1994. (Konstruktionstechnik München, Band 11). Zugl. München: TU, Diss. 1993.

D37 WACH, J. J.:
Problemspezifische Hilfsmittel für die Integrierte Produktentwicklung.
München: Hanser 1994. (Konstruktionstechnik München, Band 12). Zugl. München: TU, Diss. 1993.

D38 LENK, E.:
Zur Problematik der technischen Bewertung.
München: Hanser 1994. (Konstruktionstechnik München, Band 13). Zugl. München: TU, Diss. 1993.

D39 STUFFER, R.:
Planung und Steuerung der Integrierten Produktentwicklung.
München: Hanser 1994. (Konstruktionstechnik München, Band 14). Zugl. München: TU, Diss. 1993.

D40 SCHIEBELER, R.:
Kostengünstig Konstruieren mit einer rechnergestützten Konstruktionsberatung.
München: Hanser 1994. (Konstruktionstechnik München, Band 15). Zugl. München: TU, Diss. 1993.

D41 BRUCKNER, J.:
Kostengünstige Wärmebehandlung durch Entscheidungsunterstützung in Konstruktion und Härterei.
München: Hanser 1994. (Konstruktionstechnik München, Band 16). Zugl. München: TU, Diss. 1993.

D42 WELLNIAK, R.:
Das Produktmodell im rechnerintegrierten Konstruktionsarbeitsplatz.
München: Hanser 1994. (Konstruktionstechnik München, Band 17). Zugl. München: TU, Diss. 1994.

D43 SCHLÜTER, A.:
Gestaltung von Schnappverbindungen für montagegerechte Produkte.
München: Hanser 1994. (Konstruktionstechnik München, Band 18). Zugl. München: TU, Diss. 1994.

D44 WOLFRAM, M.:
Feature-basiertes Konstruieren und Kalkulieren.
München: Hanser 1994. (Konstruktionstechnik München, Band 19). Zugl. München: TU, Diss. 1994.

D45 STOLZ, P.:
Aufbau technischer Informationssysteme in Konstruktion und Entwicklung am Beispiel eines elektronischen Zeichnungsarchives.
München: Hanser 1994. (Konstruktionstechnik München, Band 20). Zugl. München: TU, Diss. 1994.

D46 STOLL, G.:
Montagegerechte Produkte mit feature-basiertem CAD.
München: Hanser 1994. (Konstruktionstechnik München, Band 21). Zugl. München: TU, Diss. 1994.

D47 STEINER, J. M.:
Rechnergestütztes Kostensenken im praktischen Einsatz.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 22). Zugl. München: TU, Diss. 1995.

D48 HUBER, T.:
Senken von Montagezeiten und -kosten im Getriebebau.
München: Hanser 1995. (Konstruktionstechnik München, Band 23). Zugl. München: TU, Diss. 1995.

D49 DANNER, S.:
Ganzheitliches Anforderungsmanagement für marktorientierte Entwicklungsprozesse.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 24). Zugl. München: TU, Diss. 1996.

D50 MERAT, P.:
Rechnergestützte Auftragsabwicklung an einem Praxisbeispiel.
Aachen: Shaker 1996. (Konstruktionstechnik München, Band 25). Zugl. München: TU, Diss. 1996 u. d. T.: MERAT, P.: Rechnergestütztes Produktleitsystem

D51 AMBROSY, S.:
Methoden und Werkzeuge für die integrierte Produktentwicklung.
Aachen: Shaker 1997. (Konstruktionstechnik München, Band 26). Zugl. München: TU, Diss. 1996.

D52 GIAPOULIS, A.:
Modelle für effektive Konstruktionsprozesse.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 27). Zugl. München: TU, Diss. 1996.

D53 STEINMEIER, E.:
Realisierung eines systemtechnischen Produktmodells – Einsatz in der Pkw-Entwicklung
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 28). Zugl. München: TU, Diss. 1998.

D54 KLEEDÖRFER, R.:
Prozess- und Änderungsmanagement der Integrierten Produktentwicklung.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 29). Zugl. München: TU, Diss. 1998.

D55 GÜNTHER, J.:
Individuelle Einflüsse auf den Konstruktionsprozess.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 30). Zugl. München: TU, Diss. 1998.

D56 BIERSACK, H.:
Methode für Krafteinleitungsstellenkonstruktion in Blechstrukturen.
München: TU, Diss. 1998.

D57 IRLINGER, R.:
Methoden und Werkzeuge zur nachvollziehbaren Dokumentation in der Produktentwicklung.
Aachen: Shaker 1998. (Konstruktionstechnik München, Band 31). Zugl. München: TU, Diss. 1999.

D58 EILETZ, R.:
Zielkonfliktmanagement bei der Entwicklung komplexer Produkte – am Bsp. PKW-Entwicklung.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 32). Zugl. München: TU, Diss. 1999.

D59 STÖSSER, R.:
Zielkostenmanagement in integrierten Produkterstellungsprozessen.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 33). Zugl. München: TU, Diss. 1999.

D60 PHLEPS, U.:
Recyclinggerechte Produktdefinition – Methodische Unterstützung für Upgrading und Verwertung.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 34). Zugl. München: TU, Diss. 1999.

D61 BERNARD, R.:
Early Evaluation of Product Properties within the Integrated Product Development.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 35). Zugl. München: TU, Diss. 1999.

D62 ZANKER, W.:
Situative Anpassung und Neukombination von Entwicklungsmethoden.
Aachen: Shaker 1999. (Konstruktionstechnik München, Band 36). Zugl. München: TU, Diss. 1999.

Reihe Produktentwicklung München

D63 ALLMANSBERGER, G.:
Erweiterung der Konstruktionsmethodik zur Unterstützung von Änderungsprozessen in der Produktentwicklung.
München: Dr. Hut 2001. (Produktentwicklung München, Band 37). Zugl. München: TU, Diss. 2000.

D64 ASSMANN, G.:
Gestaltung von Änderungsprozessen in der Produktentwicklung.
München: Utz 2000. (Produktentwicklung München, Band 38). Zugl. München: TU, Diss. 2000.

D65 BICHLMAIER, C.:
Methoden zur flexiblen Gestaltung von integrierten Entwicklungsprozessen.
München: Utz 2000. (Produktentwicklung München, Band 39). Zugl. München: TU, Diss. 2000.

D66 DEMERS, M. T.
Methoden zur dynamischen Planung und Steuerung von Produktentwicklungsprozessen.
München: Dr. Hut 2000. (Produktentwicklung München, Band 40). Zugl. München: TU, Diss. 2000.

D67 STETTER, R.:
Method Implementation in Integrated Product Development.
München: Dr. Hut 2000. (Produktentwicklung München, Band 41). Zugl. München: TU, Diss. 2000.

D68 VIERTLBÖCK, M.:
Modell der Methoden- und Hilfsmitteleinführung im Bereich der Produktentwicklung.
München: Dr. Hut 2000. (Produktentwicklung München, Band 42). Zugl. München: TU, Diss. 2000.

D69 COLLIN, H.:
Management von Produkt-Informationen in kleinen und mittelständischen Unternehmen.
München: Dr. Hut 2001. (Produktentwicklung München, Band 43). Zugl. München: TU, Diss. 2001.

D70 REISCHL, C.:
Simulation von Produktkosten in der Entwicklungsphase.
München: Dr. Hut 2001. (Produktentwicklung München, Band 44). Zugl. München: TU, Diss. 2001.

D71 GAUL, H.-D.:
Verteilte Produktentwicklung - Perspektiven und Modell zur Optimierung.
München: Dr. Hut 2001. (Produktentwicklung München, Band 45). Zugl. München: TU, Diss. 2001.

D72 GIERHARDT, H.:
Global verteilte Produktentwicklungsprojekte – Ein Vorgehensmodell auf der operativen Ebene.
München: Dr. Hut 2002. (Produktentwicklung München, Band 46). Zugl. München: TU, Diss. 2001.

D73 SCHOEN, S.:
Gestaltung und Unterstützung von Community of Practice.
München: Utz 2000. (Produktentwicklung München, Band 47). Zugl. München: TU, Diss. 2000.

D74 BENDER, B.:
Zielorientiertes Kooperationsmanagement.
München: Dr. Hut 2001. (Produktentwicklung München, Band 48). Zugl. München: TU, Diss. 2001.

D75 SCHWANKL, L.:
Analyse und Dokumentation in den frühen Phasen der Produktentwicklung.
München: Dr. Hut 2002. (Produktentwicklung München, Band 49). Zugl. München: TU, Diss. 2002.

D76 WULF, J.:
Elementarmethoden zur Lösungssuche.
München: Dr. Hut 2002. (Produktentwicklung München, Band 50). Zugl. München: TU, Diss. 2002.

D77 MÖRTL, M.:
Entwicklungsmanagement für langlebige, upgradinggerechte Produkte.
München: Dr. Hut 2002. (Produktentwicklung München, Band 51). Zugl. München: TU, Diss. 2002.

D78 GERST, M.:
Strategische Produktentscheidungen in der integrierten Produktentwicklung.
München: Dr. Hut 2002. (Produktentwicklung München, Band 52). Zugl. München: TU, Diss. 2002.

D79 AMFT, M.:
Phasenübergreifende bidirektionale Integration von Gestaltung und Berechnung.
München: Dr. Hut 2003. (Produktentwicklung München, Band 53). Zugl. München: TU, Diss. 2002.

D80 FÖRSTER, M.:
Variantenmanagement nach Fusionen in Unternehmen des Anlagen- und Maschinenbaus.
München: TU, Diss. 2003.

D81 GRAMANN, J.:
Problemmodelle und Bionik als Methode.
München: Dr. Hut 2004. (Produktentwicklung München, Band 55). Zugl. München: TU, Diss. 2004.

D82 PULM, U.:
Eine systemtheoretische Betrachtung der Produktentwicklung.
München: Dr. Hut 2004. (Produktentwicklung München, Band 56). Zugl. München: TU, Diss. 2004.

D83 HUTTERER, P.:
Reflexive Dialoge und Denkbausteine für die methodische Produktentwicklung.
München: Dr. Hut 2005. (Produktentwicklung München, Band 57). Zugl. München: TU, Diss. 2005.

D84 FUCHS, D.:
Konstruktionsprinzipien für die Problemanalyse in der Produktentwicklung.
München: Dr. Hut 2006. (Produktentwicklung München, Band 58). Zugl. München: TU, Diss. 2005.

D85 PACHE, M.:
Sketching for Conceptual Design.
München: Dr. Hut 2005. (Produktentwicklung München, Band 59). Zugl. München: TU, Diss. 2005.

D86 BRAUN, T.:
Methodische Unterstützung der strategischen Produktplanung in einem mittelständisch geprägten Umfeld.
München: Dr. Hut 2005. (Produktentwicklung München, Band 60). Zugl. München: TU, Diss. 2005.

D87 JUNG, C.:
Anforderungsklärung in interdisziplinärer Entwicklungsumgebung.
München: Dr. Hut 2006. (Produktentwicklung München, Band 61). Zugl. München: TU, Diss. 2006.

D88 HEßLING, T.:
Einführung der Integrierten Produktpolitik in kleinen und mittelständischen Unternehmen.
München: Dr. Hut 2006. (Produktentwicklung München, Band 62). Zugl. München: TU, Diss. 2006.

D89 STRICKER, H.:
Bionik in der Produktentwicklung unter der Berücksichtigung menschlichen Verhaltens.
München: Dr. Hut 2006. (Produktentwicklung München, Band 63). Zugl. München: TU, Diss. 2006.

D90 NIßL, A.:
Modell zur Integration der Zielkostenverfolgung in den Produktentwicklungsprozess.
München: Dr. Hut 2006. (Produktentwicklung München, Band 64). Zugl. München: TU, Diss. 2006.

D91 MÜLLER, F.:
Intuitive digitale Geometriemodellierung in frühen Entwicklungsphasen.
München: Dr. Hut 2007. (Produktentwicklung München, Band 65). Zugl. München: TU, Diss. 2006.

D92 ERDELL, E.:
Methodenanwendung in der Hochbauplanung – Ergebnisse einer Schwachstellenanalyse.
München: Dr. Hut 2006. (Produktentwicklung München, Band 66). Zugl. München: TU, Diss. 2006.

D93 GAHR, A.:
Pfadkostenrechnung individualisierter Produkte.
München: Dr. Hut 2006. (Produktentwicklung München, Band 67). Zugl. München: TU, Diss. 2006.

D94 RENNER, I.:
Methodische Unterstützung funktionsorientierter Baukastenentwicklung am Beispiel Automobil.
München: Dr. Hut 2007 (Reihe Produktentwicklung) Zugl. München: TU, Diss. 2007.

D95 PONN, J.:
Situative Unterstützung der methodischen Konzeptentwicklung technischer Produkte.
München: Dr. Hut 2007 (Reihe Produktentwicklung) Zugl. München: TU, Diss. 2007.

D96 HERFELD, U.:
Matrix-basierte Verknüpfung von Komponenten und Funktionen zur Integration von Konstruktion und numerischer Simulation.
München: Dr. Hut 2007. (Produktentwicklung München, Band 70). Zugl. München: TU, Diss. 2007.

D97 SCHNEIDER, S.:
Model for the evaluation of engineering design methods.
München: Dr. Hut 2008 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D98 FELGEN, L.:
Systemorientierte Qualitätssicherung für mechatronische Produkte.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D99 GRIEB, J.:
Auswahl von Werkzeugen und Methoden für verteilte Produktentwicklungsprozesse.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D100 MAURER, M.:
Structural Awareness in Complex Product Design.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D101 BAUMBERGER, C.:
Methoden zur kundenspezifischen Produktdefinition bei individualisierten Produkten.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D102 KEIJZER, W.:
Wandlungsfähigkeit von Entwicklungsnetzwerken – ein Modell am Beispiel der Automobilindustrie.
München: Dr. Hut 2007 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2007.

D103 LORENZ, M.:
Handling of Strategic Uncertainties in Integrated Product Development.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2008.

D104 KREIMEYER, M.:
Structural Measurement System for Engineering Design Processes.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D105 DIEHL, H.:
Systemorientierte Visualisierung disziplinübergreifender Entwicklungsabhängigkeiten mechatronischer Automobilsysteme.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D106 DICK, B.:
Untersuchung und Modell zur Beschreibung des Einsatzes bildlicher Produktmodelle durch Entwicklerteams in der Lösungssuche.
München: Dr. Hut 2009 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2009.

D107 GAAG, A.:
Entwicklung einer Ontologie zur funktionsorientierten Lösungssuche in der Produktentwicklung.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D108 ZIRKLER, S.:
Transdisziplinäres Zielkostenmanagement komplexer mechatronischer Produkte.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D109 LAUER, W.:
Integrative Dokumenten- und Prozessbeschreibung in dynamischen Produktentwicklungsprozessen.
München: Dr. Hut 2010 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2010.

D110 MEIWALD, T.:
Konzepte zum Schutz vor Produktpiraterie und unerwünschtem Know-how-Abfluss.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D111 ROELOFSEN, J.:
Situationsspezifische Planung von Produktentwicklungsprozessen.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D112 PETERMANN, M.:
Schutz von Technologiewissen in der Investitionsgüterindustrie.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D113 GORBEA, C.:
Vehicle Architecture and Lifecycle Cost Analysis in a New Age of Architectural Competition.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D114 FILOUS, M.:
Lizenzierungsgerechte Produktentwicklung – Ein Leitfaden zur Integration lizenzierungsrelevanter Aktivitäten in Produktentstehungsprozessen des Maschinen- und Anlagenbaus.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D115 ANTON, T.:
Entwicklungs- und Einführungsmethodik für das Projektierungswerkzeug Pneumatiksimulation.
München: Dr. Hut 2011 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2011.

D116 KESPER, H.:
Gestaltung von Produktvariantenspektren mittels matrixbasierter Methoden.
München: Dr. Hut 2012 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2012.

D117 KIRSCHNER, R.:
Methodische Offene Produktentwicklung.
München: TU, Diss. 2012.

D118 HEPPERLE, C.:
Planung lebenszyklusgerechter Leistungsbündel.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D119 HELLENBRAND, D.:
Transdisziplinäre Planung und Synchronisation mechatronischer Produktentwicklungsprozesse.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D120 EBERL, T.:
Charakterisierung und Gestaltung des Fahr-Erlebens der Längsführung von Elektrofahrzeugen.
München: TU, Diss. 2014.

D121 KAIN, A.:
Methodik zur Umsetzung der Offenen Produktentwicklung.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D122 ILIE, D.:
Systematisiertes Ziele- und Anforderungsmanagement in der Fahrzeugentwicklung.
München: Dr. Hut 2013 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2013.

D123 HELTEN, K.:
Einführung von Lean Development in mittelständische Unternehmen - Beschreibung, Erklärungsansatz und Handlungsempfehlungen.
München: Dr. Hut 2015 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D124 SCHRÖER, B.:
Lösungskomponente Mensch. Nutzerseitige Handlungsmöglichkeiten als Bausteine für die kreative Entwicklung von Interaktionslösungen.
München: TU, Diss. 2014.

D125 KORTLER, S.:
Absicherung von Eigenschaften komplexer und variantenreicher Produkte in der Produktentwicklung.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D126 KOHN, A.:
Entwicklung einer Wissensbasis für die Arbeit mit Produktmodellen.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D127 FRANKE, S.:
Strategieorientierte Vorentwicklung komplexer Produkte – Prozesse und Methoden zur zielgerichteten Komponentenentwicklung am Beispiel Pkw.
Göttingen: Cuvillier, E 2014. Zugl. München: TU, Diss. 2014.

D128 HOOSHMAND, A.:
Solving Engineering Design Problems through a Combination of Generative Grammars and Simulations.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D129 KISSEL, M.:
Mustererkennung in komplexen Produktportfolios.
München: TU, Diss. 2014.

D130 NIES, B.:
Nutzungsgerechte Dimensionierung des elektrischen Antriebssystems für Plug-In Hybride.
München: TU, Diss. 2014.

D131 KIRNER, K.:
Zusammenhang zwischen Leistung in der Produktentwicklung und Variantenmanagement – Einflussmodell und Analysemethode.
München: Dr. Hut 2014 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D132 BIEDERMANN, W.:
A minimal set of network metrics for analysing mechatronic product concepts.
München: TU, Diss. 2015.

D133 SCHENKL, S.:
Wissensorientierte Entwicklung von Produkt-Service-Systemen.
München: TU, Diss. 2015.

D134 SCHRIEVERHOFF, P.:
Valuation of Adaptability in System Architecture.
München: Dr. Hut 2015 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2014.

D135 METZLER, T.:
Models and Methods for the Systematic Integration of Cognitive Functions into Product Concepts.
München: Dr. Hut 2016 (Reihe Produktentwicklung).

D136 DEUBZER, F.:
A Method for Product Architecture Management in Early Phases of Product Development.
München: TU, Diss. 2016.

D137 SCHÖTTL, F.:
Komplexität in sozio-technischen Systemen - Methodik für die komplexitätsgerechte Systemgestaltung in der Automobilproduktion.
München: Dr. Hut 2016 (Reihe Produktentwicklung).

D138 BRANDT, L. S.:
Architekturgesteuerte Elektrik/Elektronik Baukastenentwicklung im Automobil
München: TU, Diss. 2017.

D139 BAUER, W.:
Planung und Entwicklung änderungsrobuster Plattformarchitekturen
München: Dr. Hut 2016 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2016.

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Supporting the Design of Management Control Systems In Engineering Companies from Management Cybernetics Perspective
München: TU, Diss. 2015.

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Beschaffungsgerechte Produktentwicklung – Abstimmung von Produktarchitektur und Liefernetzwerk in frühen Phasen der Entwicklung
München: TU, Diss. 2017.

D142 ÖLMEZ, M.:
Individuelle Unterstützung von Entscheidungsprozessen bei der Entwicklung innovativer Produkte.
München: Dr. Hut 2017 (Reihe Produktentwicklung).

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Entwicklerzentrierte Hilfsmittel zum Gestalten von Nutzererlebnissen.
München: Dr. Hut 2017 (Reihe Produktentwicklung).

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Structure-based System Dynamics Analysis of Engineering Design Processes
München: TU, Diss. 2016.

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Kritische Änderungen in der Produktentwicklung – Analyse und Maßnahmenableitung
München: Dr. Hut 2017 (Reihe Produktentwicklung).

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Planung und Entwicklung multifunktionaler Kernmodule in komplexen Systemarchitekturen und –portfolios – Methodik zur Einnahme einer konsequent modulzentrierten Perspektive
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Bio-inspired design: Ideation in collaboration between mechanical engineers and biologists
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Biologische Publikationen als Ideengeber für das Lösen technischer Probleme in der Bionik
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Situational Open Innovation – Enabling Boundary-Spanning Collaboration in Small and Medium-sized Enterprises
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Änderungen besser managen – Eine datenbasierte Methodik zur Analyse technischer Änderungen
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Planungsleitfaden für die systematische Analyse und Verbesserung von Produktarchitekturen
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Design the experience first: A scenario-based methodology for the design of complex, tangible consumer products
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Increasing Customer Acceptance in Planning Product-Service Systems
München: Dr. Hut 2017 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2017.

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Efficient Safety Method Kit for User-driven Customization
München: Dr. Hut 2017 (Reihe Produktentwicklung).

D155 PLÖTNER, M.:
Integriertes Vorgehen zur selbstindividualisierungsgerechten Produktstrukturplanung
München: TU, Diss. 2018.

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Entwicklung einer Methodik zur Ermittlung raumfunktionaler Kundenanforderungen in der Automobilentwicklung
München: Dr. Hut 2017 (Reihe Produktentwicklung).

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Modellbasierte Planung von Produkt-Service-Systemen
München: Dr. Hut 2018 (Reihe Produktentwicklung).

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Krisen in der Produktentwicklung und ihre operative Bewältigung
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Strukturbasierte Koordinationsplanung in komplexen Entwicklungsprojekten
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Im Spannungsfeld zwischen Risiken und Chancen – Eine Methode zur Ableitung von Handlungsempfehlungen zur Öffnung der Produktentwicklung
München: Dr. Hut 2018 (Reihe Produktentwicklung).

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Systematic identification of Flexible Design Opportunities in offshore drilling systems
München: Dr. Hut 2018 (Reihe Produktentwicklung). Zugl. München: TU, Diss. 2018.

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When digital meets physical – Agile Innovation of Mechatronic Systems
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Workshop-based Tailoring of Interdisciplinary Product Development Processes by Means of Structural Analysis
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From data to value: Facilitating strategy development for connected products
TU München: 2019. (als Dissertation eingereicht)

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Zukunftsorientierte und modellunterstützte Adaption bestehender Produkt-Service-Systeme
TU München: 2019. (als Dissertation eingereicht)