**20[TH] INTERNATIONAL DEPENDENCY AND STRUCTURE MODELING CONFERENCE, DSM 2018**

TRIESTE, ITALY, OCTOBER 15 – 17, 2018

# Supporting Workshop-based Tailoring of Product Development Processes by Metric-based Structural Analysis

Christoph Hollauer, Felix Kölsch, Udo Lindemann

Laboratory for Product Development and Lightweight Design, Technical University of Munich

**Abstract:** Tailoring complex product development processes for project-specific situations is a task currently inadequately supported and often carried out ad-hoc in companies. Existing approaches in software engineering target the automation of the tailoring activity, which is seen as insufficient in interdisciplinary product development. To address this gap we developed an approach using metric-based structural analysis in order to condense and visualize a process models structural information to support workshop-based collaborative tailoring. The approach has been evaluated using a semi-synthetic test case and an expert interview study.

*Keywords: Process Tailoring, Structural Analysis, Project Planning*

## 1 Introduction

Processes play a crucial role in today's product development environment (Bender & Gericke, 2016). They are a critical factor to support engineers in managing increasing requirements regarding customer demands, development costs and time-to-market. Although standard models of product development processes (PDP) are considered useful, they do not have a major added value without adapting the process to the specific context of individual product development (PD) projects (Costache & Kalus, 2011). Consequently, process tailoring is increasingly becoming a focus of process management research (Browing & Ramasesh, 2007), and is addressed in a generic manner in various process standards, such as e.g. ISO/IEC 24748-1 (2010). Nevertheless, in practice, process tailoring is often based on ad-hoc decisions without a systematic approach or support (Pedreiera et al., 2007), although it should be executed in a consistent and systematic manner (Martinez-Ruiz et al 2012). Research has strived to provide corresponding support, mainly in the field of software engineering, focusing primarily on the automated generation of tailored project-specific processes (cf. Hurtado-Alegria, 2014; Park, 2006). However, using automation approaches for tailoring PDPs is at the same time considered difficult to inapplicable (Bender & Gericke, 2016), e.g. due to the (structural) complexity of the PDP models as well as the dynamic context of PD.

Therefore, different alternatives should be explored to support systematic PDP tailoring. One possible approach is the implementation of workshop-based tailoring, including stakeholders affected by tailoring decisions, in order to discuss and collaboratively make tailoring decisions. As a basis for collaborative decision making, profound knowledge is required, e.g. regarding the impact and possible consequences of adaptions in complex process networks, e.g. through the removal of activities. The objective of this paper is to present an analysis framework for condensing and visualizing the information contained in tailoring-relevant knowledge via structural complexity metrics, in order to support workshop-based tailoring. The usage of this information is not limited to the support of individual tailoring decisions, but also used to support the preparation of tailoring workshops in general, e.g. by identifying process stakeholders with common tailoring decisions.

The remainder of this paper is structured as follows: Following the research methodology, the most relevant related work is briefly characterized. Subsequently, the developed analysis framework is described and further explained by concrete application scenarios for supporting workshop-based tailoring. Finally, the evaluation of the analysis concept is presented.

## 2 Research methodology

This work follows the Design Research Methodology (DRM) (Blessing & Chakrabarti, 2009). The research clarification in this paper is mainly based on previous empirical studies. The second stage, the descriptive study I (DS I), includes reviews regarding relevant topics such as process tailoring and structural metrics, as well as a systematic literature review regarding existing analysis approaches for investigating tailoring knowledge (section 3). The prescriptive study (PS) covers the elaboration of the analysis framework for investigating tailoring knowledge using structural metrics and its application for preparing and conducting tailoring workshops (section 4). The evaluation (descriptive study II, DS II) of the presented concept consists of two parts (section 5): The application evaluation focuses on the applicability of the analysis framework, by testing the approach with a semi-synthetic test case based on real data. An initial success evaluation, investigating the added-value of the developed concept, is conducted via an initial interview-study performed with industry experts.

## 3 Related work and research gap

The paper at hands presents a systematic approach for analyzing tailoring knowledge. Ginsberg and Quinn (1995) describe tailoring generally as “[t]he 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 […].”. In the context of PDPs and this work, this is understood as the adaptation of a reference process to a project-specific process applied in a project-specific context. The context of a project can be described by context variables and related values which describe particular specifications (e.g. “project task” and “new development”, “adaptation”). Thereby, dependencies between context values and process adaptations can be modeled as process tailoring rules (PTRs), by including the appropriate tailoring operator (e.g. “select” and “delete”) (cf. Martinez-Ruiz et al 2012, Hurtado-Alegria, 2014). Tailoring knowledge can thus be represented in a rule-based manner and visualized as a graph model using nodes and edges to describe and connect the different entities (e.g. context values, tailoring rules, and process elements).

Utilizing this rule-based representation between context and process model, research has focused on creating tools for automating process tailoring. Different techniques (e.g. feature-based tailoring, neural networks, …) have been applied mainly in software development (cf. Kalus (2013), Park (2006)). However, due to dependencies between context values, their dynamic change over time, and the complexity of PD, adapting the PDP using a configurator with predefined tailoring characteristics is considered not possible (Bender and Gericke, 2016), thus requiring alternative approaches to perform tailoring in a more flexible and interactive manner. A possible concept is to discuss process adaptations during specific tailoring workshop. In order to implement such workshops, a sound basis for decision-making has to be provided by analyzing, condensing and visualizing available tailoring knowledge, due to the structural complexity of PDPs.

Based on this insight, a systematic literature review has been conducted to identify existing approaches for analyzing tailoring knowledge. This procedure did not yield sufficient results for further investigation, indicating that so far little research has been done on this topic. In order to verify this conclusion, the systematic literature review has been modified to enlarge its focus, changing the objective to identifying approaches for analyzing rule-based knowledge in general. As tailoring knowledge can be represented in a rule-based manner, the two systematic reviews are still thematically connected. Nevertheless, expanding the focus of investigation did not increase search results. Most of the identified sources addressed analyzing knowledge transfer in social networks. Hereby the objective is to describe the knowledge flow within an organization by analyzing structural characteristics of the network.

The structural characteristics considered in social network analysis (e.g. centrality) are based on the mathematical fundaments of graph theory and can be transferred to other disciplines as well. An approach for investigating a PDP using graph and network theory by computing structural complexity metrics is presented in detail by Kreimeyer (2009). With the aid of test cases, Kreimeyer (2009) shows that it is possible to evaluate the relevance of individual process elements on a quantitative basis by analyzing the structure of a graph-based PDP model. Since the PDP is the main subject of the tailoring process, the approach presented by Kreimeyer (2009) provides an initial starting point for systematically analyzing tailoring knowledge using structural metrics.

To summarize, tailoring a structurally complex PDP to a project-specific context is complex and knowledge-intensive. Existing tailoring approaches relying on automation techniques focus on “producing” a project-specific process, are limited in terms of applicability due to the software required, and do not foster communication between project stakeholders during tailoring. Tailoring PDPs however requires the inclusion of a multitude of relevant project stakeholders in a collaborative manner, e.g. through workshops. Since the PDPs to be tailored can be quite complex, a systematic approach is needed to analyze and prepare the tailoring knowledge, contained e.g. in the PDP model, required in order to provide a sound basis for the decision-making during tailoring. Approaches for the systematic analysis of tailoring knowledge as well as workshop-based collaborative tailoring are currently lacking. A metric-based structural analysis of graph-based modeled tailoring knowledge provides a starting point for such analyses.

## 4 Design support: Metric-based structural analysis framework

In order to enable workshop-based tailoring, a five-step methodology has been developed, consisting of the following phases: Preparation, information acquisition, modeling tailoring knowledge as a graph-based "tailoring system model" (TSM), analyzing the TSM, and operationalization of the results in tailoring workshops (cf. Hollauer et al 2018). This paper focuses on presenting the structural analysis of the TSM and thereby support the preparation and realization of tailoring workshops. The analysis consists of four consecutive steps (cf. Figure 1) and has been implemented as a demonstrator using the software Soley Studio (www.soley.io).

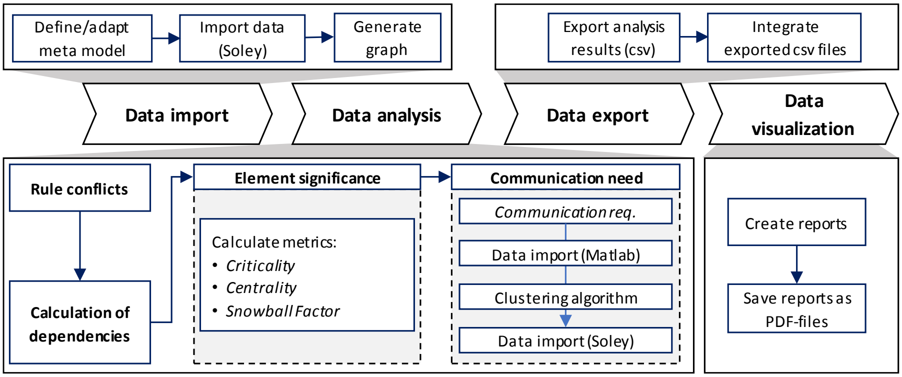



Figure 1. Overview of the analysis procedure

Provided the tailoring knowledge has already been acquired and modeled as the graph-based TSM, the first step of the systematic analysis procedure is to import relevant tailoring knowledge into the analysis tool, modifying the underlying meta model if necessary. The meta models node and edge types are presented in Figure 2.

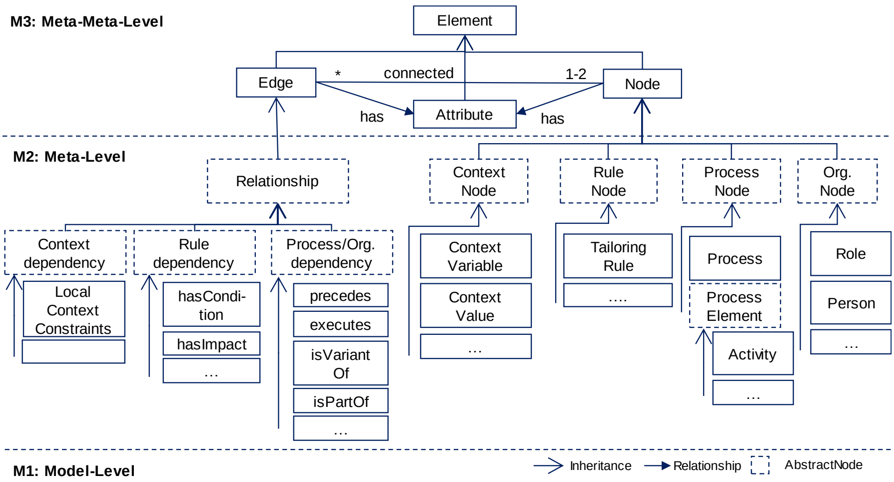
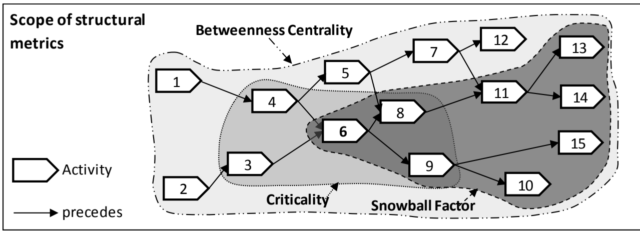



Figure 2. Meta model class diagram for documenting the tailoring knowledge within the four domains Context, Process, Organization, and Rules (excerpt from Hollauer et al 2018)

The model (nodes and edges) can be stored as a csv-file and subsequently imported into the analysis tool which enables visualization in form of a graph and further computational analyses. The actual structural analysis is then carried out on the graph-based TSM using graph rewriting (cf. Helms 2013 XXX). In order to support workshop-based tailoring, the data analysis contains four major parts which are: identification of rule conflicts, calculation of indirect dependencies, calculation of element significance and derivation of communication need among tailoring-afflicted project stakeholders.

PTRs can cause potential *conflicts*. Examples are process elements which are simultaneously impacted by PTRs with different tailoring operators (e.g. “delete” vs. “select”) and a process element variant which is selected by one PTR although an incident and superordinate element is removed by another PTR. Such conflicts can be automatically identified through pattern matching and subsequently, e.g. by adding conditions between context factors which ensure that only one of the corresponding PTRs can be selected simultaneously. Subsequently, *indirect dependencies* between different nodes can be calculated and investigated. On the one hand, indirect dependencies between elements can be used for the metric calculation, on the other hand, the dependencies themselves can be transformed to analytical characteristics of the graph model (e.g. responsible activities per person). Three key *structural complexity metrics are calculated* in order to assess the significance of individual process elements within the PDP, in particular when changes are made to these process elements. These metrics are: *Criticality*, *Snowball Factor* and *Betweenness Centrality* (Figure 3).




**Structural metrics of node 6**

| | |
|---|---|
| **Criticality (Cri):** | 4 |
| **Snowball Factor (SF)** | 10 |
| **Betweenness Centrality (Cen):** | 29 |

| **Algorithm for calculation per metric** | **Description** | **Structural significance** | **Sources** |
|---|---|---|---|
| $Cri = active\ sum\ * passive\ sum$ (1)<br>*active sum: number of outgoing edges*<br>*passive sum: number of incoming edges* | Product of number of incoming and outgoing edges. | Relevance of an element within its immediate environment. | Lindemann et al. (2009) |
| $SF = \sum_{i=1}^{height} \frac{width(i) * height}{i}$ (2)<br>*height: height of the hierarchy; width: width of the hierarchy; i: hierarchy level* | Sum of product of width per hierachy level and total height, weighted according to inverse of shortest path length to the investigated node. | Relevance of an element for subsequent activities. | Kreimeyer (2009) |
| $Cen(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$ (3)<br>*s,t,v: nodes of the node set V*<br>$\sigma_{st}(v)$*: no. of shortest paths between s and, including v*<br>$\sigma_{st}$*: total no. of shortest paths between s and t* | Sum of number of shortest paths between a pair of nodes including the investigated node weighted according to the total number of shortest paths betweeen this pair of nodes. | Relevance of an element within the entire network. | Brandes (2001); Freeman (1977) |

Figure 3. Overview of selected structural metrics quantifying the relevance of process elements with equations 1-3 for metric calculation

The metrics indicate the importance of an individual process element within three different scopes (cf. Figure 3, including formulas 1 to 3 for calculation). This enables the consideration of the process element significance within different neighbourhood sizes during the interpretation of the analysis results, as relying only on a single metric can lead to incorrect conclusions. Calculating the metrics for all elements of the PDP subsequently allows to draw conclusions about the relevance of PTRs. A PTR affecting process elements with high values for *criticality, snowball factor* and *betweenness centrality*, has a potentially large effect on the process. Based on this data, the importance of a PTR can be determined by calculating the mean of each metric for the impacted process elements. Analysing the relevance of single process elements and PTRs, is followed by the fourth stage of the data analysis: *Identifying the need for communication* between project stakeholders regarding tailoring decisions. The need for communication is made up of both process-related and organizational aspects (cf. Heimberger 2017). In our case, process-related communication needs are determined by calculating the number of PTRs affecting two particular stakeholders (via their activities), weighted by the mean metrics per PTR. Therefore, two individuals have a high need for communication, if they have many PTRs in common, which in turn have a large effect on the process. The organizational aspect is based on the fact that the quality of knowledge exchange decreases with increasing (organizational) distance between two stakeholders (Muyun, 2017). The need of communication thus correlates with the distance between two stakeholders within the organizational hierarchy. Combining process and organizational aspects, equation 4 can be formulated to calculate the requirement of communication (RoC).

$$RoC = (\alpha + \beta + \gamma) * (Number\ of\ common\ PTRs) * (Organisational\ Distance)^2 \qquad (4)$$

$$With{:}\ \alpha = \frac{\emptyset Cri}{max(\emptyset Cri)};\ \beta = \frac{\emptyset SF}{max(\emptyset SF)};\ \gamma = \frac{\emptyset Cen}{max(\emptyset Cen)}$$

Based on the calculated RoCs for each stakeholder pair, a square RoC matrix can be derived and clustered by importing the generated analysis data in a software tool which supports clustering algorithms (e.g. Matlab). After the analysis procedure has been executed, all relevant analytical characteristics of the TSM required for planning and executing of tailoring workshops have been determined. Thus, the data is exported for further processing and visualization.

In order to support the preparation and execution of tailoring workshops, the analysis results are further prepared and visualized (using Excel-based VBA macros in our demonstrator). Consequently, seven types of analysis **reports** with different levels of detail are generated (cf. Figure 4). These reports are grouped into three categories: network level, cluster level, and node level. Reports on **network level** contain information about all nodes of a particular type and give an overview about these elements. Regarding preparing and conducting tailoring workshops it is useful to have such reports for elements of the node class **PTR** and **Stakeholder**. The network-level PTR report contains all PTR nodes including information about the calculated metrics and dependencies between PTRs. Thus, the data sheet enables the identification of outliers and possible errors during modeling on the one hand, and the prioritization of rules based on their effect on the process on the other. In addition, the stakeholder report contains the number of related activities and dependent rules per individual as well as the corresponding cluster assignment. This enables the identification of key stakeholders who need to be involved in the tailoring process and the division of stakeholders into workshop groups (clusters). Reports on **cluster level** then contain information about PTRs which have to be decided during a workshop. Due to the generated metric data regarding the relevance of individual rules, prioritizing the PTRs becomes possible, enabling the derivation of an agenda for each tailoring workshop. To support the decision-making process during such a meeting, reports at **node level** provide detailed information about individual elements (**context**, **PTR**, **process** or **person**). Whereas the reports of the node classes PTR, process element and context mainly serve as reference basis, the stakeholder reports at node level can be used as individual preparation material because they contain all relevant tailoring information (e.g. dependent PTRs, responsible process elements and requirements of communication with other stakeholders) from a particular person's perspective.

However, not every report type is of equal interest to every involved stakeholder, as different stakeholders can assume different **roles** during the tailoring process. Within the scope of this work the three roles **"tailoring expert"**, **"tailoring organizer"** and **"tailoring stakeholder"** are defined. Tailoring experts have a detailed understanding of acquiring and modelling tailoring knowledge and the significance of structural metrics. The reports on network level as well as the node specific reports support the role owner(s) in modelling the tailoring knowledge as well as assisting the workshop participants and moderators during the decision-making process. Tailoring organizers do not require detailed knowledge of graph modeling but must be familiar with the significance of the calculated metrics. Using this knowledge and the stakeholder report on network level, the tailoring organizers can determine appropriate workshop participants. In addition, an agenda for each meeting can be derived with the help of the cluster specific reports. Most of the people involved belong to the "tailoring stakeholder" role (participants of the design process/project) and actively participate in the workshops. This includes the discussion of individual tailoring decisions and submission of a decision recommendation. To prepare for workshops, the tailoring stakeholders can use the stakeholder reports on node level, to familiarize themselves with the relevant PTRs and discussion partners. Thus, the analysis results support the documentation and generation of knowledge, division of workshop groups, development of agendas for meetings and training of involved persons during the preparation of workshops, and decision making regarding process-adaptations during the workshop.

## 5 Evaluation and discussion

The analysis approach presented in section 4 is evaluated in two ways: First, the functionality of the analysis framework is tested using the developed demonstrator applied on a semi-synthetic test case consisting of real-world PDP data. Missing data (e.g. organizational structure) is generated for the evaluation. After importing the data, the graph-based model consists of 948 nodes and 1553 edges (Figure 4). Performing the four steps of the computational graph enables the automated generation of the reports regarding the different levels of detail (Figure 4). In order to further customize the report generation, an interface allows the selection of specific reports to be generated. The test case confirms the assumption that the analysis framework enables the analysis of complex tailoring knowledge and the condensed visualization with user specific reports.

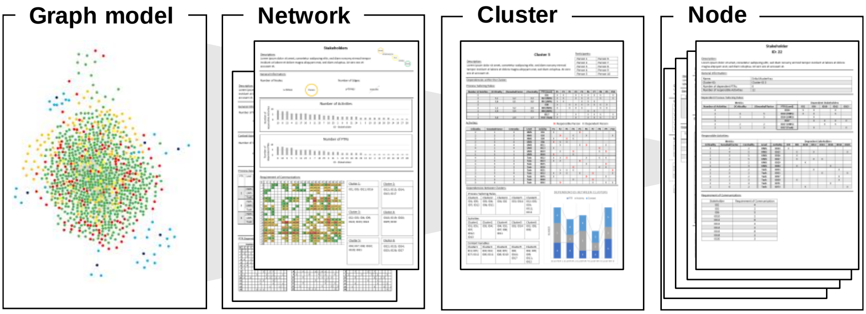



Figure 4. Overview of test case graph model and report types (templates)

Second, the applicability of the approach and its potential added value for workshop-based tailoring has been evaluated via an interview study. The analysis approach and the application of the results (reports) in the context of workshop-based tailoring has been presented to 11 industry professionals. During the semi-structured presentation and interview, discussion with the interview partners produced immediate qualitative feedback. In addition, a questionnaire with 22 question items was handed out after the interview, with eight questionnaires returned. Besides descriptive questions regarding the experts' background, the evaluation form consists on the one hand of questions about the necessity of a systematic support regarding tailoring and on the other hand of an evaluation of the presented approach and analysis results (using five-step Likert scales with 1='strongly agree' and 5='strongly disagree'). Structuring of the tailoring process, internal coordination regarding process adjustments, consideration of dependent stakeholders, complexity of the tailoring process and estimation of the effects of tailoring decisions are all considered challenging by the experts. The quantitative assessment of the added value of the presented reports is shown in Figure 5. In particular, the derivation of suitable workshop groups as well as the metric-based structuring and prioritizing of the rules are to be emphasized positively. The potential of the reports with regard to the other evaluation criteria is also classified as tending to exist. Furthermore, it should be noted that the benefit of the analysis results in the preparation and implementation of tailoring workshops were more appreciated by experts with previous experience in tailoring ($\emptyset = 2.0$; $N = 4$) than by interview partners without experience ($\emptyset = 2.5$; $N = 4$). Besides the quantitative evaluation results, the following points of criticism must be noted from the findings of the qualitative questions and the open discussion:

- The concept assumes that all data is available at a certain level of detail.
- Certain basic knowledge is required to use the reports, requiring additional training.
- The applicability of the concept depends on the size (or duration) of the project. With small projects, the ratio between effort and benefit deteriorates.

| The presented reports enable… | Rating [Ø] (Completely agree 1 – Completely disagree 5) |
|---|---|
| … the identification of inconsistencies in modeling. | 2.3 |
| … the identification of suitable w orkshop groups. | 1.9 |
| … the structuring and prioritization of PTRs & process elements. | 1.8 |
| …the derivation of a w orkshop agenda. | 2.3 |
| … the training of individual stakeholders. | 2.5 |
| … support of internal communication | 2.4 |
| … to make the complexity of the tail. process more manageable. | 2.6 |

Figure 5. Quantitative evaluation results of the questionnaire regarding the assessment of the presented reports.

The application of the analysis framework requires the availability of an initial data basis, with the data quality being a decisive factor for the quality and value of the analysis results. However, the criticism regarding training can be mitigated, as the training can be adapted to the task of the respective roles. The criticism regarding the relationship between the benefits of the concept and the size of the respective project is countered by automating the analysis.

The presented approach represents a step towards using established structural analysis techniques to support the organization of and decision making during collaborative tailoring of complex PDPs. Using the reports, practitioners can increase transparency regarding tailoring decisions in the complex network structures of PDPs. For example, by ranking PTRs according to impact and identifying communication needs, the tailoring activity can be made more efficient, reducing communication errors, which is not possible using a purely automated approach which solely focuses on the “production” of a project-specific process and does not integrate relevant stakeholders.

## 6 Summary and future work

This paper presents an analysis framework to quantify the structural characteristics of tailoring decisions and relevant PDP properties using selected structural metrics. This allows to support the design and execution of workshop-based tailoring by identifying communication needs among tailoring stakeholders and providing decision makers with relevant, condensed information regarding the complexity of individual tailoring decisions. Tailoring workshops then allow a collaborative approach for adapting PDPs. A software demonstrator has been implemented and tested, showing the successful automated generation of user-specific reports. In addition, the initial success evaluation indicates that the analysis results create added value for workshop-based tailoring. Nevertheless, points of criticism and limitations exist, which create room for improvement. A first step of future work is the end-to-end application of the design support including the analysis framework in industry. This may require adapting the selected structural metrics and refining the formula for calculating communication requirements. However, more empirical data regarding workshop-based tailoring is necessary in order to test and compare further structural metrics and algorithms. In further steps, a training concept is required, as is a more interactive software support.

## References


Bender, B. & Gericke, K. (2016). Entwicklungsprozesse. In U. Lindemann (Hrsg.), Handbuch Produktentwicklung (S. 401-424). München: Hanser.

Blessing, L. T. & Chakrabarti, A. (2009). DRM, a Design Research Methodology. London: Springer London.

Brandes, U. (2001). A faster algorithm for betweenness centrality. Journal of mathematical sociology, 25(2).

Browning, T. R. & Ramasesh, R. V. (2007). A Survey of Activity Network-Based Process Models for Managing Product Development Projects. Production and operations management, 16(2), 217-240.

Costache, D., Kalus, G. & Kuhrmann, M. (2011). Design and Validation of Feature-based Process Model Tailoring - A Sample Implementation of PDE. Proceedings of the 19th ACM SIGSOFT < and the 13th European conference on Foundations of software engineering, 464-467.

Freeman, L. C. (1977). A set of measures of centrality based on betweenness. Sociometry, 35-41.

Ginsberg, M. P. & Quinn, L. H. (1995). Process Tailoring and the Software Capability Maturity Model. Advance online publication. https://doi.org/10.21236/ADA302689

Heimberger, N. (2017). Strukturbasierte Koordinationsplanung in komplexen Entwicklungsprojekten. Dissertation. Technische Universität München.

Hollauer, C., Langner, M. & Lindemann, U. (2018). Supporting Tailoring of Complex Product Development Processes: An Approach Based On Structural Modelling and Analysis. INTERNATIONAL DESIGN CONFERENCE - DESIGN 2018 -

Hurtado Alegría, J. A., Bastarrica, M. C., Quispe, A. & Ochoa, S. F. (2014). MDE- based process tailoring strategy. Journal of Software: Evolution and Process, 26(4), 386-403.

ISO/IEC TR 24748-1, 2010. Systems and software engineering -- Life cycle management -- Part 1: Guidelines for life cycle management. International Organization for Standardization.

Kalus, G. (2013). Projektspezifische Anpassung von Vorgehensmodellen: Feature-basiertes Tailoring. Dissertation. Technische Universität München.

Kreimeyer, M. F. (2009). A Structural Measurement System for Engineering Design Processes. Dissertation. Technische Universität München.

Lindemann, U., Maurer, M. & Braun, T. (2009). Structural Complexity Management: An Approach for the Field of Product Design. Berlin, Heidelberg: Springer Berlin Heidelberg.

Martinez-Ruiz, T., Munch, J., Garcia, F. & Piattini, M. (2012). Requirements and constructors for tailoring software processes: a systematic literature review. In: Software Quality Journa (20), pp. 229–260. DOI: 10.1007/s11219-011-9147-6.

Muyun, S. (2017). The Relation between Organizational Network Distance and Knowledge Transfer Based on Social Network Analysis Method. International Journal of Emerging Technologies in Learning (iJET), 12(6), 171-177.

Park, S., Na, H. & Sugumaran, V. (2006). A semi-automated filtering technique for software process tailoring using neural network. Expert Systems with Applications, 30(2), 179-189.

Pedreira, O., Piattini, M., Luaces, M. R. & Brisaboa, N. R. (2007). A Systematic Review of Software Process Tailoring. ACM SIGSOFT Software Engineering Notes, 32(3), 1-6.


**Contact: C. Hollauer,** Technical University of Munich, Laboratory for Product Development and Lightweight Design, Boltzmannstraße 15, 85748 Garching bei München, Germany, +49 89/28915136, +49 89/28915144, christoph.hollauer@tum.de