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SFB 768

ZYKLENMANAGEMENT AKTUELL
INNOVATIONEN GESTALTEN

Greetings

Dear readers,

the Collaborative Research Center 768 "Managing Cylces in Innovation Processes – Integrated Development of Product -Service Systems Based on Technical Products" (in German: SFB 768) is coming to an end this year after 12 years of research.

On behalf of all employees who have put their heart and soul into this project over the past 12 years, I am pleased to announce this newsletter.

The topic of SFB 768 is getting more relevant than ever. Agility in processes and organizational forms is currently one of the most dominant topics in management literature, on which SFB 768 has been working for 12 years under the name of "cycle management". This call for agility is reinforced by the impact that rapid digitalization and the Internet of Things have on the business models of manufacturing companies - the essence of working on "bundles of services based on technical products".

Against this background, I am delighted to be able to refer to the project results for industrial practice, which are examined in more detail in this newsletter. In this issue, you will find an overview of the **SFB Congress Innovation360°** - a transfer event for practitioners - which took place on 17-18 September in Sindelfingen. The transfer of results is also the focus of the "**Gestaltenplattform**" (innovations.sfb768.de), as well as the industrial guidelines developed in the context of transfer projects, which are presented in this newsletter. Also, discovering how **Soley, a start-up that** emerged from SFB 768, helps manage product and portfolio complexity.

The last newsletter of the SFB 768 has prepared for you interesting contributions to the topics:

- **Congress Innovation 360°in Sindelfingen**
- **Start-up Soley**
- **Consistent design of the PSS**
- **Integration of user knowledge**
- **Handling change cycles in product development and production**

and much more!

Take a look behind the scenes of the 12-year research of the SFB 768!

I hope you enjoy reading this newsletter and look forward to exploring the opportunities arising from the industry-academic collaboration on the topics of agility and digitization.

Sincerely,

Stefan Langer

Dr.-Ing. Stefan Langer,
Head of Digital Solutions - Corporate Technology and Innovation,
BSH Hausgeräte GmbH

Innovation 360° Congress in Sindelfingen impressively demonstrates the theory and best practices in innovation management

The need for a new era of collaborative innovation management goes hand in hand with the issues surrounding industry 4.0, digitally networked machines, and modern business models. The Collaborative Research Centre 768 (SFB 768) of the Technical University Munich (TUM) and the Ludwig-Maximilians-University (LMU) focuses on the optimal design and handling of innovation processes under consideration of cyclical influencing factors. After 12 years of research, the SFB 768 organized its final colloquium in the form of the 360° Innovation Congress. Forty project participants of the SFB 768 presented their results to numerous participants from industry and science.

Johann Wiesböck,
Dr. Daria Ryashentseva

The significance and scope of software development in automation and in mechanical and plant engineering are continually increasing. At the same time, it is essential to ensure the innovative strength and practicability of the Original Equipment Manufacturer (OEM) and industrial production in general. Mature development processes and methods must be established to ensure short development times and long-term competitiveness.

Knowledge management, change management, inconsistency management, stakeholder integration, and information modeling were the topics of the Innovation 360° congress of the SFB 768, which took place parallel to the ASE congress.

The TUM and LMU put together a competitive field of speakers from industry and research who passed on their knowledge in a practice-oriented manner. On 17 and 18 September 2019, the speakers presented their findings on innovation management (see Fig. 1, 2 and 3).

The aim of the Innovation 360° congress in Sindelfingen was to create an interactive and practical forum for the further development of cyclic innovation management in complex systems. The congress offered around 150 participants from industry and science a platform for the exchange of innovative concepts, ideas, applications and experiences. A particular focus was on networking the various domains such as mechanical engineering, systems engineering, automation engineering, control engineering, technology management, economics, psychology as well as product development and production engineering.

Professor Birgit Vogel-Heuser, the speaker of the SFB 768, gave two keynotes on "Technological Innovations" and "Forever Young Software." We want to share a quote that was particularly well received with our readers: "In the development of automated production systems

Figure 1: Participants of the seminar "Knowledge Management - Using knowledge agilely for innovations" (Source: VCG)

Figure 2: Keynote by Prof. Vogel-Heuser on technological innovation management (Source: VCG)

(aPS), the increasing demand from customers for individualized mass products and the associated demand for more flexibility and convertibility in the production process not only has an influence on the hardware used but above all on the corresponding control software. According to current studies, however, despite many known disadvantages, unplanned reuse strategies such as "Copy, Paste and Modify" are still the most frequently used methods in the control development of new aPS.

Professor Vogel-Heuser gave an overview of the conception, implementation, reuse, documentation, maintenance, and evolution of modular control software. In her second keynote, she spoke about the right choice of technological innovations, taking into account the relationship between change and stability. The focus here was on current challenges and approaches to solutions from research in innovation management.

More information on the Innovation 360° and ASE congresses can be found on the Elektronikpraxis website: www.elektronikpraxis.vogel.de or on the Innovation 360° website: www.innovation360grad.de.

The SFB members would like to thank all participants and sponsors of the congress!

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Figure 3: Organizers and speakers of the Innovation360° congress (source: VCG; from left to right: Prof. Birgit Vogel-Heuser (TUM), Minjie Zou (TUM), Dr. Daria Ryashentseva (TUM), Prof. Oliver Mayer (Bayern Innovativ GmbH), Siegfried Weigert (ibw Siegfried Weigert Industrieberatung), Huaxia Li (TUM), Prof. Manuel Wimmer (JKU Linz) and Sabine Wolny (JKU Linz)).

Soley solutions already successfully in use at Krones, Festo, MAN, Brückner, ZF and Bosch Rexroth

Soley, the Munich-based scale-up specializing in product portfolio optimization is making the long-established company Viessmann fit for its future markets. As one of the leading international manufacturers of energy systems, Viessmann cleans up and optimizes its product portfolio with Soley and uses the resources released in the process specifically for innovation and sustainable growth. With the help of the software solution, Viessmann increased its product phase-out by around 25-30 percent within a short period of time, thus consistently and efficiently separating itself from products that were no longer in demand and opening up an annual savings potential in the seven-digit range.

Soley's software solutions enable industrial companies to digitize complex product management processes and optimize their complex product portfolios in the shortest possible time. Soley considers relevant interdependencies between customer orders, products, components, and suppliers to ensure total visibility. With Soley, companies eliminate margin eaters, cost drivers, redundancies, and legacy issues across their entire product portfolio. This reduces complexity, lowers costs and frees resources for innovation and growth along the entire value chain. Founded in 2015, Soley GmbH digitizes expert knowledge and methods for data-based complexity management and uses them to develop powerful apps - for faster, better and more transparent decisions. This increases the efficiency of product management many times over and realizes annual savings potentials in the millions.

Dr. Markus Klausner, CTO of Viessmann Heizungssysteme GmbH: "Viessmann is changing from a classic heating manufacturer to a provider of seamlessly integrated climate solutions. Due to the associated higher complexity in the product range, the topic of product discontinuation is becoming more and more important. Soley shows the economics of the product, including the accessories, and helps us determine whether it still makes economic sense or whether we are phasing it out." Data-supported portfolio cleansing reduces internal effort. Soley provides the necessary transparency and supports the complex decision-making process. Where employees used to collect data of all kinds - e.g. piece lists, inventories, sales figures, usage records - for several days, Soley now links this data to a digital image of the entire product range in no time at all. Once Soley has identified successful and unprofitable products, those responsible evaluate products and components in the digital decision-making process based on shared data and decide whether to continue or discontinue them. This enables decisions to be made about the product life cycle at a completely new speed and quality. Soley co-founder and Managing Director Dr.-Ing. Maximilian Kissel: "Soley acts

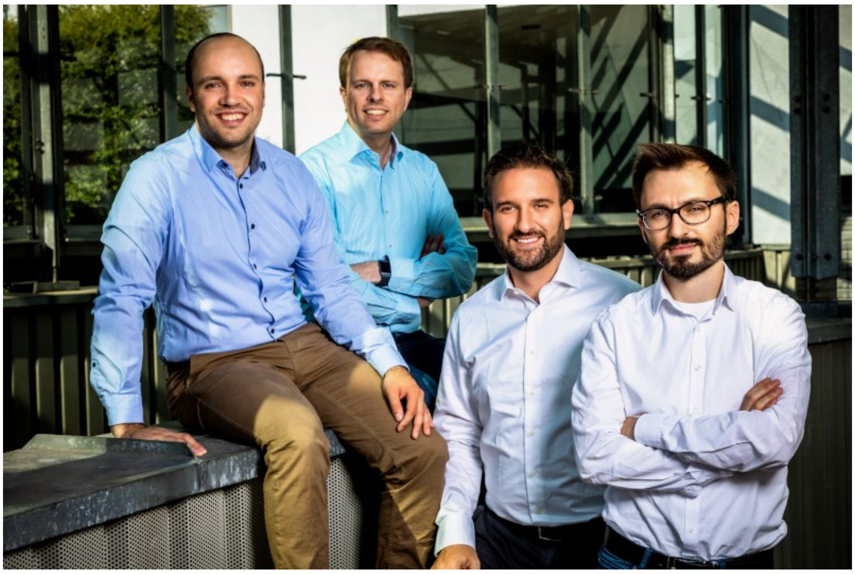

Figure 4: Soley founders: Peter Grüner, Bergen Helms, Maximilian Kissel, Alexander Golovatenko

like a fitness program for complex product portfolios: our solution quickly and systematically reduces unnecessary ballast at product and component level. We are thus sustainably strengthening the performance of our customers - with an enormous leverage effect for the entire value chain".

For Viessmann CTO Klausner, the cooperation with Soley has another significant advantage: "Soley is a great fit for us because it interacts seamlessly with other systems we have in-house. Soley is scalable, which means that this solution is applied to the entire Viessmann program. I'm happy that we chose Soley's solution because it significantly accelerates our decision making process for product phase-out and improves the decision-making process". Soley's approach is fast and effective at sustainably reducing costs, mobilizing tied-up working capital, and increasing profitability based on existing data. Soley supports industrial companies wherever the growing complexity of their product portfolio is slowing down operations in product management, purchasing, logistics, or production. Soley's various solutions are already being used by numerous renowned companies, including Krones, Festo (go.soley.io/festoStory), MAN, Brückner Maschinenbau, ZF and Bosch Rexroth.

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Integration of user knowledge into product-service systems

Users have been recognized by research and practice as a valuable source of innovation. The integration of user knowledge is particularly relevant for complex Product Service Systems (PSS) since their development and marketing requires both technical and increasingly use-related knowledge. For this reason, the researchers of the SFB 768 investigated how manufacturers of PSS can best benefit from user knowledge. The analyses focused, in particular, on the information flow between users and manufacturers and the design of user innovation communities.

Juliane Wissel,
Ertug Olcay

"User Innovation" focuses on the user as an active contributor to the PSS innovation process. The basic idea is that users, e.g., individuals or companies, develop innovations for their use rather than for sale. Manufacturers and users differ in their knowledge. While producers can primarily demonstrate technical knowledge, which is systematically built up through research and development, users possess *usage-based* knowledge that results primarily from the user's own experience.

The design of the information exchange focused on user-manufacturer interactions. The reciprocal flow of information across company boundaries enables users and manufacturers to learn from each other. The continuous exchange of information between manufacturers and users is a highly dynamic and complicated process that presents companies with different challenges. In order to enable companies to design their user-manufacturer interaction effectively, the SFB 768 focused on investigating and design of the interface between innovative users and PSS manufacturers and developing levers for better management of the integration of user knowledge into the PSS innovation process.

Looking at the information flows from users to manufacturers, it was a critical finding that user knowledge is primarily relevant in the early development and later use-related phases of the

PSS innovation process. In addition, the integration of user knowledge is of great importance, especially for the development of services. Looking at the information flows from PSS manufacturers to users, it was noticeable that the value of PSS for customers can be significantly increased through targeted adaptation to their wishes.

Besides, PSS manufacturers can use information and feedbacks to guide users in a purposeful manner, thereby influence their purchasing decisions. A decisive factor for fruitful interaction between manufacturers and users is the mutual learning and mutual building of Open Innovation skills, especially by enabling their own employees to identify, evaluate, and better integrate external user knowledge.

The design of the dynamics of socio-technical systems dealt with the modeling and analysis of socio-technical systems, as well as the existing design of cycles within socio-technical and social systems. The innovation process served as a basis and motivation, which consists of both technical and social components. The starting point of the project was the User Innovation Communities.

Novel methods were developed to model the complex temporal behavior (dynamics) of the cycles occurring in the innovation process of product-service systems (e.g., the product life cycle).

Reasonable design and modeling of dynamics are essential in order to master the complexity of such interdisciplinary systems and to be able to design them purposefully. At this point, some existing classical modelling methods are utilized, e.g., system dynamics, to depict the cyclical behavior of a company. A three-stage modeling approach for quantitative data of the innovation process of PSS was developed, which contains both technical (e.g., production) and social processes (e.g., customers or employees in the company).

Communities have complex internal dynamics, which should be considered in their design. Through a combination of methods of machine learning and fuzzy modeling in modeling, both known functional and qualitative relationships within the socio-technical systems, as well as existing time histories, were taken into account.

In the social sciences, complex systems consist of several entities interacting with each other and also with their environment. In comparison to traditional approaches, such as a modeling with differential equations, agent-based modeling technique allows to represent the heterogeneity of a system and the interactions between the entities explicitly. Thus, it makes a transparent consideration of both micro levels (agent level) and macro levels (e.g., social changes) possible.

Agents are separate system parts that represent interacting actors, such as individuals, organizations, or companies. They can transmit information to each other. Agent-based modeling method is to map the interactions between agents and between agents and their environment over time.

The findings and technical expertise from the design of the dynamics of socio-technical systems helped for the cooperation with the design of user innovation communities. In these communities, users present their ideas to each other, share experience and answer questions. Companies can use such communities as a source of innovative ideas and thus achieve a higher acceptance of the PSS on the sales market. The design of user innovation communities involves with the performance increase and time optimization (higher quality and quantity of ideas generated in the communities).

This means that the cycles in which communities generate innovative ideas should be controllable. User innovation communities are usually characterized by a high degree of self-organization, but can also be influenced from outside.

The combination between the dynamics of socio-technical systems and the User Innovation Communities aimed at investigation the design and control of User Innovation Communities using an agent-based simulation model.

In addition to the technical expertise in design of the dynamics of socio-technical systems, the results from the design of user innovation communities served as a basis for the division of labor between users and manufacturers. A key finding was that manufacturers tend to develop product innovations, whereas users tend to process innovations. This allows the external innovation cycle (of the communities) to be synchronized with the internal innovation cycle (of the PSS manufacturers).

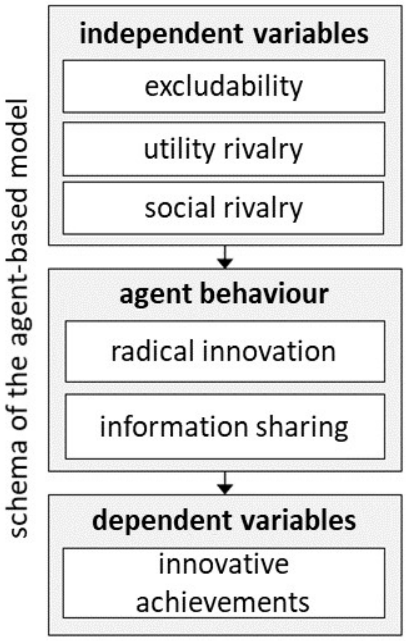

Figure 5: Schema of the agent-based model

The results were covered by an agent-based simulation model (see Fig. 5), with the help of which essential insights for the optimal design of user innovation communities could be gained.

The utility rivalry can increase the radicality of innovations. In addition, social rivalry promotes the diffusion and radicality of innovation. These findings open up implications for PSS manufacturers on how they can best shape and influence user innovation communities to use them as a valuable source of innovative ideas.

The findings expand the understanding of "user innovation" and underlined the need to integrate the need for the integration of user knowledge into the PSS innovation process in order to achieve successful user-manufacturer interaction.

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Consistent design of mechatronic PSS

Supporting decision making in the early phases of the PSS innovation process in industrial production automation is essential. The impact of decisions taken early in the innovation process can often only be assessed much later, leading to potentially costly changes. The integration of the various disciplines involved is, therefore, useful for identifying and eliminating errors and inconsistencies at an early stage. As a result, unnecessary iterations can be avoided, saving time and money during consistent design.

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The development of product-service systems is characterized by increasing integration of various disciplines involved, such as mechanics, electrical engineering/electronics (E/E), and software. Due to the different frequencies of innovation cycles of the respective disciplines and the implicit cyclic dependencies between these disciplines, the development of PSS is highly complex. An example of this is the component change of mechatronic modules in mechanical and plant engineering. While mechanical parts of a mechatronic component have operating times of up to 50 years, the sensors and actuators (E/E) of the components are changed several times during this period. Software changes are made much more frequently.

Current research reports show that interface specifications between the disciplines involved are often missing or have not been developed uniformly. Consequently, changes to components and the overall system cannot be recorded and handled systematically and holistically. The effects of changes can only be predicted with insufficient accuracy, and troubleshooting is correspondingly complex.

In order to meet these challenges, an interdisciplinary system modeling process and workflow were developed (see Fig. 6) based on the basic idea of Model-Based Systems Engineering (MBSE). The central element is the inter-disciplinary modeling approach, SysML4Mechatronics. It maps the interdisciplinary dependencies (mechanics, electrics/electronics, and software) of an overall system.

In order to manage product-related data such as models, documents and even the entire life cycle of production systems, the approach developed is based on PLM software that acts in the background as the central data management software. In order to facilitate the exchange of information in the industrial environment between the disciplines, a standardized data exchange format was used. AutomationML (AML) is a neutral data format for the storage and exchange of plant-specific information. In applied research and the industrial environment, AML is enjoying increasing popularity and acceptance.

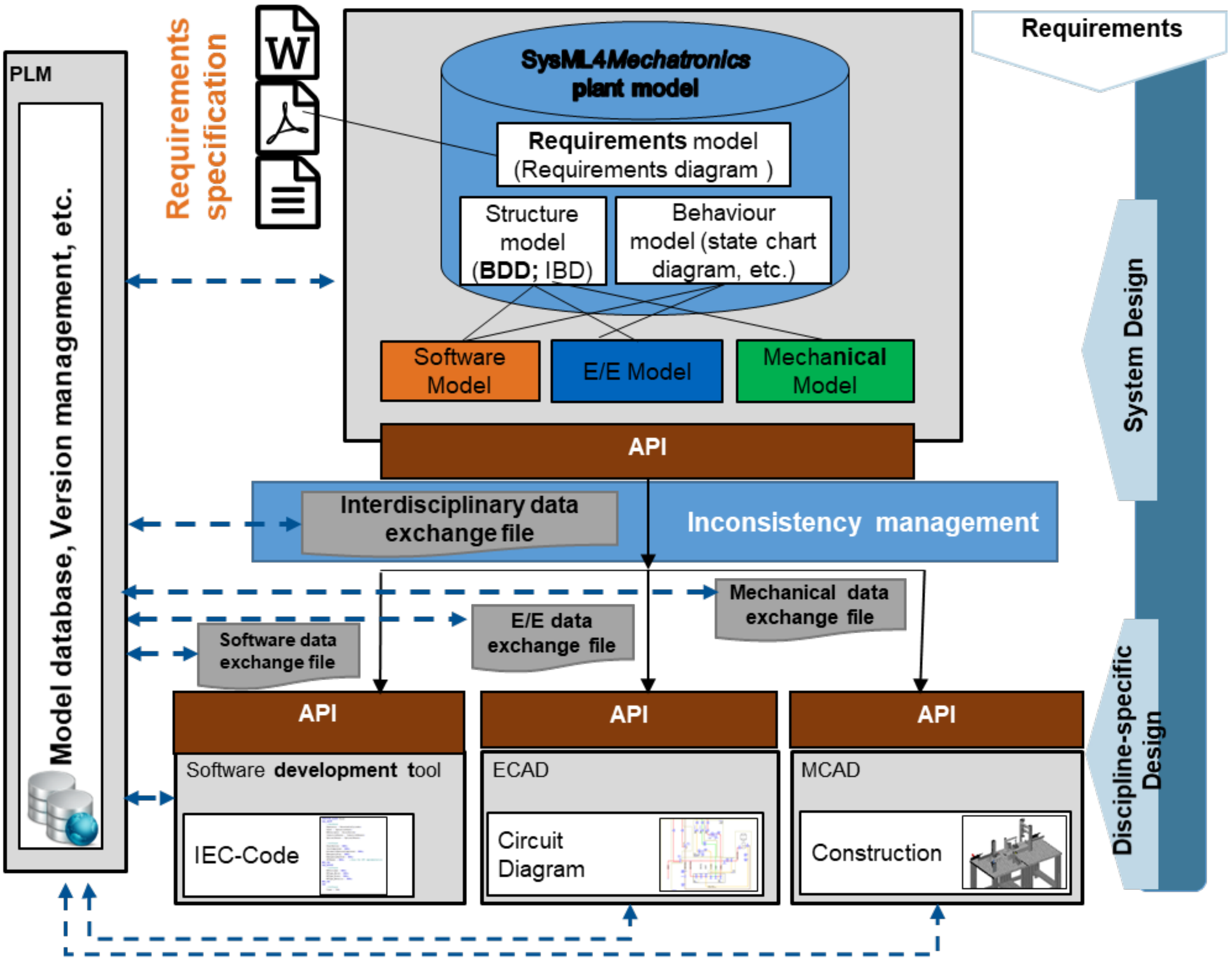

Figure 6: Interdisciplinary system modeling process and workflow based on SysML4Mechatronics and AutomationML

In order to present the applicability of this approach in mechanical and plant engineering, five application cases were derived in cooperation with two industrial partners. These applications are based on an industrial development environment and were demonstrated using the example of a prototype production plant. The results meet the requirements identified for the industrial development process: This includes requirements for interdisciplinary modeling, comprehensibility of system modeling, reusability of modeling components, the coupling of different engineering models and inconsistency management.

Modern production systems also have to meet high demands in terms of flexibility and efficiency. However, this leads to an increasing system complexity, which is attempted to handle with the help of different models. The heterogeneity of the models is another primary driver of complexity in the PSS innovation process. Models are characterized by various formalisms and levels of abstraction, each of which has been developed for specific disciplines. However, a representation of the same information in different models implies semantic dependencies. This forms the basis for interdisciplinary inconsistencies, which in the event of changes, can lead to costly errors in the overall system.

An integrated framework allows not only to recognize different types of inconsistencies but also to process and evaluate them accordingly. The framework developed (see Fig. 7) is geared precisely to the requirements of PSS development and maps the work processes in close cooperation between teams and disciplines. First, the general types of inconsistencies that may occur during PSS development were investigated. A five-step procedure was then introduced to allow practitioners from different teams to systematically search for inconsistencies between their models. Besides, various influencing factors for the realization of such a systematic approach were identified.

With regard to the existing situa-

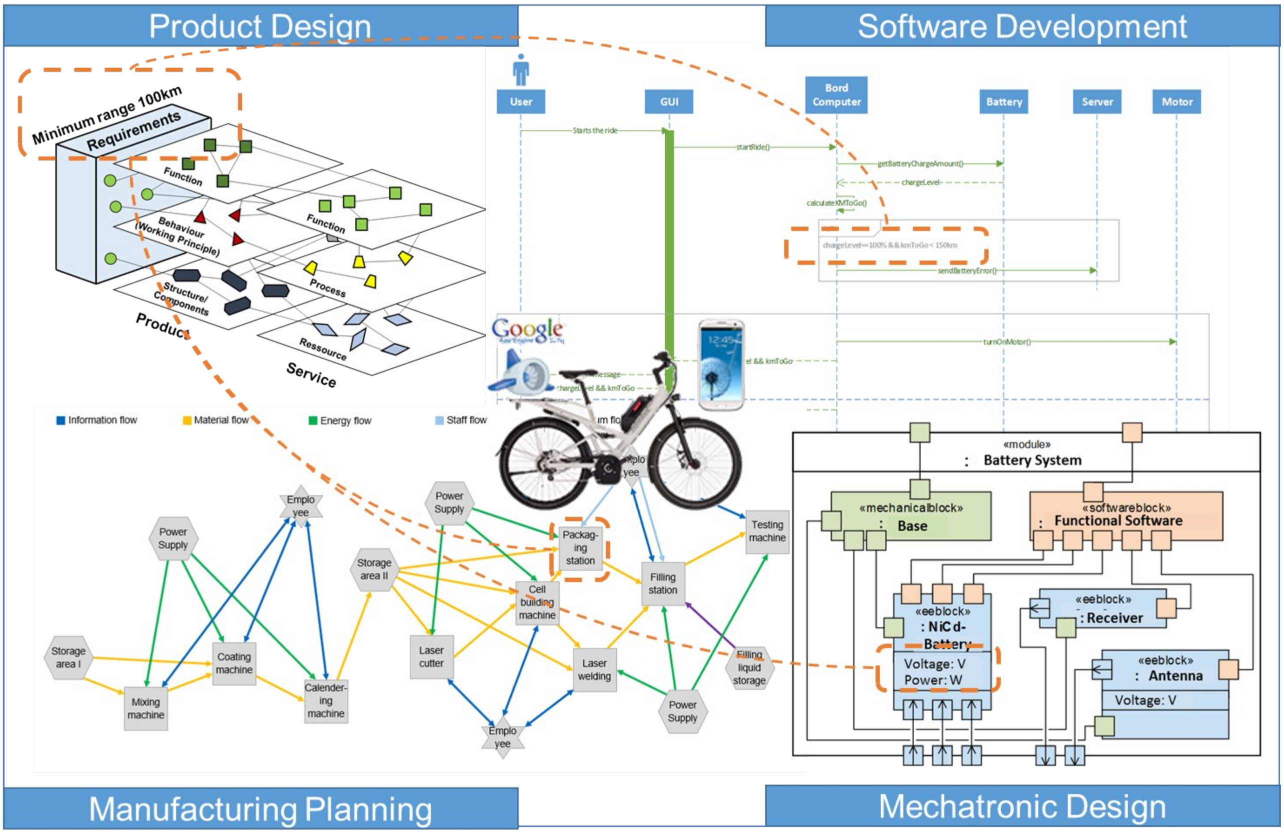

Figure 7: Systematic Framework for Inconsistency Management in a Heterogeneous Model Landscape

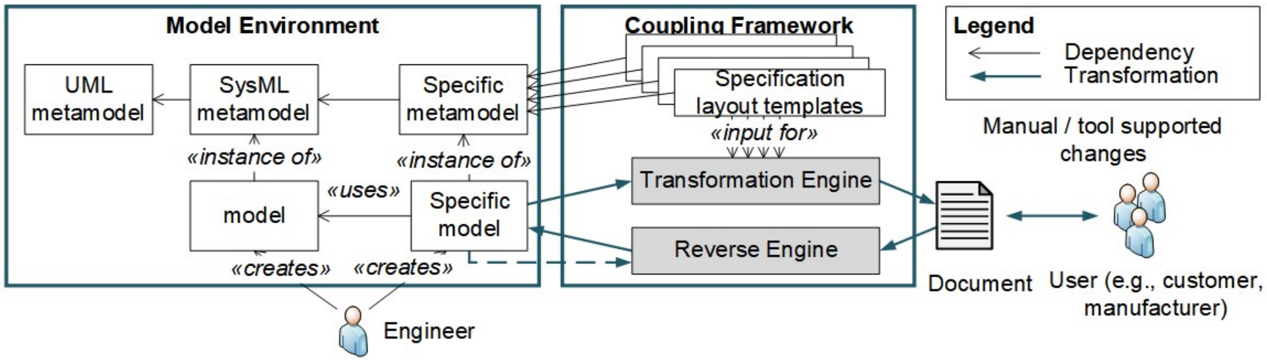

Figure 8: Bidirectional coupling approach for models and documents of the entire life cycle

tion in which inconsistencies may occur, the degree of formality, the degree of criticality, and the nature of the inconsistencies are vital factors. The same solution cannot be applied to situations where these factors are different. For example, the same inconsistency identification solutions cannot be used for formal models, such as mathematical models for simulations, and informal models of requirement specifications that contain natural language.

The developed framework was verified for different models: Requirements management and business models, product models, models of the manufacturing system, system dynamics simulation models, and mechatronic design models. Besides, the workflow was validated in an industrial environment. It was found that industrial inconsistency management prefers manual solutions in order to be able to carry out process interventions at any time. On the other hand, so-called syntax inconsistencies (e.g., naming conventions) also accumulate, which should be handled automatically in order to save time. After these initial validation attempts, the framework was adapted and extended accordingly.

The efforts in system development to move from an exclusively document-driven working style to a model-driven approach were proclaimed in particular by the Model-Based Systems Engineering approach. Numerous methods and approaches have been developed to support a model-driven approach in mechatronics, including the interdisciplinary modeling language SysML4Mecha-tronics. Nevertheless, the industrial environment of mechanical and plant engineering is characterized by a model- and document-driven approach: Partly, these models and documents (information carriers) evolve parallel, partly they are transferred into each other by the transformation. While companies increasingly develop and use integrated, interdisciplinary models in the early phases of the life cycle (i.e., development), documents are mainly used in the late phases (i.e., commissioning, maintenance and operation). These documents are often printed out, whereby the structure of a document that can be interpreted by machines is lost. During the usage phase, there are often changes to the mechatronic system, which results in changes to the documents. Although these document changes are understandable for humans, they have no structure concerning machine-interpretable document structure and automated further processing. Consequently, it is considerably more challenging to return to the models of the development phase when, for example, a change occurs. Classical inconsistency management and other coupling approaches can only be applied to a limited extent.

In order to couple models and documents, a bidirectional coupling approach was developed (see Fig. 8). In this case, models are regarded as the central information representation, while documents only represent the redundant information carrier. Consequently, these documents can be generated automatically from the models. The developed coupling approach uses model-driven techniques and templates for this purpose. Here, the templates access the corresponding meta-information in models in order to fill the documents with corresponding model information at the beginning of the usage phase and finally generate the document. The methodology was tested in various representative industrial cases (e.g., generation of specifications from requirement models).

Actors do not always want to let or want to adapt to the original model. The developed coupling approach combines algorithms of image processing with standardized modeling techniques, whereby first structureless information (e.g., handwritten notes) is identified and then stored in a structured model. The concept was successfully tested using the example of modified circuit diagrams in electrical engineering.

SFB members are always interested in transferring the developed methods into industrial practice or in supporting new partners in a constructive and advisory way in similar challenges. We look forward to hearing from you, even beyond the duration of the SFB 768.

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Networking of heterogeneous actors in innovation networks

In the innovation processes of product-service systems (PSS), the question of how organizations can coordinate and shape the cooperation of heterogeneous actors in a targeted manner is gaining in importance. This article presents three packages of measures that support the successful networking and cooperation of heterogeneous actors in innovation processes: First, measures that support teams and networked actors to successfully deal with the complexity and dynamics of PSS innovation and share knowledge; second, measures that support organizations in developing organizational learning; third, measures that reveal and graphically illustrate relationships and dependencies of actors in innovation processes.

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Dr. Julia Reif,
Dr. Katharina Kugler,
Prof. Dr. Felix Brodbeck

Designing cycle management of teams and networks

The complexity and dynamics of PSS innovations require cross-disciplinary and cross-functional cooperation between individuals in various teams and network structures. The actors, who often work together in team structures, have to cope with recurring (cyclical) changes and events. If teams and networked actors perceive recurring events and processes as cyclical, they can actively and successfully shape them in the future. Against this background, the SFB 768 was concerned with the question of how teams and networked actors manage to deal with the high complexity and dynamics of PSS innovations. The focus was on developing and improving the cycle management of teams and networked actors.

A psychological model of effective cycle management was developed for this purpose (see Fig. 9), which describes how individuals and teams successfully manage cycles through (a) anticipation and design of cycles, (b) adaptation to cycles, and (c) standardization of new work processes, thereby increasing their innovative power [Rei15a, Rei15b]. Besides, the model considers that leadership, cognitive and emotional states of the team, such as shared mental models of temporal coordination and transactive memory systems, support the successful handling of cycles and innovation.

Based on this model, the SFB 768 developed different, practically applicable approaches to organizational development for the design and optimization of cycle management. This includes, for example, an innovation training that helps teams to improve phases of idea generation and implementation in the course of innovation work [Fel17].

In addition, questionnaire scales were developed for the psychometric assessment of team adaptation in teams [Geo18] and the quality of process standardization [Rei17]. Another essential feature of successful cycle management is the active social organization of the heterogeneous knowledge network of actors from different teams. Therefore, further questionnaire scales were developed for the assessment of knowledge sharing between teams [Gam16] and a model for socio-technical knowledge management for the context of PSS innovations [Gam19]. Researchers and practitioners can use the instruments for diagnosis (i.e., identification of strengths and weaknesses or levers in the organization), intervention design (i.e., active design based on the diagnosis), and evaluation of intervention success (i.e., evaluation of the intervention). If teams and networked actors thereby learn to anticipate future events and processes, proactively adapt their behavior accordingly, standardize new behaviors in new work processes, and develop shared understanding of the collective knowledge organization and temporal processes in the network of actors, innovative strength can increase.

Support organizational learning

The ability of companies to create lasting and targeted changes is referred to as institutional reflexivity. The term describes a principle of organizational learning and aims to develop organizational rules and practices that enable companies to systematically question routines, start interventions and productively use the resulting tensions [Mol07]. Institutional reflexivity thus also aims to ensure that companies acquire new knowledge, adapt it and expand it.

Since concrete forms of institutional reflexivity may differ in practice, a central concern of SFB 768 was to identify suitable forms of institutional reflexivity. First of all, it can be stated that institutional reflexivity can refer to different objects of organizational action, such as the development of organizational knowledge or specific organizational fields of action, such as innovation, product development, or working methods. Institutional reflexivity always asks how something can be changed and made the object of permanent and targeted change measures. However, a systematic renewal of knowledge management, for example, requires measures other than the learning of new ways of working. Furthermore, how the durability of a change process is established

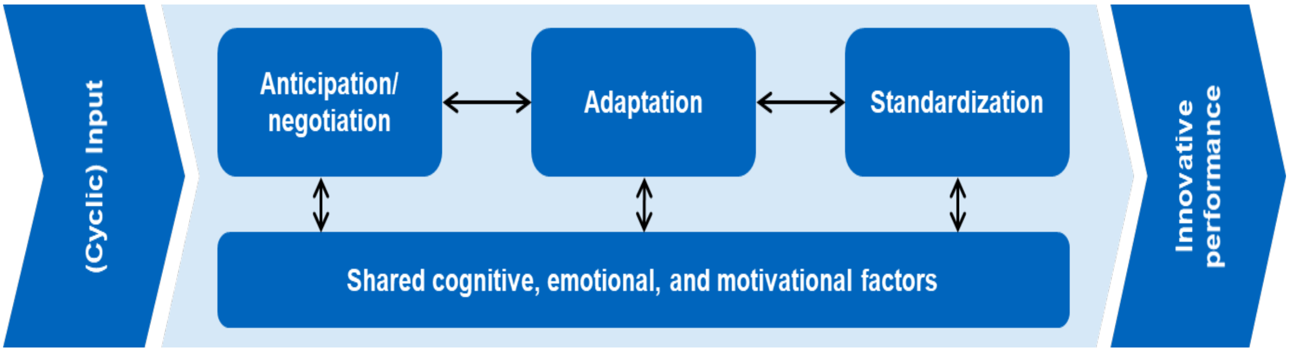

Figure 9: Model of effective cycle management of teams (simplified)

can be differentiated. With a serial-discrete approach, concrete points in time have defined that trigger and accompany change processes. A continuous approach, on the other hand, relies on an ongoing dynamic of change. Finally, the conditions of implementation can be asked, which must be given for the use of specific instruments. Concrete projects may differ from certain individuals or groups in terms of their duration, effort and extent of involvement. The distinction between these dimensions should help to promote concrete measures to develop institutional reflexivity. An exemplary use case will now be used to show how institutional reflexivity can be promoted.

The use case presented here aimed to establish an open and incremental learning process for developing new ways of working. A European corporation with more than 10,000 employees is faced with the challenge of fundamentally reforming its working practices. Many regulations and practices no longer seem up to date. Many customers expect flexible and agile working methods. But a large proportion of employees also want changes and want to work more mobile. However, there are very different attitudes and views concerning the design of new regulations, which develop along different lines of conflict in the company. In order to proceed productively in this situation, it was decided to experiment with new working methods in a practice laboratory for a limited period. However, instead of setting precise targets, company teams can apply to participate in the experiment room and make suggestions on how they would like to work for a limited period. This allows each team to decide for itself on working time regulations, the choice of workplace and the use of collaboration software. Both employer and employee representatives sit on the steering committee. These lay down the basic rules of the procedure and guarantee continuous and accompanying evaluation. Approximately 200 employees participate in the test phase, which is divided into different project teams. In this phase, for example, technologies (e.g., apps for recording working hours) can be used that were previously not permitted. After the test phase of 12 months, a report is drawn up which provides comprehensive information on the opportunities and dangers of the deployment. This experimental open-ended approach illustrates how organizations can reflexively shape change processes.

Action-oriented interactive visualization of model dependencies

Particularly in the development of modern PSS, the communication and coordination effort within interdisciplinary teams is increasing, and the successful handling of such complex processes is becoming a decisive success factor. A big challenge is the different understanding of the individual actors about the different processes, based on their very individual requirements and their different views on the cyclical innovation processes. They have individual mental models of the innovation process based on their specific knowledge and experience. Also, the various disciples use their tools and terminologies as well as their specialized languages and models, with very different degrees of abstraction, to describe their processes. This leads to a complex heterogeneous model landscape with a multitude of discipline-specific models - e.g., requirement models, engineering models as well as analysis models, and much more. - With dependencies and overlaps among each other and information flows between the models. Within the innovation process, it is, therefore, all the more essential to create a shared understanding between the actors regarding the information flows and dependencies between the disciplines and their models. At this point, the SFB 768 attacks and offers an interactive cross-disciplinary visualization approach to reduce complexity, which also considers the individual task of the actor. However, the challenges in the implementation are (1) the identification of model dependencies to find the connections between the discipline-specific models and thus the information flows, (2) the implementation of an integrative interactive visualization approach to visualize these dependencies that is understandable for all actors involved, and (3) the evaluation using use cases.

Cross-disciplinary model dependencies are not anchored on an abstract level but are located on the level of detail between the models and above abstraction levels. Using semi-structured interviews, the actors or "model providers" were first asked about their understanding of the interaction of their model in the heterogeneous model environment and the dependencies were determined. In a further step, the model dependencies were extended and refined with the help of focus groups. Each focus group represented a use case and involved all stakeholders involved in this use case. The information obtained in this way is now the basis for the visualization approach (see Fig. 10).

The challenge in developing an interactive visualization in an interdisciplinary environment is to find a form of presentation that is easy for all participants to understand and which promotes a common understanding of the interdependencies represented across models. For this reason, we have chosen a graph-based approach [Pan19] because it contains only two model elements: Objects and their relationships with each other.

However, since industrial models, in particular, can contain thousands of model elements, mechanisms to improve understanding are imperative. Consequently, our visualization approach requires some information filtering, aggregation and/or abstraction.

In order to meet these requirements, all models involved and their dependencies were first presented on an abstract level in a so-called model network. Each object in this network represents a model within the innovation process and each relationship between objects represents a model dependency. Based on the theory of Shneidermann (Visual Information Seeking Mantra - overview, zoom, filtering, details on demand) the complexity can be reduced by filter mechanisms and thus the visualization can be adapted to

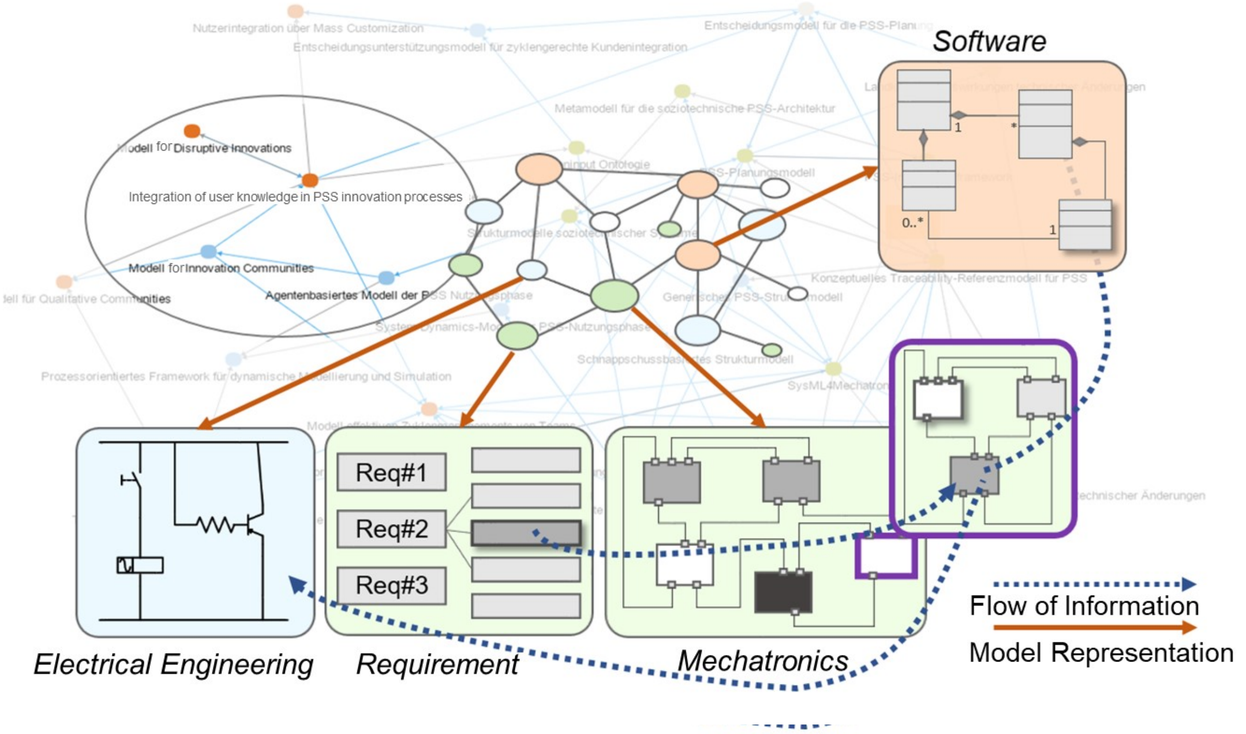

Figure 10: Model dependencies in the interdisciplinary innovation process

certain action objectives/use cases [Shn96]. The representation of the dependencies on the detail level was also realized by means of graph-based visualization. According to the *Focus+Context principle* [Car99] both views - abstract level and detail level - are displayed in a split window. The relationships presented in this visualization represent the information flows between the models involved and now increase the understanding of the relationships across model boundaries.

Bottom line

In order for organizations to successfully use cross-disciplinary and cross-functional collaboration of heterogeneous actors to generate innovation, aspects of cycle management need to be promoted at several levels: Individuals and teams of central importance, because they must first understand recurring events as cyclical and organize team states and processes accordingly cyclically; in addition, suitable organizational forms must be identified through which heterogeneous actors can be specifically linked in order to promote organizational learning processes. The principle of institutional reflexivity and concrete forms of practice, such as experimental spaces or learning factories, are suitable approaches for shaping innovation processes under dynamic conditions; in order for teams and organizations to better understand and shape the interaction of heterogeneous actors, relationships and dependencies must be made visible. Here graph-based visualization techniques can help.

In order to make cyclical innovation processes sustainable, it is essential to take these measures into account in their interaction. Further concrete measures are presented on the design platform of the SFB 768 (see Infobox).

References see http://innovations.sfb768.de/publications/

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Handling change cycles in product development and production

Cyclical influencing factors force companies to make regular changes to products and production systems. Due to the close networking of the disciplines, a local consideration of changes is not sufficient. A management approach is needed that reaches beyond departmental boundaries and disciplines. The systemic approach of the SFB 768 describes the framework for a successful implementation of holistic change management. Reference processes, analysis methods and innovation environments were designed and developed for this purpose.

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Felix Brandl,
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Christian Dengler

Change management is becoming an increasingly important discipline in the increasingly dynamic environment companies are exposed to. On the one hand, change management affects the dynamics of the organization, which must be structured in a targeted manner through pronounced organizational change management. On the other hand, the increasing dynamism is also noticeable in the development of technical products. As technology cycles - especially software components - become shorter and shorter, a planned and proactive management of changes to industrial products becomes indispensable. However, changes cannot

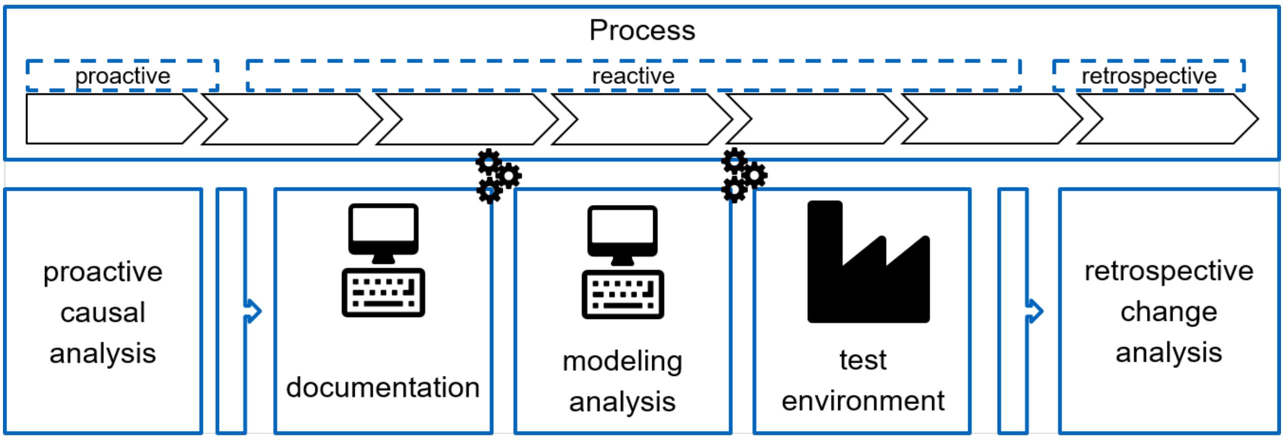


Figure 11: Holistic change management of the SFB 768

only be viewed locally but require a management approach that extends beyond departmental boundaries and domains.

For this reason, the SFB 768 developed holistic, systematic approaches to the design of changes both in product development and in production. This is referred to as a change as soon as a previously defined state, with which other participants continue to work, loses its validity due to innovation. Changes are also larger change projects, which in turn can consist of many small changes. Change management aims to enable rapid changes (see Fig. 11). This requires a proactive, a recitative and a retrospective view of changes. In the holistic change management of the SFB 768, the individual phases are guided through a collaborative process (see Fig. 12). In each phase, different analysis methods and tools are also used to enable effective and efficient handling of changes.

Reference Process of Systemic Change Management

A reference process for systemic change management was developed as a general framework for research and for classifying industry requirements and approaches. This describes the necessary process of change projects in product development and production. The interaction of the two is crucial for an efficient and effective implementation of change in parallel development.

Proactive cause analysis

Many changes do not occur immediately or unpredictably, but can be planned early with appropriate change management. The proactive root cause analy-

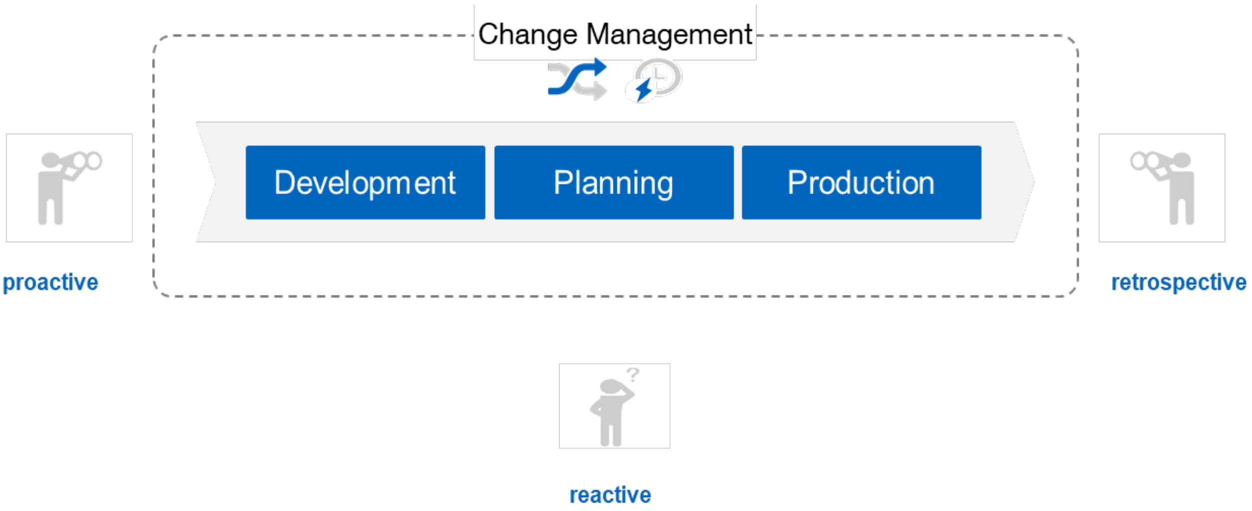


Figure 12: Phases of change management

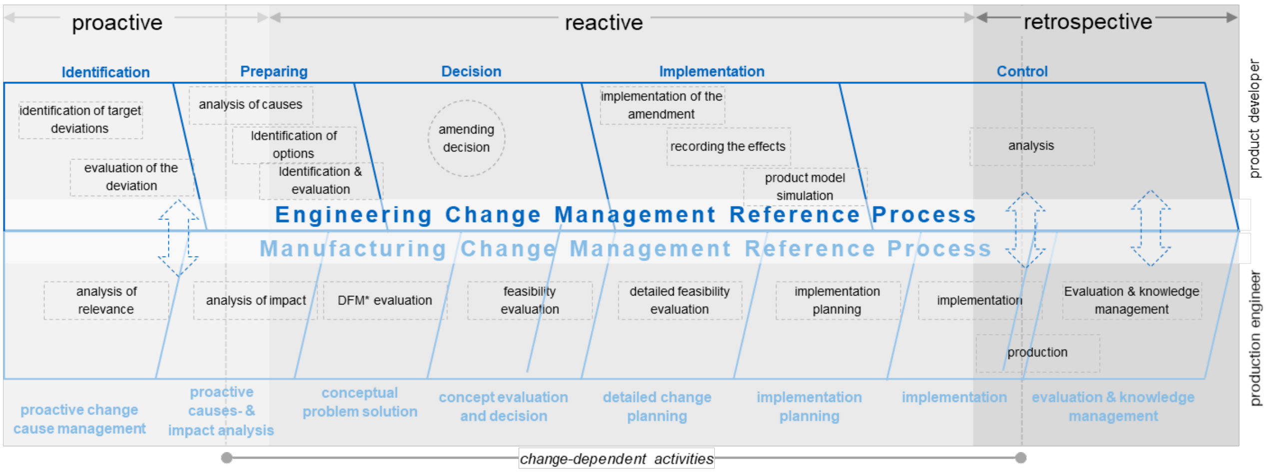


Figure 13: Reference Processes of Systemic Change Management

sis is concerned with investigating the causes of possible changes and determining the timing for making the change. For the proactive cause analysis prognoses must be provided. To this end, information from historical data and model knowledge must be used and integrated into a prediction model. The consideration of business dynamics as a network of interacting cycles represents an effective tool for this, since the temporal course of important company variables, each with distinctive characteristics within the cycle phases, is suitable as a forecasting model. The cycle progressions can also be identified as mathematical models based on historical data. Another useful tool for proactive root cause analysis is fuzzy sets, which can be used to consider fuzzy conditions or requirements in root cause analysis. Forecasts do not only contain uncertainties, but much information in the forecast model is challenging to determine precisely. Using fuzzy sets, ranges of values can be used instead of exact values, and probabilities and uncertainties can be coupled.

Analysis of change impacts

An expert workshop will be held to analyze the propagation of change. In this model, a graph-based model of the system to be considered is first created. Subsequently, the relevant edges are provided with a probability of propagation of the analysed change as well as best-case, worst-case and most-likely effects on costs as well as duration of the changes. The probability distribution of the change

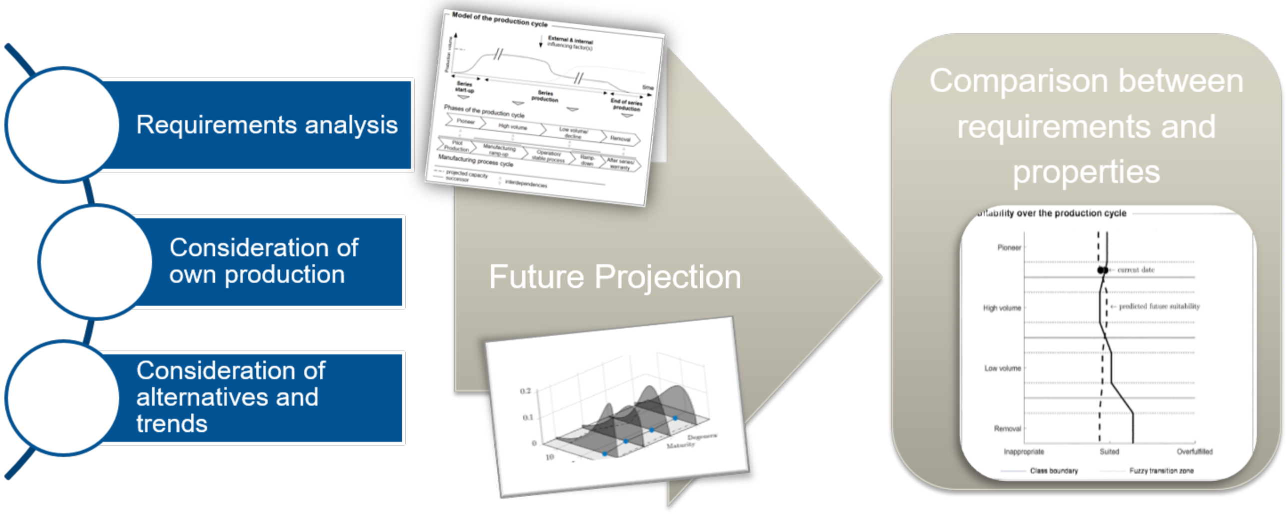


Figure 14: Proactive Cause Analysis-Example Production

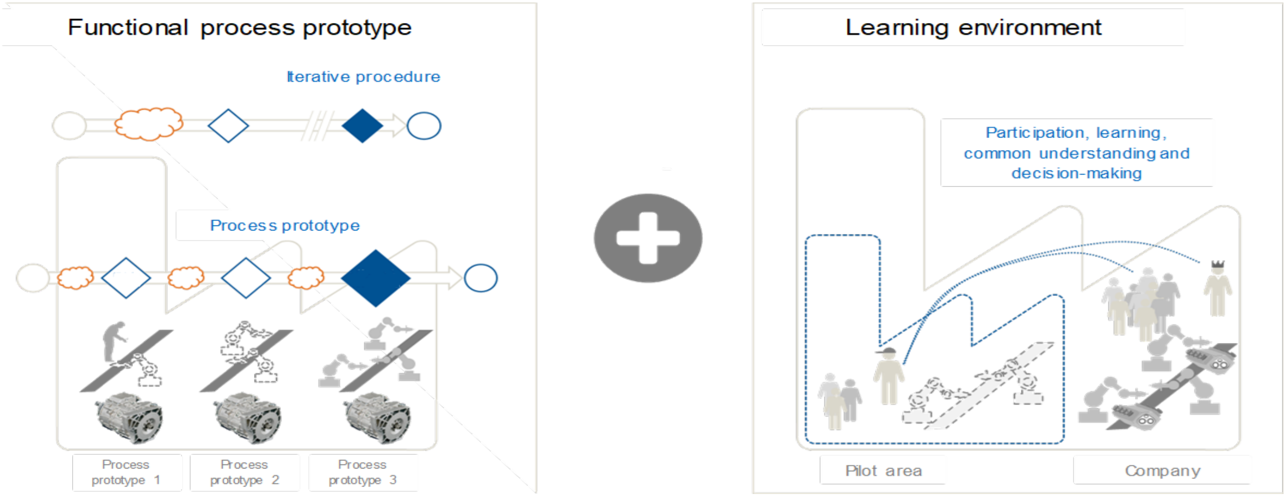
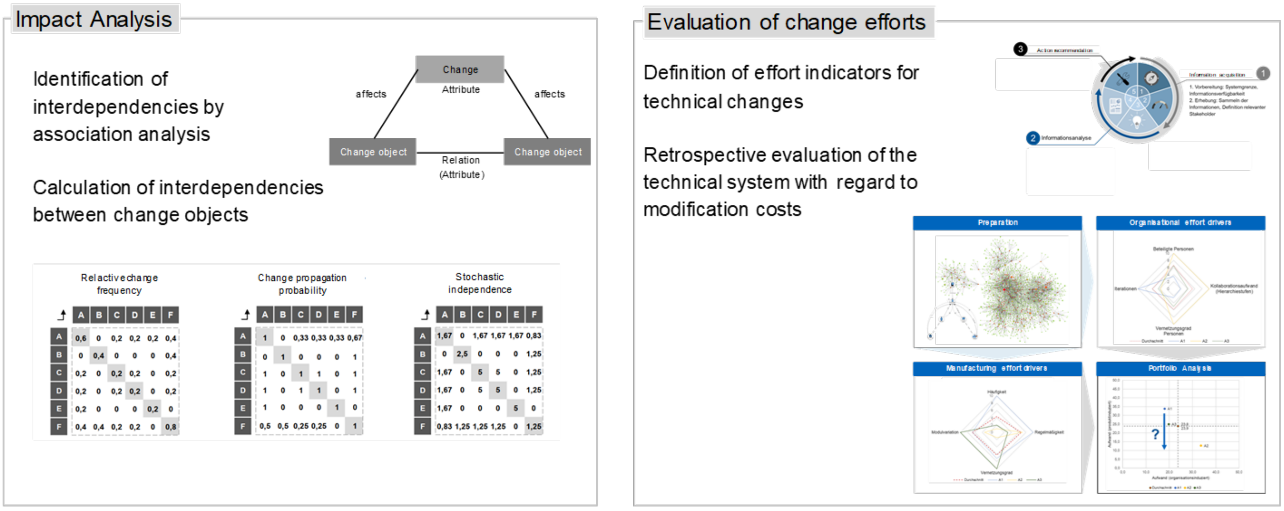


Figure 15: Test environment example production

effects is generated from this using a beta distribution. For the final simulation of the reproductive and impact effects, a combination of a Breadth-First search algorithm and a Monte-Carlo simulation is executed. The result of the analysis is probability distributions regarding the propagation of change as well as the cost and duration of the change. Based on this, it can be decided in the next step whether the change under consideration is to be carried out and which further steps are necessary.

Test environment for testing changes

The framework conditions for today's companies can increasingly be described by the terms volatility, uncertainty, complexity, and ambiguity. In this environment, the emerging challenges cannot be mastered with the classical methods that are intended to support project management. Instead, companies are called upon to increase their agility so that they remain competitive. This requires, among other things, innovation projects that are often associated with entrepreneurial change. The developed methodology describes a way for affected companies to better support and thus more effectively shape entrepreneurial change in the course of complex innovation projects. For this purpose, requirements are derived from practical experience, which has been recorded within the framework of industrial co-operation, and existing theoretical approaches are used to find solutions. The methodology represents the use of methods for



Identification of interdependencies by association analysis

Calculation of interdependencies between change objects

Relactive change frequency

↱	A	B	C	D	E	F
A	0,6	0	0,2	0,2	0,2	0,4
B	0	0,4	0	0	0	0,4
C	0,2	0	0,2	0,2	0	0,2
D	0,2	0	0,2	0,2	0	0,2
E	0,2	0	0	0	0,2	0
F	0,4	0,4	0,2	0,2	0	0,8

Change propagation probability

↱	A	B	C	D	E	F
A	1	0	0,33	0,33	0,33	0,67
B	0	1	0	0	0	1
C	1	0	1	1	0	1
D	1	0	1	1	0	1
E	1	0	0	0	1	0
F	0,5	0,5	0,25	0,25	0	1

Stochastic independence

↱	A	B	C	D	E	F
A	1,67	0	1,67	1,67	1,67	0,83
B	0	2,5	0	0	0	1,25
C	1,67	0	5	5	0	1,25
D	1,67	0	5	5	0	1,25
E	1,67	0	0	0	5	0
F	0,83	1,25	1,25	1,25	0	1,25

Definition of effort indicators for technical changes

Retrospective evaluation of the technical system with regard to modification costs

1. Vorbereitung: Systemgrenze, Informationsverfügbarkeit
2. Erhebung: Sammeln der Informationen, Definition relevanter Stakeholder

Figure 16: Retrospective use of change data

iterative problem solving that support the development of minimally functional prototypes through close customer relations (see Fig. 16). Besides, it describes the implementation and use of a highly variable learning environment in the form of a learning factory for this purpose. The methodology is based, among other things, on findings from expert interviews with project managers of complex innovation projects.

Retrospective use of change information

The retrospective phase of technical change management primarily addresses the gain of knowledge after the implementation of the change. The targeted evaluation of personal changes, as well as information about the entire change process, can point out the potential for improvement. Due to the increasing digitalization of companies, the retrospective evaluation of change data in the form of process documentation of individual changes offers excellent potential. Since systematic change documentation is usually carried out through certification efforts (e.g., ISO 9000), change data is usually available on a large scale in companies. The SFB 768, therefore, examined how this data can support and improve the management of change cycles. Among other things, approaches were examined that improve the prognosis of change propagation during the implementation of technical changes. Using a shopping basket analysis, past changes and their documentation are used to obtain correlations between components of a technical system. For future changes, this knowledge can be used to estimate propagations better. Another approach to the use of change data addresses the structural complexity of technical changes across the product. Above all, the investigation of organizational interrelationships offers an excellent lever for improving cooperation in change management. Change data is used to derive complexity and effort indicators for the technical system, which allow a characterization of the technical system concerning the effort behavior during changes and uncover structural dependencies within the technical system as well as the organizational system. This enables a target-oriented improvement of the cooperation, the product structure with regard to the change effort behavior.

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Development of a guideline for efficient change management in production

Within the framework of transfer projects, research results from Collaborative Research Centres can be transferred into practice and applied prototypically. The transfer project "Guidelines for Change Management in Production" was started in November 2018 in cooperation with BMW AG and will continue after SFB 768 until April 2021.

A systematic change management process was developed to make change cycles in production more efficient and effective. The development of a guideline for production management aims at transferring the developed scientific methods and models into practice and applying them prototypically to research partners. With the planned findings, the research-

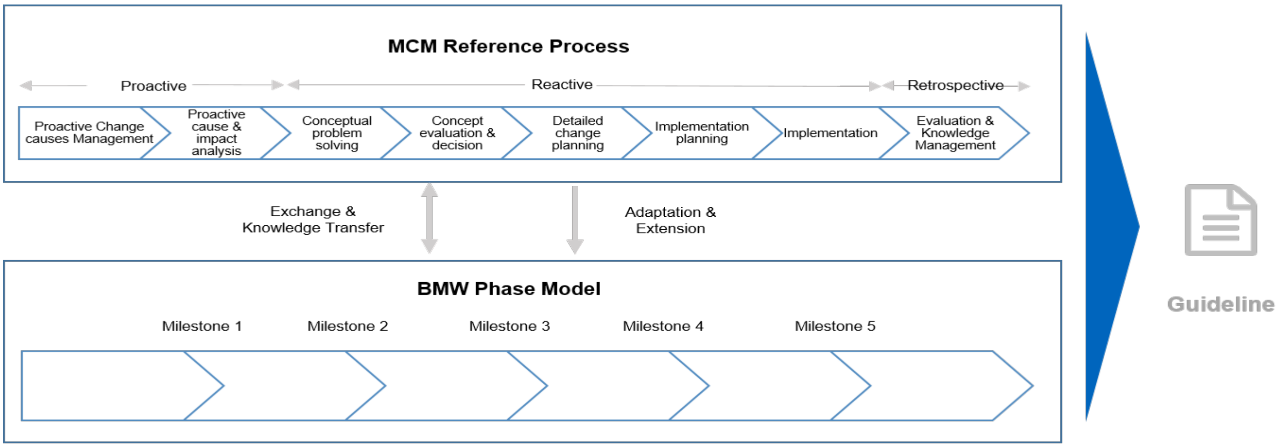

Figure 17: Development of a guideline for efficient change management

ers will validate their approaches with the help of practical cases and identify adaptation needs. In today's highly dynamic world with short product life cycles and rapidly changing technologies, change management is a critical success factor for manufacturing companies. The permanent cost pressure, accompanied by continually growing customer requirements for the up-to-dateness of the technologies and concepts used, requires companies to adapt and change their production systems continuously. A significant challenge here is the systematic and holistic handling of these changes since, as a rule, many change projects run in parallel and may have physical or procedural dependencies. The developed methods and models of the SFB 768 offer a holistic approach, which can serve as a basis for the development of proper change management for the project partner.

The aim of the transfer project is, therefore, to develop a guideline for the cycle-oriented identification, analysis, planning and implementation of changes in production systems. The reference process developed at *iwb* for change management in production (MCM*) is to be used as the basis for this.

In the first step, the implemented processes for the design and documentation of changes will be recorded based on four project examples at BMW AG. The initial situation determined is compared and evaluated with the approaches from SFB 768. Utilizing comparative analysis, improvement potentials are identified and addressed in the subsequent design of the company-specific change management process. This includes, in particular, the definition of a content flowchart, the definition of a rough timetable which can serve as a basis for the backward planning of future projects, as well as the creation of a guide which can be used as a supporting configurator for future projects.

In the first phase of the project, various workshops were held to find suitable project examples for the research project. From various ongoing modification projects, four have been identified which focus both on equipment and the changes induced by new product variants. The proactive phase of the projects was recorded according to the MCM* reference process. The next step is to accompany the change projects during the entire detailed planning and implementation phase. At the same time, the fields of action resulting from the comparison with the MCM reference process are derived and discussed in expert rounds.

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Institutional reflexivity in cooperation projects

How can organisations make their own actions the subject of observation, evaluation and the adaptation and improvement measures based on them? This ability is referred to as "institutional reflexivity" - SFB 768 investigated the conditions and forms of institutional reflexivity.

To this end, participatory design methods were used to productively combine social science research interests and design activities in companies. In this way, observations, interviews, and workshops could be used in a meaningful way both by the companies and for research.

For example, within the framework of the *work-integrated competence development,* a research project was carried out on the experience-led acquisition of digital media competences in a medium-sized industrial company from the plant construction sector and in a service company in the insurance sector.

The insights gained in the project have reflected the companies and integrated into the process of media competence development. At the same time, the conditions under which forms of institutional reflexivity can be established were elaborated.

The findings from this process (and other approaches) are currently documented on the design platform: innovations.sfb768.de. In future cooperation projects, own projects can be carried out which deal with the particular questions of the participating companies. We can contribute social science expertise and, for example, accompany the process of questioning, adapting and improving routines that have arisen with the help of established methods and procedures.

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Integration of external stakeholders in the cyclical design of PSS business models

PSS business models are changing ever faster and increasingly rely on the surrounding value-added network in the complete innovation cycle. The SFB 768 investigates this context and provides solutions for the integration of external stakeholders into business model innovations.

Business models, especially product service systems (PSS), are subject to ever-changing requirements. Business models must be adapted cyclically to the changing requirements of stakeholders. External stakeholders (especially customers) can serve as a source of knowledge and requirements for the development of new products, services and business models. In particular, the implementation of PSS business models often requires several players in the value creation network, such as customers, suppliers, external service providers, universities and start-ups.

The aim is therefore to provide models, methods and tools for the integration of external stakeholders in business model innovations. Besides, IT-based tool support for the development of PSS-based business models and the support of PSS business model innovations will be developed. In order to address these goals, the first part focused on one of the most prestigious groups of stakeholders in the innovation process: customers. A process model was developed to support customer integration. This specifies how customers can be integrated into the innovation process. Subsequently, a method kit was developed, which gives an overview of customer integration methods. In order to be able to apply these in a targeted manner, a decision support system was subsequently developed. The system suggests suitable customer integration methods based on user input, such as planned costs, duration or current innovation phase. A customer input ontology was then developed in order to record and manage customer inputs in the innovation process, structured according to properties, and to use them several times if necessary. In the second part, the group of customer stakeholders was expanded to include all possible stakeholders in the business model innovation process. In order to support business model innovations, existing patterns of successful business models were first compiled and characterized in a hierarchical structure. The hierarchical structure supports the applicability of the patterns. Second, domain-specific patterns and transformation paths were examined in the context of PSS and Industry 4.0. Finally, the findings of the pattern-based business model innovations were summarized in a software tool. This allows business models to be modeled and further developed based on recommendations (see Fig. 18).

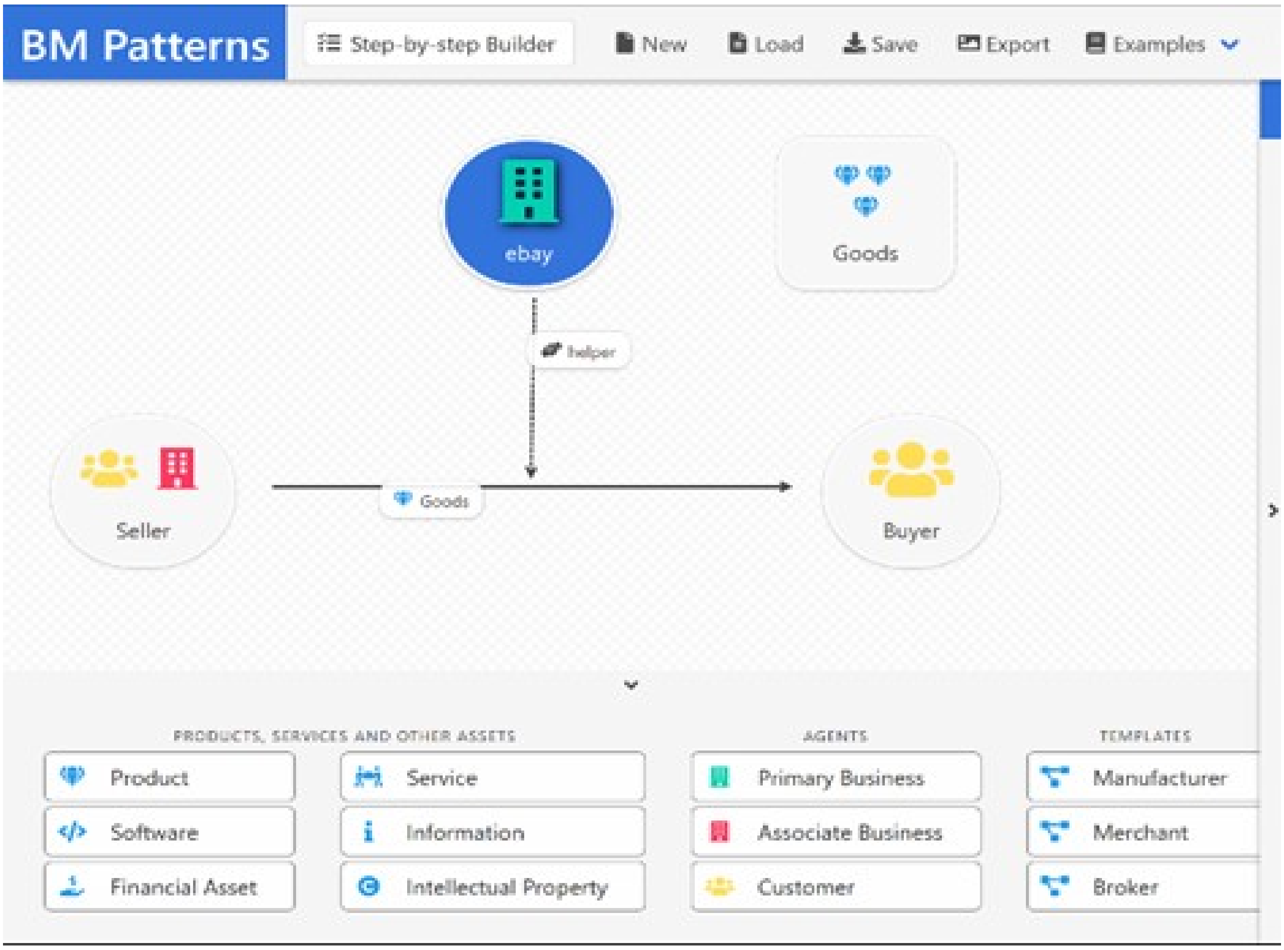

Figure 18: Tool for designing business models

Supporting innovation by evaluating data from the PSS usage phase

Due to increasing digitalization, new products consist not only of hardware and software elements but also of connective components. The networked products continuously transfer data to providers and users. The share of such products will continue to rise in the coming years, as will the amount of data from the usage phase. Due to the size, speed and variety of the data generated, the term big data is often used. This term covers not only the data itself but also the process of analysis. These analyses, especially based on usage data, offer companies numerous new opportunities to increase their success.

The overall goal of this research project was, therefore, the effective and efficient integration of usage data into the strategy development and operational implementation of product-service systems. Usage data is all data generated by the product itself or by associated services during use.

In order to achieve this goal, a procedure model was first developed to derive a usage data strategy (see Fig. 19). The model consists of six steps, starting with assigning team members and defining project goals. In the second step, the digital maturity of the company is evaluated and the current situation (i.e., available usage data, competitive situation, infrastructure, etc.) analyzed. Based on the context of the project, possible application areas are identified and possible use cases are collected. These use cases are then further detailed and consolidated by identifying their data needs in step four. In the following step, the remaining use cases are evaluated in detail in order to make a well-founded selection possible. Finally, in the last step, the usage data strategy can be formulated. In this way, an initial implementation of the roadmap can be derived. At the end of the model, it is reflected whether the defined objectives of the project have been achieved or whether the strategy needs to be readjusted before implementation. Methods have been developed or researched for each of these steps to make application as easy as possible for practitioners. For example, a use case catalog was developed for step 3, which contains over 200 use cases from industrial projects and is thus intended to en-

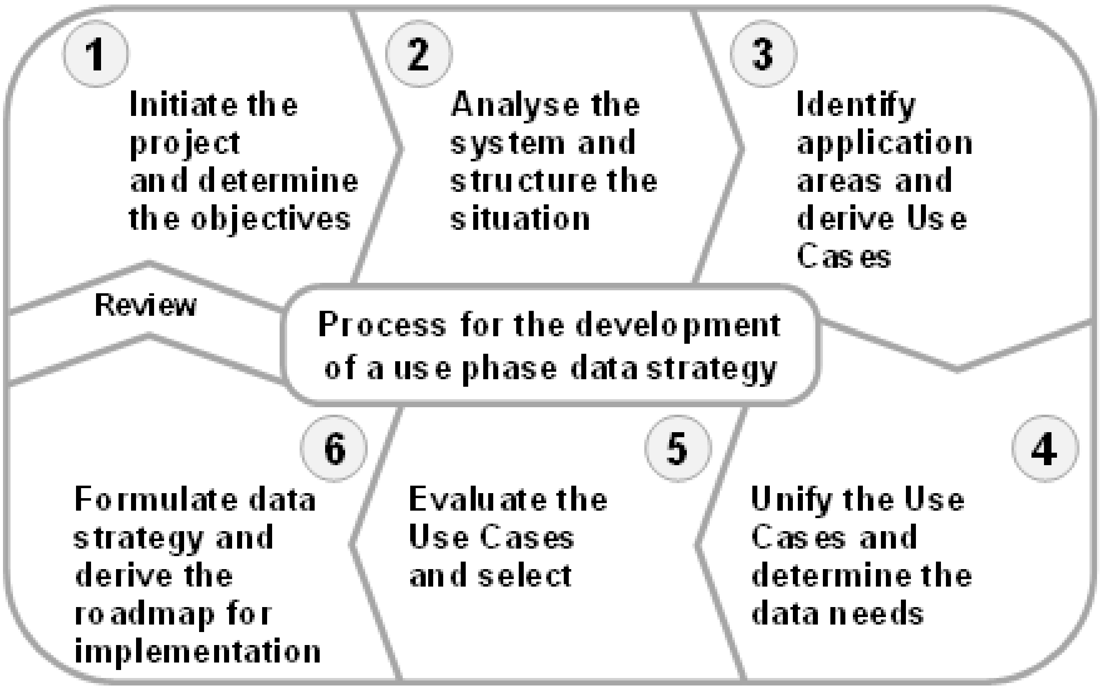

Figure 19: Procedure model for deriving a usage data strategy

able a suitable use case to be found. However, the implementation of this approach is only the first step. The strategy developed also results in changes for existing product development processes. This problem was addressed with a tailoring approach for flexible adaptation of processes.

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Support of the actors in the interdisciplinary, lifecycle-accompanying innovation process of product-service systems

The continually increasing complexity in mechanical and plant engineering, coupled with increasing competitive pressure in the global market, represents a central challenge for German plant engineering. Engineering in mechanical and plant engineering is characterized by the involvement of a large number of trades, e.g., mechanics, hydraulics and pneumatics, electrics/electronics, and software for automation and visualization, but also safety technology. Already today, various domain-specific simulations and visualizations for process control and regulation, as well as factory and plant planning, are used.

For the success of mechatronic development projects in mechanical and plant engineering, suitable coordination between these trades is of essential importance - especially since current development processes in today's practice are often characterized by a sequential process running over many months and an integrated, collaborative, agile engineering is missing or only insufficiently available.

The aim of this transfer project is the development, implementation, and evaluation of a scalable Engineering and Operation Support System to support interdisciplinary innovation cycles of large-scale industrial plants in the steel and non-ferrous metal industry. An evolving digital twin aggregates the models of a plant with operating data and design changes during operation from the manufacturer's point of view. On the one hand, it allows existing engineering solutions (hidden innovations) to be found and, on the other hand, it forms the platform for plant services as a product service system, so that customers can, for example, use simulation models to secure constructive or process-related changes. As a basis, methods for an integrated mechatronic system model will be further developed and adapted interfaces of the development approach will be provided for the various actors.

In developing the research objectives, new modern approaches to object-oriented modeling for coupling native CAD systems are to be used in particular in order to achieve integrated and more efficient engineering. For engineering processes in the field of automation, AutomationML, in particular, is being tested, which is intended to serve as a common database for the exchange of data and thereby offers a tool-neutral, integrated the system model of the various disciplines - for example, for the function trees defined in the early development phases and for electrical planning (EPLAN Engineering Center).

In the first phase of the project, various workshops were held to find suitable project examples for the research project. For the detailed recording of the process flows during the development phase of the transfer company SMS group, interviews were conducted with experts at the cooperation partner. In order to identify the optimization potential for accelerating the development cycle and the concrete needs of the interdisciplinary actors, first of all, precise process documentation, as well as a deep understanding of the processes in the run-up to the development of the Engineering and Operation Support System, is necessary. Therefore, the next steps are the identification of particular starting points to support the actors through expert interviews as well as the prototypical implementation of a support system.

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Transfer in Science and Practice: The Gestaltenplatform

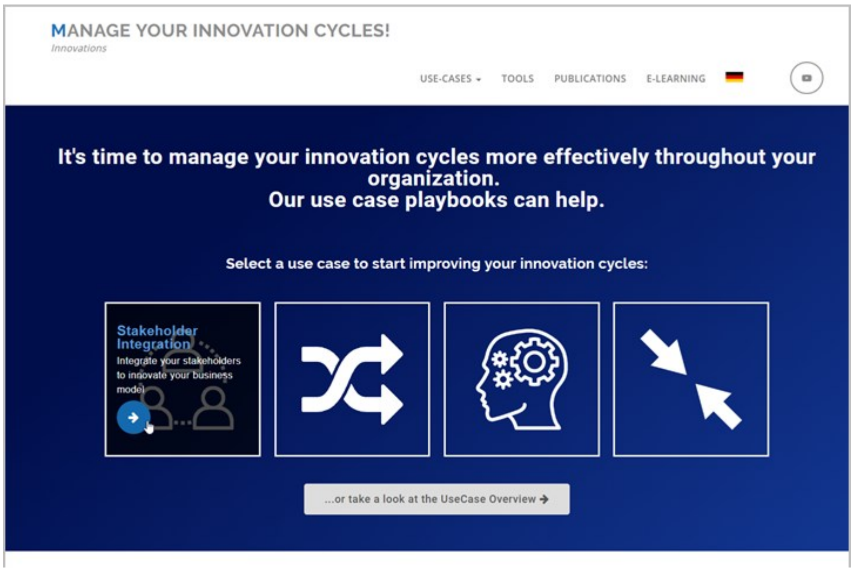
The *Gestaltenplattform* is the central platform of the SFB 768 to present the results and tools of the research project to a scientific and practice-oriented audience. The web-based platform pursues two main goals: on the one hand, it serves to enable the use of the developed methods and tools in the context of further research, and on the other hand, it supports the transfer of research results into practice.

Julia Eggers

As a central platform for the integrative use of the methods and tools of transdisciplinary cycle management, the "Gestalten-Plattform" was developed in the course of the third funding period (available at innovations.sfb768.de). The possibility to use the developed methods and instruments in the context of further research and to support the transfer of research results into practice will enable practitioners to analyze the impact on the different cycles and to estimate the expected economic efficiency.

For this purpose, the structure of the design platform is divided into different areas.

The SFB768 resulted in a broad spectrum of design methods and tools, for example, recommendations for action, best practices, prognosis models, assistance systems, or interventions that affect employees, structures or users. In order to facilitate the applicability of the various methods in practice, the area of the design platform aimed at practitioners is divided into the four Use Cases Stakeholder Integration, Knowledge Management, Inconsistency Management and Change Management. The Use Cases provide a smooth and solution-oriented introduction to the research results by building directly on problems known from practice. Each use case contains a set of developed methods ("tools"), which offer solutions for existing problems ("problems") from the use case and thus enable the realization of essential value potentials ("bene-fits"). For further in-depth study, relevant publications are offered for each use case, which was published in the context of SFB 768. Besides, the design platform offers access to a range of MOOC videos ("e-learning"), which serve the interactive experience and learning of research results. In addition, the cycle and model networks devel-



It's time to manage your innovation cycles more effectively throughout your organization.
Our use case playbooks can help.

Select a use case to start improving your innovation cycles:

Stakeholder Integration
Integrate your stakeholders to innovate your business model

...or take a look at the UseCase Overview →

Figure 20: Start page of the design platform with use case overview

oped in funding period 3 are available as a transdisciplinary toolbox for cycle management of innovation processes ("Concept Models"), which enables integrated design at different starting points.

The area of the Gestaltenplattform directed at scientists focuses on the research-oriented preparation of the results of the SFB 768. In the "Publications" section, you will find a selection of journal publications, workshops and lecture materials as well as dissertations that were created within the framework of the SFB 768. A complete list of all publications is also linked. In the Research Briefings available on the homepage, both practitioners and scientists can obtain a brief overview of the questions and scientific results of each subproject of the SFB 768.

The many MOOC videos offered on the Gestalten platform and many other videos can also be accessed on the YouTube channel of the SFB 768 (name of the channel "SFB 768", see Fig. 21). We summarize different views on cyclic innovation management in different playlists: the four uses mentioned above cases, guidelines, thematic clusters or the PSSycle - the demonstrator of the SFB 768.

Gestaltenplattform

innovation.sfb768.de

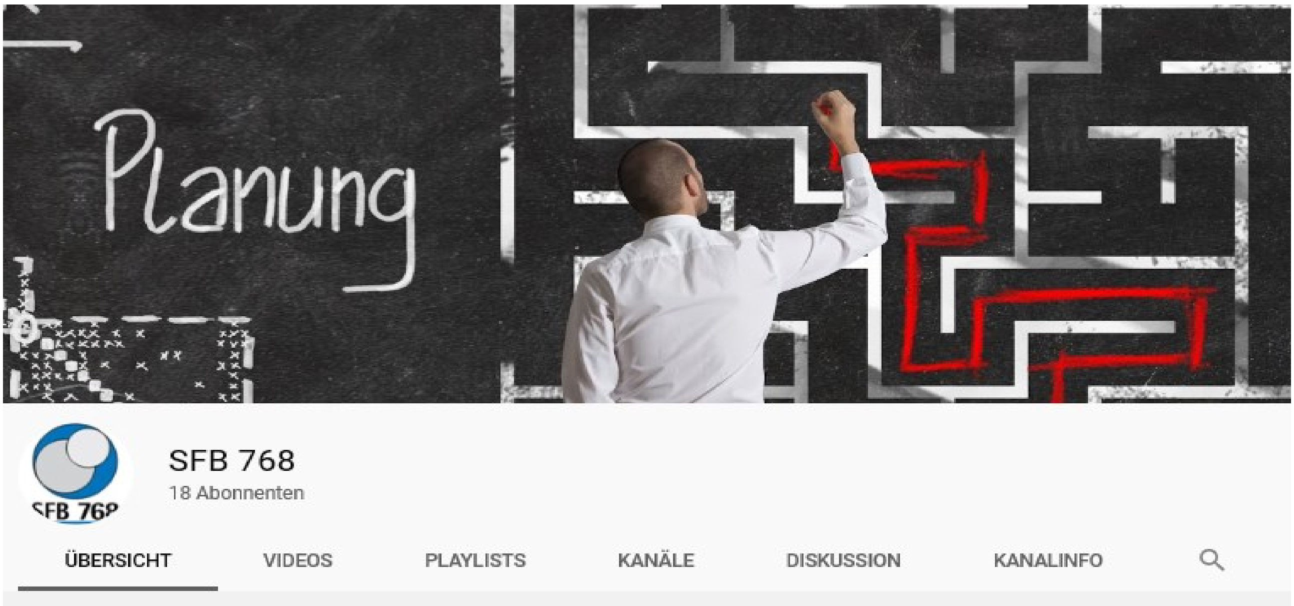


Figure 21: Youtube Channel "SFB 768" Homepage

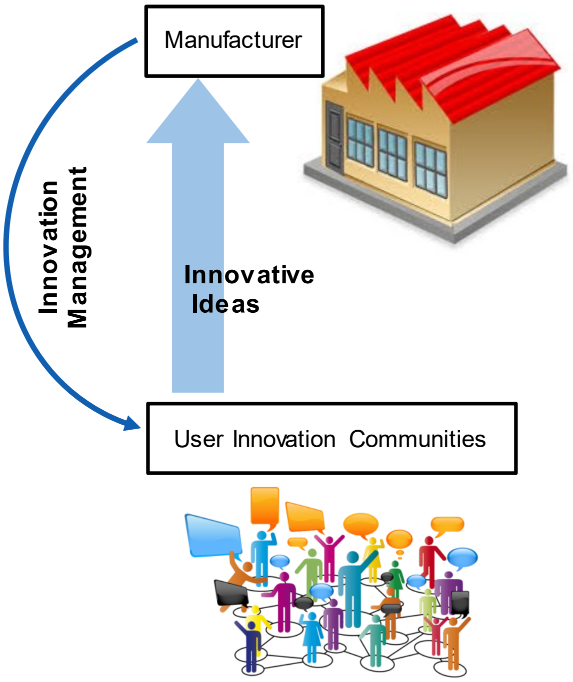
Back to the future: SFB 768 over 12 years of age

During the 12 years of existence of the SFB 768, we have collected many pictures of how our SFB has changed over the years. During this time, around 200 employees have driven the project forward.

Withi

SUCCESSFUL DESIGN OF INNOVATION CYCLES

- **Increased ability to innovate**
  - Measures to increase effectiveness in product, production, process and organisational development
  - Flexible engineering to continuously changing customer requirements
- **Transformation from product supplier to product service supplier**
- **Transdisciplinarity and integrity**
  - Transparent communication in teams and interdisciplinary, integrated modelling tool chains
  - Procedural change management using technical change impact analysis and visualizations
- **Effective "time-to-market" through innovative business models and early stakeholder integration**



Manufacturer

Innovation Management

Innovative Ideas

User Innovation Communities

OUR USE CASES

Stakeholder Integration

Possibility of involving external stakeholders in innovation processes and especially in business model innovations

Change Management

Efficient implementation of innovations through integrated change management

Knowledge Management

Approach for socio-technical knowledge management, which supports companies in dealing with the diversity, dynamics and distribution of knowledge

Inconsistency Management

Managing interdisciplinary inconsistencies to achieve a positive outcome of system development

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