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PROCESS VISUALISATION OF PRODUCT FAMILY DEVELOPMENT METHODS

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ABSTRACT
Development methods for modular product families have shown their usefulness in case studies, but are only seldom applied in practice. To support the active transfer of methods from research into practice an understanding of the working principles of methods is needed. In this contribution, a newly developed process visualisation approach is presented that allows design researchers to visualise and analyse existing methods to create this understanding. A special emphasis of the visualisation task is set to the analysis of interfaces that are used to include information and knowledge from different company stakeholders into method based development processes and back into the business. A visualisation nomination is presented that gives an easy and intuitive way of understanding this interaction. The approach is exemplary applied to the method "Integrated PKT-Approach for the Development of Modular Product Families". Finally an outlook on the possible use of the presented visualisation approach to foster methods transfer to practice is given.

Keywords: product families, process modelling, design methods, process visualisation, method integration

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1 INTRODUCTION

Globalisation and the shift to customer driven markets are forcing companies to further individualise their products. Handling the resulting complexity of highly variant product families is a significant challenge that affects multiple company functions and departments. Methods for developing modular Product Families (mPF) aim to support the development of product families that offer high external product variety to customers. These methods provide ways to reduce internal complexity within the company to ensure profitability of products despite high external product variety. Examples of such methods are the Structural Complexity Management (Lindemann et al., 2009), Product Family Master Plan (Harlou, 2006) and the Integrated PKT-approach for the Development of Modular Product Families (Krause and Eilmus, 2011a).

While a variety of methods has been developed, they are rarely used in practice (Wallace, 2011). Badke-Schaub et al. (2011) discussed three general shortcomings of existing methods: Unproven performance of methods, inadequate presentation and formulation of methods, and process-related problems, such as poor adaption to the constraints of the development task and company. However, case studies (for example, Eilmus et al., 2012) have shown the general usefulness and performance of modular product family development methods. This paper does not focus on improving the performance of the method but emphasises the integration issue of methods addressing inadequate presentation and process related issues. Gebhardt et al. (2012) presented a first step for describing barriers that hinder the integration of methods in practice, focusing on knowledge and information that needs to be exchanged during development and the visualisation of product families. To provide a method implementation support, an understanding of the working principals of methods from the area of research is needed (Figure 1).

This paper aims to provide an intuitive visualisation of the methods that give detailed insights into the methods and help design researchers to create a better understanding of methods. The process visualisation should illustrate how information and knowledge is processed by methods. Within mPF development methods information from different domains is needed. Thus, process visualisation needs to illustrate how people from different domains are included into the development (for example, using workshops). The question of how the internal information and knowledge processing and the interfaces of a method for the development of mPF can be visualised should be answered.

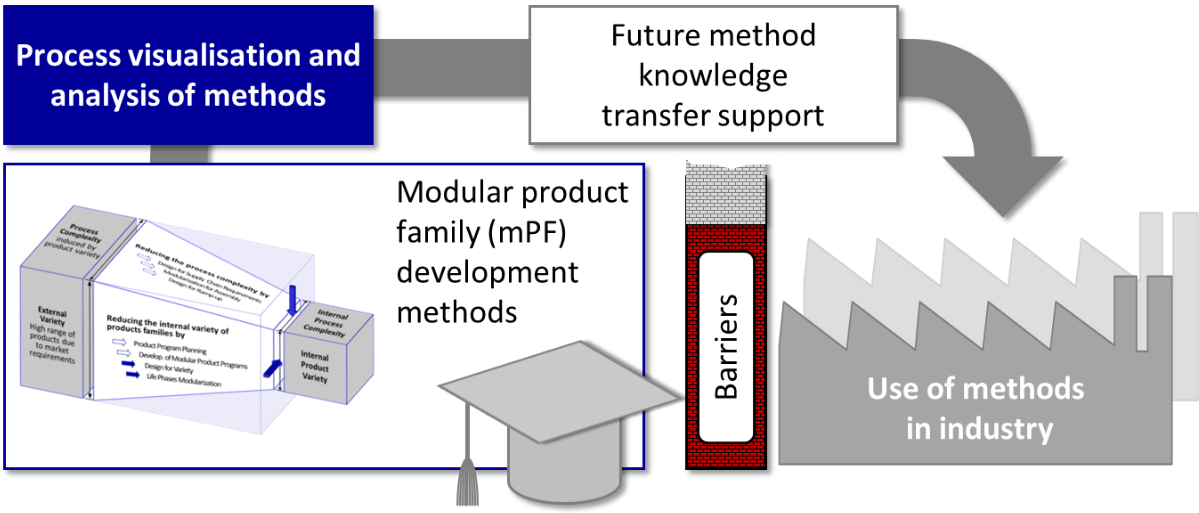


Figure 1. Motivation and scope of contribution (cf. Gebhardt et al., 2012)

The paper focuses on the developed process visualisation and presents the following steps:

- Background: Integrated PKT-approach that will be used as an example method for visualisation, basic definitions and overview of existing process visualisation and modelling techniques.
- Developed process visualisation approach and application example introduces the proposed process visualisation and its application to the example method.
- Reflection of the use of the approach.
- The outlook for using the approach to foster method transfer into practice.

2 BACKGROUND

2.1 Method to be visualised – Integrated PKT-approach

The Integrated PKT-approach for the Development of Modular Product Families (Krause and Eilmus, 2011b) was developed at the Institute for Product Development and Mechanical Engineering Design (PKT) based on existing methods for reducing internal variety and contains several method units. It will be used and visualised as an example of a product family development method (Section 3). Jiao et al. (2007) provide an overview of other methods for the development of mPF. The Integrated PKT-approach aims to generate maximum external product variety, using the lowest possible internal process and component variety (Figure 2). Its main characteristics are:

- A workshop-based approach integrating product knowledge from different disciplines
- Visualisation methods fostering discussion in project teams
- Redesign, modification and new design of components to reduce product variety.

The method units Design for Variety and Life Phases Modularization (Figure 2) consider optimisations at the product family level and constitute the core of the approach. New method units like Product Program Planning and Development of Modular Product Programs broaden the view from a single product family to the product program. Method units Design for Supply Chain Requirements, Modularization for Assembly and Design for Ramp-Up facilitate consideration and handling of process complexity induced by the product variety. The method units have been developed to suit specific needs of companies (Krause and Eilmus, 2011a). Currently, research is undertaken to consolidate and transform the units into a methods toolkit, providing flexible case specific support. The process visualisation approach presented in this paper should contribute to this by providing a language for describing, structuring and understanding these method units.

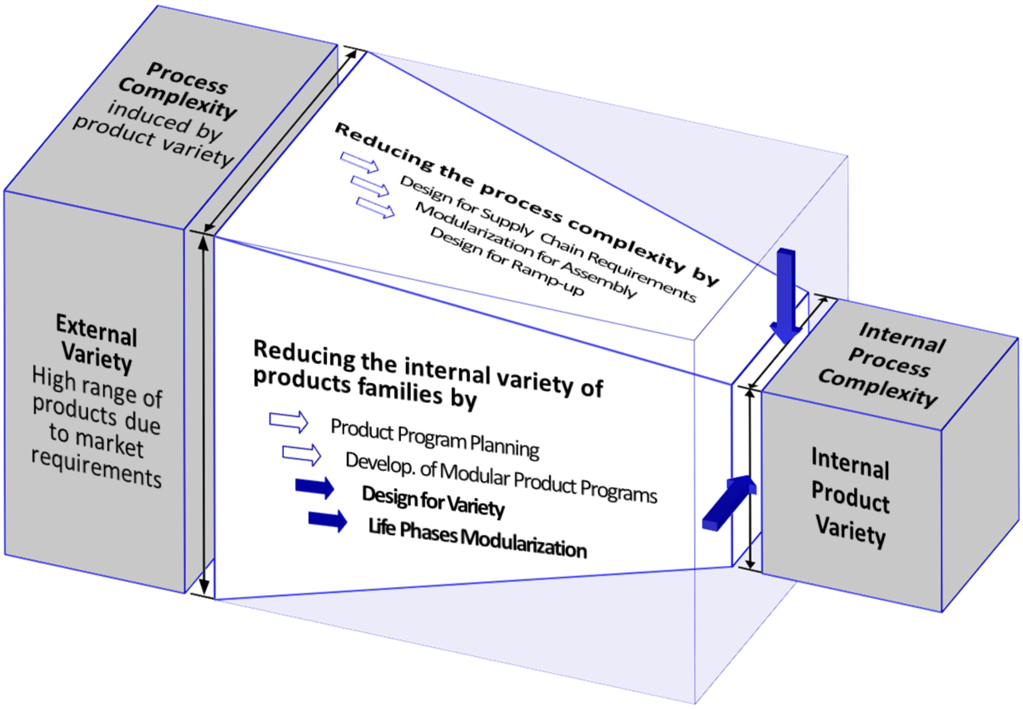


Figure 2. Integrated PKT-approach – Method to be examined (Krause and Eilmus, 2011b)

The modelling example in this paper will focus on the Design for Variety and Life Phases Modularization method units. Design for Variety maps variant product properties offered on the market to variant functions, working principles, and components. The product family structure is analysed using the Variety Allocation Model (VAM, Blees et al., 2010). An improved product family structure is derived in the next step along with recommendations for component design changes that reduce the internal variety of the product family. The improved product family is modularized using the Life Phases Modularization (Blees et al., 2010). For each relevant product life phase a preferred modularization is developed using life phase and company-specific module drivers in workshops with experts from each product life phase. The specific concepts are merged into an overall module concept. In general, the overall concept allows different modularizations in each product life phase, but conflicts between different modularizations may occur. Hence, harmonising of the life phase specific modularizations is done in a workshop by discussion between the different life phase's representatives.

2.2 Understanding of information and knowledge

The desired process visualisation requires an understanding of the terms knowledge and information. North (2011) distinguishes data and information from knowledge. Data put into context is information; information linked for a specific purpose is knowledge. According to Probst et al. (2010), knowledge is always related to persons. Knowledge can be explicit or tacit. Explicit knowledge is easy to articulate while tacit knowledge cannot be easily transferred. To communicate knowledge to other people or store it, information is used as its medium (North, 2011). In the development of mPF the structure of the product family needs to be analysed. For this purpose, documentation of the structure from product data systems can be used (information). Most of the understanding of why this structure was designed in this specific way is only known to the incorporated developers of earlier projects. To include this partial tacit knowledge, methodically supported communication (e.g. workshops) is required. A process visualisation of methods for developing mPF needs to consider both knowledge and information to recognise the specific information and knowledge transfer limitations.

2.3 Process visualisation parameters and constraints of mPF development

Maier and Störrle (2011) have done a literature study to collect a set of characteristics of engineering design processes. They found that engineering design processes are complex and iterative, and problems are ill-defined. Collaboration during development is challenging due to the interaction with various processes, people with different professional backgrounds and organisational structures. Engineering design processes are constrained by the properties of the product, economic and market constraints as well as regulations (Maier and Störrle, 2011). Methods for the development of mPF focus on developing a set of closely related product variants that constitute the product family. Transferring the above findings intensifies the observed challenges. By considering more variants the structure of the product gets more complex and mPF development methods – especially the Integrated PKT-approach – try to handle this complexity by using visual analysis tools (for example, to illustrate variety of the product). These visualisation tools must be considered in a process visualisation. The development of mPF requires more integration of different stakeholders and organisational units. Thus, a special emphasis of a process visualisation approach must be set to illustrate the involvement of different people and the technique of integration (providing documents or cooperative workshops). General descriptions of methods are needed. For example, Birkhofer et al. (2002) use input and output, the method's sequence of activities, the required user abilities, general conditions of application, hints, working aids, a method classification, relationship to other methods, and specification (like aims and benefits) to describe methods within a Processes-oriented Method Model (PoMM).

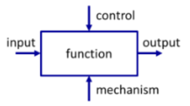
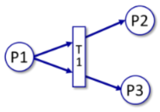
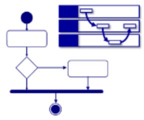
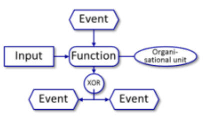
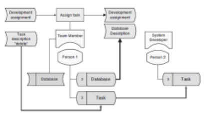
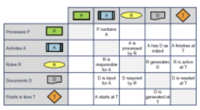
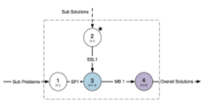
2.4 Approaches to visualise and model methods and processes

In the literature a number of general notation and modelling techniques are presented (Table 1, 1-3) that were mainly developed for software engineering but have also been used for process descriptions. Typically, the whole processes are decomposed into smaller sub-processes that are connected by relations or flows and form a process network. Thus, a detailed analysis of the different process steps is made possible. The Structured Analysis and Design Technique (SADT) describes the sub-processes by their input and output conditions. Using this modelling technique for methods could be helpful to visualise information and knowledge required and generated by the methods. Petri nets are used to describe the system behaviour by transition processes from one state to another. As discussed above, engineering design processes are iterative and defining sharp states can be problematical. Unified Modelling Language is a notation and language used in software and system modelling. Its activity diagrams visualise activities along with their logical relation and can contain swim-lanes to allocate steps to organisational units.

Event-driven process chains (eEPK, Table 1, 4, Scheer, 2000) are widely used for business process modelling. In the case of a particular event, a function is performed that transfers the system into another event. The functions require inputs and organisational units are assigned to them. Software like ARIS allows simulating processes. Knowledge Modelling and Description Language (KMDL) was developed by Gronau et al. (2005) to model knowledge-intense business processes by extending the existing eEPK descriptions (Table 1, 5). To simulate processes, eEPK is usually very detailed and would not be able to give a quick overview of the mPF development method but could provide detailed insights into finely decomposed steps of the method. Like petri nets, eEPKs also require fixed states (events), which are usually not given in iterative design processes.

König et al. (2008) and Danilovic and Browning (2007), for example, use Multiple Domain Matrices (MDM, Lindemann et al. (2009), Table 1, 6) to visualise the interactions within development methods. The MDM contains Design Structure Matrices (DSM) which are able to highlight dependencies in one domain (for example, between activities) and Domain Mapping Matrices that allow connection between different domains (for example, activities and roles). Sosa et al. (2004) used DSM to analyse both product and organisational structures. They have compared the relation between interfaces in the product and interfaces in team communication and were able to show a misalignment between the interface types. The MDM and DSM are powerful tools to illustrate the interdependencies (for example, identifying clusters of roles with high interaction) but lack an intuitive graphical visualisation of the chronological sequence of activities.

Table 1. Approaches to visualise and model methods and processes

#	Method		Summary
1	SADT – Structured Analysis and Design Technique (Ross and Schoman, 1977)		• System description by decomposition of systems and description of interfaces
2	Petri net (Jørgensen, 2004)		• Process description notation using states and transitions • Used in modelling of State Machines
3	UML – Activity diagrams of the Unified Modelling Language (Jørgensen, 2004)		• Activity diagrams enable modelling of processes in swim-lanes to consider different organisational units
4	Event-driven process chain (eEPK) (Scheer, 2000)		• Modelling and simulation of business processes • Description based on events and functions
5	KMDL - Knowledge Modelling and Description Language (Gronau et al., 2005)		• Modelling based on eEPK, but adapted notation to model knowledge-intense processes
6	MDM – Multi Domain Matrix (Lindemann et al., 2009)		• Interdependencies between entities in or across different domains • Matrix-based, including visualisation
7	Genome Approach (Zier et al., 2011)		• Decomposition of method into elementary steps (e.g. list) • Cognition of similar patterns to describe methods

Zier et al. (2011) (Table 1, 7) use the genome approach to describe design methods. The approach decomposes the methods into elementary methods (for example, list and sort) and was applied to different methods to recognise similar patterns. This elementary method description will be used to communicate and select methods. While the decomposition of methods into chunks seems a promising way to offer customized methodical support, the high level of decomposition and resulting abstractness may hinder the use of the approach. The genome approach follows the idea of consolidating design methods by describing them in a structured and standardised way. This was also addressed by Birkhofer et al. (2002) using the Processes-oriented Method Model (PoMM). It describes methods by their process characteristics (like inputs, outputs and the sequence of the process) along with meta-level information (aims and links to other methods) that ease the selection of methods.

The collected methods would in general allow a visualisation of design methods. Browning and Ramasesh (2007) have done a literature study of process models for managing product development and were critical that most methods focus on actions but not on the interactions within the process and the people doing this processes. As mentioned above, the integration of different stakeholder and organizational units is crucial in the mPF development and the basic visualisation approaches presented above lack focus on the interaction issue. Of the presented approaches, only DSM and MDM approaches concentrate on the interaction and interfaces in design processes. However, these matrix-based approaches miss an intuitive chronological visualisation of the activities.

3 PROCESS VISUALISATION APPROACH AND APPLICATION EXAMPLE

A visualisation of the methods should support the design researchers' understanding of the working principles of methods. A better understanding of the interface between the method and its user as well as the users' application conditions is needed. These interfaces are the information and knowledge inputs for each step of the method, the generated output of the method and not least the manner of interaction, cooperation and communication that is needed to work with the method and to exchange inputs and outputs. This understanding is mandatory to transfer method into practice to be able to match methods to the existing development processes and organisational structures of the companies. For this purpose, the method requires the following characteristics:

- An intuitive chronological visualisation of method steps and their relationships to each other
- Visualisation of required and created information and knowledge of each step
- Inclusion of work and communication formats within each step
- Adaptable level of detail and expandable.

To find a suitable method for visualising the process of the Integrated PKT-approach, first an adapted event-driven process chain (Section 2.4) was used that represented a well-known and software supported modelling procedure. However, the modelling using certain events and functions was found to be too rigid to suit the visualisation of the methods procedure. In addition, it did not focus on required inputs and generated outputs. For this reason the visualisation is changed to SADT, which allows easy and intuitive visualisation of inputs and outputs. The SADT approach is adapted and expanded to allow the visualisation of interaction of stakeholders. While matrix-based approaches are also able to show these interactions, they lack a chronological order and thus are not used in this paper for the described purpose. The developed approach is described in the following section.

3.1 Developed process visualisation approach

The developed visualisation follows an input and output notation, as used in SADT modelling (Section 2.4). It interprets the input and output from a knowledge perspective to illustrate information and knowledge used and generated in each step of the method. A method step description card is introduced to give further information about the methodical proceeding of each step. The interactions during the steps of the method and ways of collecting the inputs from different information and knowledge sources are illustrated by symbolic notation. A detailed description of the modelling is given using only one example step (Analysis of external product variety) for the Integrated PKT-approach (Figure 3).

An arrow-shaped box is used to describe each step of the method and the applied working and cooperation types are represented by symbols. It distinguishes between workshop/teamwork (symbol: six items (circles) circular arranged) and individual work activities (symbol: item and documents). Blue items represent developers that are participating in the methodical development (method users), while different coloured items, including letters, represent stakeholders from a specific product life phase or department. Red items marked with 'M' represent method experts who are able to moderate the workshops due to their high methodical skills and knowledge. In the method example of Figure 3, variant customer properties are distinguished and weighted. This requires discussion (teamwork) of marketing representatives with the developers moderated by a method expert, as symbolically shown.

A method step description card provides more information about the method. It contains the aim of the step, the required methodical knowledge of method users, the supporting tools and visualisations provided by the tool as well as the sequence of recommended sub-activities. Methodical knowledge is needed to generally perform this step and is not connected to the company or product-specific knowledge that is considered in the input and output description. The tools and visualisations are the most important parts of the method step description card. They are used to create transparency of the product family and its structure and thus are vital working aids of methods, especially the Integrated PKT-approach. In this example, the Tree of Variety (TEV, Blees et al., 2010) is used to illustrate the variant customer product properties and its facilitation in the different product variants. The process visualisation thus provides a snapshot of the visual tools to trigger a graphical recognition of each step and tool. Finally, sub-steps of the step could be listed, which is useful if the method is decomposed into steps only coarsely.

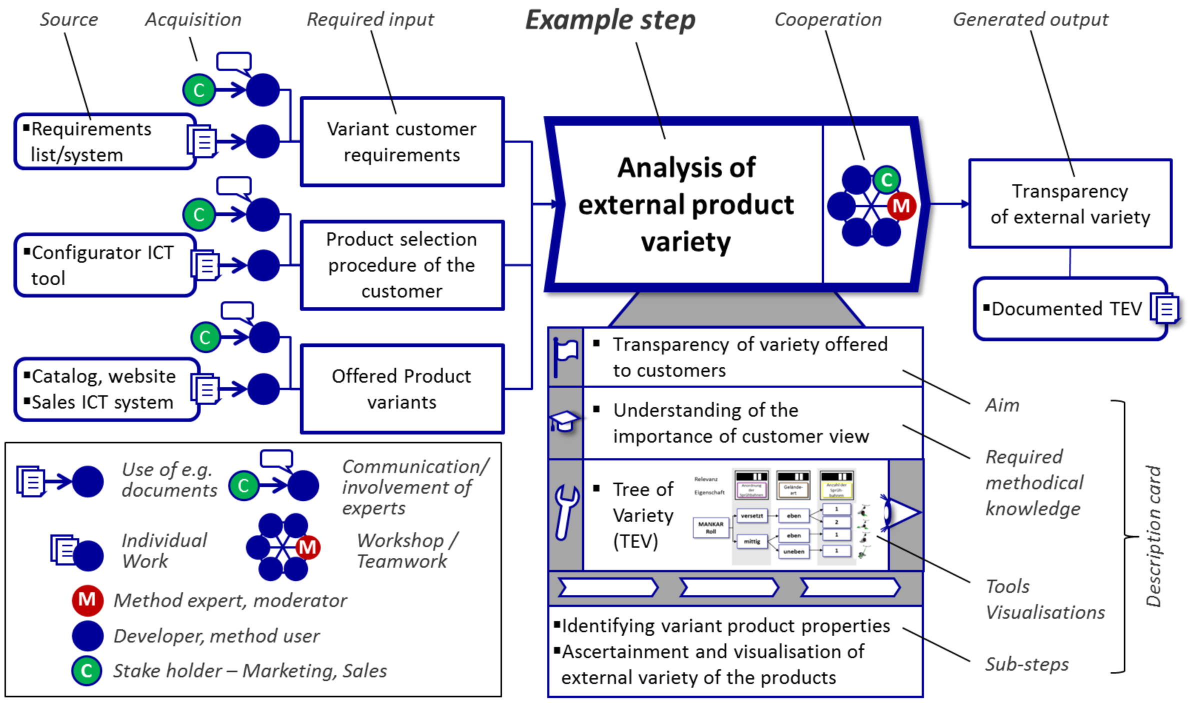


Figure 3. Developed notation to visualise steps of methods
(as an example applied to one step of the Integrated PKT-approach)

Required inputs of the method steps, including its source and acquisition process, are shown to the left of each step. Boxes contain the description of the required input, like the variant customer requirements needed in the example. These boxes only contain inputs specific to the company, product or project and are not general methodical skills, which are addressed in the method step description card. The input is linked to possible sources using two symbols. A document linked to a blue item points out that the input can be gathered from an information source like the requirement list or system used in the example. A coloured item marked with a letter connected to a blue item (method user) with a balloon points out that the input is part of the knowledge from stakeholders from a specific product life phase (e.g. marketing). Thus, knowledge needs to be included, which means that there must be some dialog or inclusion of the people from this domain in the process. Dialog is also needed if documents can only be used and understood with the help of an expert. The evidence of knowledge and information acquisition is important when interfaces between the method and the applying company should be designed during a future method transfer to practice. By using different coloured items a fast overview of which life phase representatives need to be considered in certain steps is provided.

Generated output is described right to the method step. It is assumed that the generated output knowledge is inherited by the participants of the methodical step. If created information is stored in documents this is shown by an additional box marked with a document. In the example, transparency of external variety is generated and stored as information in the documented Tree of Variety.

3.2 Visualisation example

The described approach to visualise the processes of a method for the development of mPF was applied to steps of the Integrated PKT-approach. In the following, an example of the results achieved is given using the methodical steps of the Life Phases Modularization (Section 2.1). The observed parts of the approach were decomposed into steps using methods described in papers and theses (for example, Blees et al., 2010). This visualisation is done using two levels of detail (Figure 4 and 5). A high level view with coarse decomposition of the method gives an overview of information and knowledge flows while a finer decomposition gives detailed information of sub-steps of the method.

In the high level description (Figure 4) the Integrated PKT-approach is broken down into less than ten steps. The steps "Create strategic modularizations for all relevant life phases" and "Combine modularization" of the Life Phases Modularization are used to illustrate visualisation of the method. In the first step, modularizations for each different life phase are created. Participation from various different product life phases is needed to include specific requirements into the modularization process. Thus, teamwork of multiple stakeholders is moderated by a method expert (visualised using coloured items for each life phase in the input side and on the cooperation symbol). The method step description cards are simplified and provide information about the used tools and visualisation. A Network Diagram is used to formulate and describe the combination of components to modules while the Module Interface Graph (MIG) gives a graphical representation of spatial arrangement and interdependencies of the components of the product family (Blees et al., 2010).

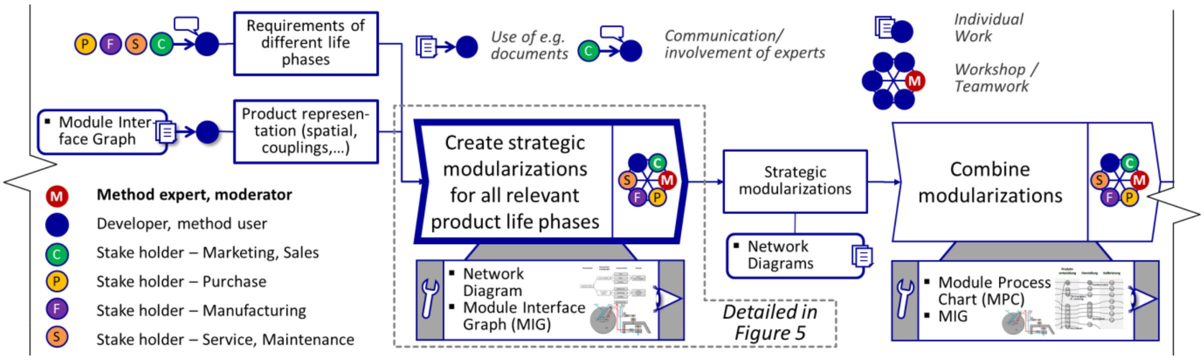


Figure 4. Extract of the visualised Integrated PKT-approach

Generated outputs of the step are strategic modularizations that are documented using Network Diagrams. In the next visualised step, "Combine modularizations", this output is used to combine the modularizations. This step again requires a workshop with participation of each life phase to aligned and adapted conflicting life phase specific modularizations. In this high level examination, both steps seem to have the same level of interaction, including four different stakeholders in each workshop. However, the creation of strategic modularizations requires a series of four workshops, each including one stakeholder, while the task of combination requires a workshop that includes all four stakeholders for discussion. These differences can only be made obvious by using a finer decomposition. Nevertheless, the coarse decomposition allows for a quick overview of different stakeholders and the global flow of information and knowledge within the method. The step of creating strategic modularizations is further detailed. The process splits into four parallel branches for each life phase. Only the branch for the Purchase life phase is shown (Figure 5).

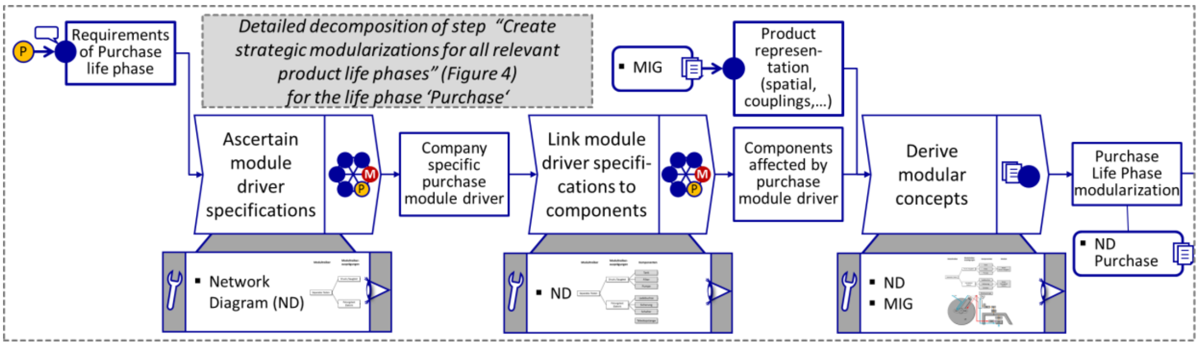


Figure 5. More detailed decomposition of one step from Figure 4

The first sub-step input from purchase representatives is collected to discover company-specific purchase module drivers within a workshop. They are linked to the product components in discussion with purchase representatives. The developer derives modular concepts without the participation of other life phases, based on the output of the second step. A Network Diagram and the Module

Interface Graph support these steps. Using this more detailed decomposition of the methods allows for a more detailed view of the activities, the needed participations and cooperation in these sub-tasks. However, the number of steps and interrelations make it harder to get a quick overview of the method.

4 REFLECTION ON THE APPLICATION OF THE VISUALISATION

Visualising the integrated PKT-approach worked in an intuitive way. Focusing on the integration of knowledge into the method application helped to understand which resources are needed from the company and which interactions between product developers and other company stakeholders may be necessary. In a first industry workshop the visualisation was used and allowed for good discussion about the integration of different stakeholders. The work on the visualisation fosters consolidation of methods by identifying improvement potentials of method details, like the order of steps or visualisation tools used. Examples discovered by the support of the visualised method are given by Gebhardt et al. (2012). For instance, it became obvious that modularisation from the perspective of Life Phase Purchase exists only and no strategic future suppliers are considered.

The decomposition of the method into steps for visualisation is challenging. In this example, steps are chosen that have been presented by the method developers. However, the visualisation makes it evident that a different decomposition or regrouping of steps may be worthwhile considering. This structuring of methods could follow different grouping criteria. It could be useful to group steps that are using the same tools, following the same aim or including the same stakeholders. An alignment of the decomposition or a regrouping into method blocks that better fit the requirements of companies may support method integration into companies.

While the method visualization is useful for improving the methods, it cannot fully replace teaching materials like textbooks or interactive workshops. The method step description card gives some meta information about the method but is not a user manual. However, the detailed decomposition into steps and the inclusion of visual images of the used tools in each step supports the recapitulating if the method is already known.

The modelling was undertaken using standard visualisation software and thus time-consuming. But the developed notation gives a quicker and better insight (interaction between stakeholders) compared to using existing event-driven process chain software tools. The development of a tool or the introduction of customised shapes could improve the currently missing software support in the future.

5 OUTLOOK – SUPPORT OF METHOD INTEGRATION INTO PRACTICE

Future research is envisaged to use the approach to visualise product family development methods to support the transfer of methods developed in the research domain to practice. The visualisation approach can be used to highlight the designated interfaces of the method to company knowledge and information. To be able to include a method in practice, these interfaces have to be aligned to available information or knowledge sources of the company. To study the current development organisation of the company in which the method needs to be included, the developed visualisation can be applied to the product development processes of the company. By comparing the companies' requirements and the existing support offered by the method, suitable parts of the method can be selected for permanent integration. However, the method will probably need adaption to fit company processes. Browning and Ramasesh (2007), for example, state the importance of finding the balance "between standard processes which can be scaled and tailored and purely innovative processes". While the core of the methods (for example, product structure visualisation approach) will probably be reusable, details like sequences and setups of workshops need company specific modification. Especially, the interface to connect the method to company knowledge and information resources will often require customisation. Information sources, like the product structure of the company-specific PDM system, should be used to reduce the effort required for information acquisition. Structuring of method steps into method blocks (modules) that are more easily adaptable and combinable might be one possibly way to support method integration. This requires a visualisation of the method to create a basis for discussing how to structure the methods to allow easier integration into companies.

REFERENCES

Badke-Schaub, P., Daalhuizen, J. and Roozenburg, N. (2011), 'Towards a Designer-Centred Methodology: Descriptive Considerations and Prescriptive Reflections'. In Birkhofer, H. (Ed.) *The Future of Design Methodology*. London: Springer, pp. 181–197.

Birkhofer, H., Kloberdanz, H., Sauer, T. and Berger, B. (2002) ‘Cleaning up design methods - describing methods completely and standardised’, *7th International Design Conference, DESIGN* 2002, Dubrovnik, University of Zagreb/The Design Society.
Blees, C., Kipp, T., Beckmann, G. and Krause, D. (2010) ‘Development of Modular Product Families: Integration of Design for Variety and Modularization’, *8th International NordDesign Conference*, Göteborg, Chalmers University of Technology/The Design Society, pp. 159–170.
Browning, T.R. and Ramasesh, R.V. (2007) ‘A Survey of Activity Network-Based Process Models for Managing Product Development Projects’, *Production And Operations Management*, Vol. 16, No. 2, pp. 217–240.
Danilovic, M. and Browning, T.R. (2007) ‘Managing complex product development projects with design structure matrices and domain mapping matrices’, *International Journal of Project Management*, Vol. 25, No. 3, pp. 300–314.
Eilmus, S., Gebhardt, N., Rettberg, R. and Krause, D. (2012) ‘Evaluating a methodical approach for developing modular product families in industrial projects’, *12th International Design Conference, DESIGN 2012*, Dubrovnik, University of Zagreb/The Design Society.
Gebhardt, N., Beckmann, G. and Krause, D. (2012) ‘Product Family Models and Knowledge Transfer Support for the Development of Modular Product Families’, *9th International NordDesign Conference*, Aalborg, Aalborg University/The Design Society.
Gronau, N., Müller, C. and Korf, R. (2005) ‘KMDL - Capturing, Analysing and Improving Knowledge-Intensive Business Processes’, *Journal of Universal Computer Science, JUCS*, Vol. 11 No. 4, pp. 452-472.
Harlou, U. (2006) *Developing product families based on architectures:* Contribution to a theory of product families, 1st ed., Lyngby, Technical University of Denmark.
Jiao, J., Simpson, T.W. and Siddique, Z. (2007) ‘Product family design and platform-based product development: a state-of-the-art review’, *Journal of Intelligent Manufacturing*, Vol. 18 No. 1, pp. 5–29.
Jørgensen, H.D. (2004) ‘Interactive Process Models’, Trondheim, Norwegian University of Science and Technology.
König, C., Kreimeyer, M. and Braun, T. (2008) ‘Multiple-Domain Matrices as a Framework for Systematic Process Analysis’, *10th International DSM Conference,* Stockholm, Hanser, pp. 231–244.
Krause, D. and Eilmus, S. (2011a) ‘Methodical Support for the Development of Modular Product Families’. In Birkhofer, H. (Ed.) *The Future of Design Methodology*. London: Springer, pp. 35–45.
Krause, D. and Eilmus, S. (2011b), “A Methodical Approach For Developing Modular Product Families”, 18th International Conference on Engineering Design (ICED 11), Copenhagen, Technical University of Denmark/Design Society, pp. 299–308.
Lindemann, U., Maurer, M. and Braun, T. (2009) *Structural Complexity Management:* An Approach for the Field of Product Design. Berlin: Springer.
Maier, A.M. and Störrle, H. (2011) ‘What are the characteristics of engineering design processes?’, *18th International Conference on Engineering Design (ICED 11*), Copenhagen, Technical University of Denmark/Design Society, pp. 188–198.
North, K. (2011) ‘*Wissensorientierte Unternehmensführung:* Wertschöpfung durch Wissen’, *Gabler Lehrbuch,* 5th ed., Wiesbaden: Gabler / Springer.
Probst, G., Raub, S. and Romhardt, K. (2010) ‘*Wissen managen:* Wie Unternehmen ihre wertvollste Ressource optimal nutzen’, 6th ed., Wiesbaden: Gabler.
Ross, D. and Schoman, K. (1977), ‘Structured Analysis for Requirements Definition’, *IEEE Transactions on Software Engineering*, Vol. 3 No. 1, pp. 6–15.
Scheer, A.-W. (2000), *ARIS - business process modeling:* With 179 figures, 3rd ed., Berlin: Springer.
Sosa, M.E., Eppinger, S.D. and Rowles, C.M. (2004), ‘The Misalignment of Product Architecture and Organizational Structure in Complex Product Development’, *Management Science*, Vol. 50 No. 12, pp. 1674–1689.
Wallace, K. (2011) ‘Transferring Design Methods into Practice’. In Birkhofer, H. (Ed.) *The Future of Design Methodology.* London: Springer, pp. 239–248.
Zier, S., Kloberdanz, H., Birkhofer, H. and Bohn, A. (2011) ‘Investigating Elementary Design Methods Using and Extending the Genome-Approach’, *18th International Conference on Engineering Design (ICED 11*), Copenhagen, Technical University of Denmark/Design Society, pp. 236-245.