INTERNATIONAL DESIGN CONFERENCE - DESIGN 2012
Dubrovnik - Croatia, May 21 - 24, 2012.

TOWARDS AN INTEGRATION OF SUPPLY CHAIN REQUIREMENTS INTO THE PRODUCT DEVELOPMENT PROCESS

M. Brosch, G. Beckmann and D. Krause

Keywords: design for supply chain requirements, complexity, design for value chain

1. Introduction

Companies are facing new and changing challenges caused by globalization of competition, dynamic requirements and shorter product life cycles. These trends are often encountered by the development of customized product variants, which increase complexity internally at the product level and also at the level of value and supply chain (Figure 1).

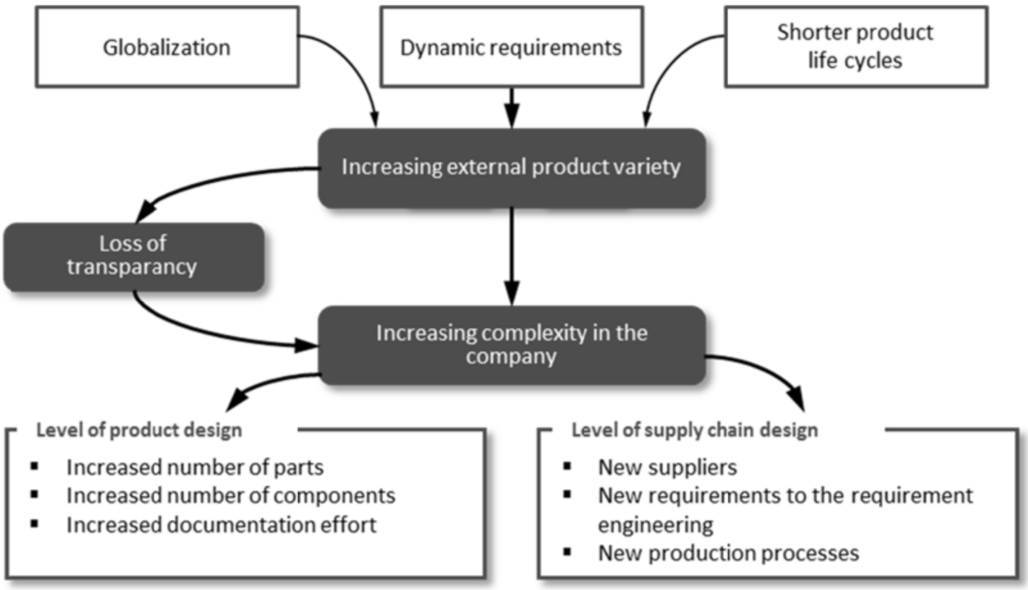

Figure 1. Causes and effects of product variety [Brosch 2011b]

To be able to fulfil the diverse and dynamic requirements of global markets, countries and customers, companies must deal with the question how an understanding of the current complexity in the global supply and product distribution can be used to reduce, control and avoid complexity in the early stages of the product development process. However, an analysis of different complexity management approaches has shown that existing methods either focus on the level of the product design or on the level of the value and supply chain design [Brosch 2011].

An existing method of complexity management is the integrated PKT-approach for developing modular product families (Integrated PKT-approach) created by the Institute for Product Development

and Mechanical Engineering Design (PKT). This approach adapts the product architecture to offer a high external variety on the market without increasing the internal diversity in the company in the same extend. The approach currently focuses on the product level of complexity management. Elements of the approach are the modules Design for Variety and Life Phases Modularisation. The aim of Design for Variety is designing variant-friendly products which are close to the ideal product family, e.g. default and variant components are decoupled from each other and a 1:1 correspondence of differentiating features and components is achieved.
By the Life Phases Modularisation modular structures can be developed that are aligned with different life phases. Objective is not the definition of one product structure, but the definition of multiple product structures, which are aligned to the needs of the corresponding life phases. Additional elements are under development to expand the approach [Krause 2011].
Since high product variety induces a high complexity at the level of the supply chain, as described above, an expansion of the integrated PKT-approach to the level of the supply chain is required. The extension focuses on the simultaneous management of complexity at supply chain and product level (Figure 2).

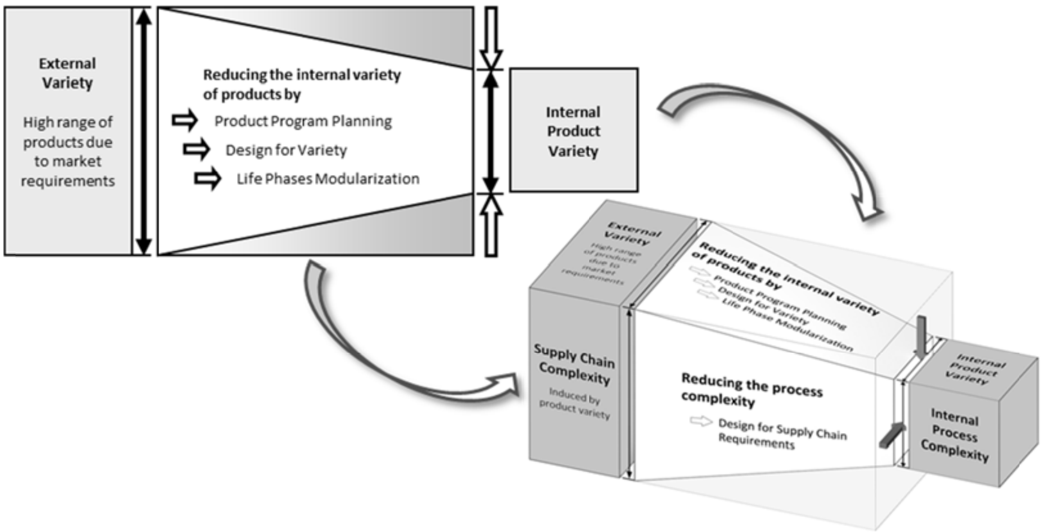

Figure 2. Integrated PKT-approach

This paper ‘toward an integration of supply chain requirements into the product development process’ subsequently describes the extension of the Integrated PKT-approach. From a practical study of the complexity occurring in the industry (Section 2), the need for supply chain specific requirement engineering is derived. The created approach will be described based on a literature review in the fields of complexity and requirements engineering (Section 3). The main research question of this paper is how the Integrated PKT-approach can be expanded to take the level of the supply chain into account. Emphasis is the analysis of the complexity and the complexity drivers within the supply chain and their subsequent conversion into supply chain requirements to the product and product development processes.

2. Design for value chain – Industrial study to identify fields of action of complexity management

In the past, the methodological study Design for Value Chain was conducted to identify company specific fields of action of complexity management [cp. Brosch 2011].
The study Design for Value Chain proceeds in three steps. In the first step ascertainment and analysis of the order fulfilment processes take place. On this basis the second step is to identify the causes for the complexity, which are further described as complexity drivers. In the third step the identified company-specific complexity drivers are mapped to the generic fields of action within a complexity management. These fields of action were previously identified by a comprehensive literature review.

The linkage of identified fields of action to the complexity in the company conclusively allows deriving a customized package of measurements to reduce, avoid and handle the complexity. These three steps are explained in more detail in [Brosch 2011].
The implementation of this study and the evaluation of its results have identified the need for a value chain specific requirement engineering (Figure 3). Therefore, the requirements of the supply and value chain have to be integrated into the product development process to extend the integrated PKT-approach.

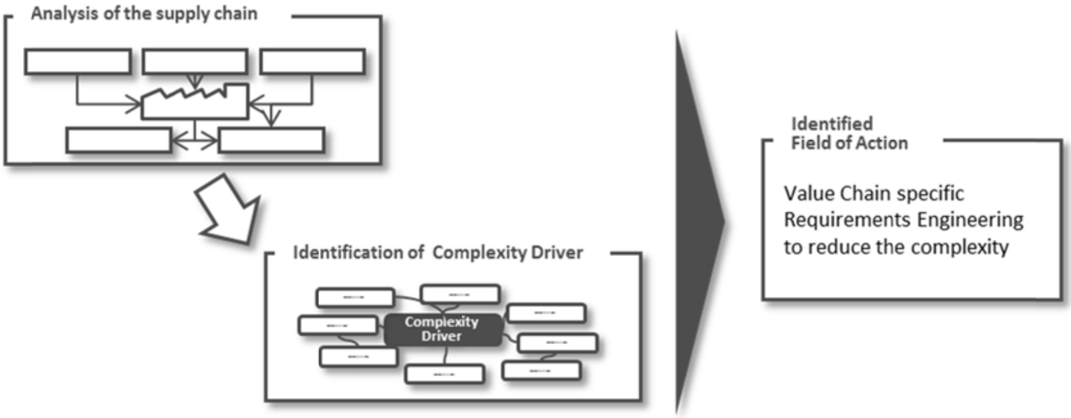

Figure 3. Design for value chain approach [cp. Brosch 2011]

3. State of the art

In the following, the concept of complexity and the requirements management and engineering is described. The concept of complexity was first investigated in detail by a literature research and a framework for complexity was derived using four different perspectives. Then complexity is classified in the context of Design for Supply Chain Requirements. Requirements management and engineering is analysed and described from the perspective of the methodical product development.

3.1 Complexity

First, the concept of complexity has to be considered closer as it is nowadays a frequently used buzzword which is often used interchangeable with the term complicated. A comprehensive literature research was conducted in [Brosch 2011a]. Dealing with complexity varies from scientific fields such as biology or physics, to engineering science like systems theory, cybernetics and theoretical computer science, to scientific fields like sociology. Thereby, not only one, but many definitions of complexity exist [Abdelkafi 2008]. For a general and holistic understanding of complexity a framework for complexity is derived, which distinguishes four different perspectives (design property, reference, appearance and impact) (Figure 4).
Within the perspective of the design features the definition of complexity is based on the characteristics of the number and variety of system elements, the relationships between these elements and the variability of the elements and relationships. In the case of the perspective of the appearance, a distinction is made between the objective and the subjective form of complexity. The objective form is due to the volume and heterogeneity of elements of the system and the subjective form is reflected by people who interact with the system. At the perspective of the references it depends on the level of detail, whether a system is defined as a complex system. At the perspective of the impact, the business relevance of complexity and its positive or negative characteristics is considered. In general, a system can be defined neither as complex nor as not complex. Complexity is a gradual property that depends on the perspectives described above [Brosch 2011a].
In summary, complexity can be understood as a design property, which has both an objective and a subjective appearance. This complexity is the reason for additional efforts, the use of additional resources and an increased need for information for the global enterprise [Brosch 2011a].

The subjective complexity can be reduced through staff training or by increasing the transparency. Different visualization tools are used within the Design for Supply chain Requirements to increase the transparency. The objective complexity should be reduced by integrating the supply chain requirements into product development process.

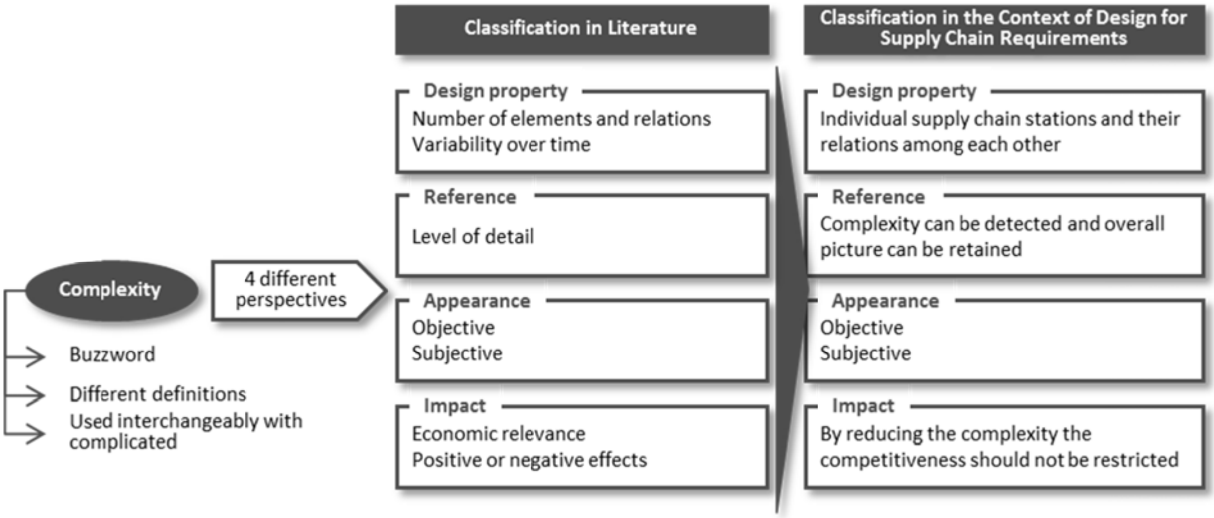

Figure 4. Classification of the literature in four different perspectives

3.2 Requirements management and engineering

The goal of requirements management and engineering is to achieve a common understanding of the system to be developed between the contractor (company) and client (customer). At the same time, the resulting documents are often used as a contractual basis for the implementation.
According to Ebert, the requirements engineering is divided into the requirements analysis and requirements management. The requirement analysis consists of collecting, documenting, testing and handling requirements. The requirements management includes describing the processes and entrepreneurial objectives [Ebert 2008].
The classical design methodology (cp. [Lindemann 2009], [Pahl 2007], [Ulrich 2011]) describes the technical requirements list as one of the most important documents within the product development process. It must continually be updated. To create this list of requirements the following questions have to be clarified in close collaboration with the customer:

- What is the purpose of the planned solution?
- Which properties should be fulfilled and which not?

The entirety of requirements must result in a product with the desired functionality and the desired quality. The main supplier of requirements is the end user. Before a product arrives at the end user, multilevel customer-supplier relationships exist. Therefore, the requirements of the interim customers have to be considered as well (Figure 5).

Figure 5. Resources for requirements [Lindemann 2009]

A frequently used method for mapping customer requirements to the product and its subsystems is the V-model. The V-shape expresses that at every step, a conceptual equivalent verification or validation step occurs. For example, the necessary requirements of the user are specified in a requirements specification for each sublevel of the system. During the realization of the individual subsystems, fulfilment with this specification is tested [Ebert 2008].

4. Design for supply chain requirements

The study Design for Value Chain showed that supply chain requirements are not yet integrated into the product development process. The approach of the Design for Supply Chain Requirements will close the identified gap and expand the integrated PKT-approach to the level of the supply chain. Design for Supply Chain Requirements consists of several blocks, which need to be connected to a common approach and have to be integrated into the product development process. Figure 6 shows the different blocks, which are described below and a possible connection.

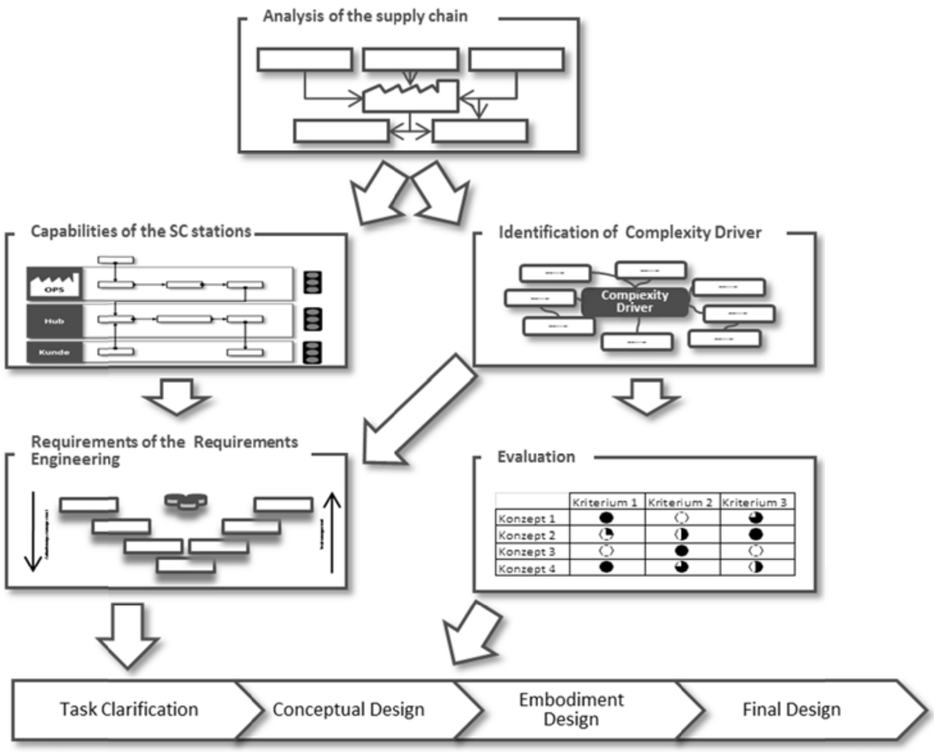

Figure 6. Connection of the different blocks of the design for supply chain requirements

4.1 Ascertainment and visualization of the order fulfilment process

The ascertainment and analysis of the processes can be performed either by reviewing existing documents, interview discussions with experts or by the observation of the processes. The level of detail depends on the framework conditions and the general aim of modelling. On one hand, the complexity need to be detected, on the other hand the overall picture has to be retained and the expense of the ascertainment has to be in relation to the benefit. The application of the approach shows that the processes have to be considered both globally and locally. In terms of global goods distribution through a global company a structural representation of the Supply Chain is provided. This offers a quick overview of the existing supply chain stations, their number and geographical location and the existing flow of goods. At this level of detail, however, no complex processes of the value chain can be visualized. For this reason, the processes of the local value and supply chain stations are visualised using swimlane diagrams. Those processes are ascertained, which are planned for the Value and Supply Chain stations at this time and will be called actual-plan-process. Thereupon for each increasing complexity scenario, a further representation is received, in which the additional sub-processes are marked in grey. These are called actual-complexity-process. The increase in complexity by increasing the number of elements (sub-processes), their compounds and their time-variability can thus be represented. These different scenarios are put together in one illustration to visualize the complexity in the order fulfilment process. Due to small numbers in the lower right corner of the grey boxes, complexity can be assigned to their scenarios [Brosch 2011]. This ascertaining and analysing of the order fulfilment process is shown in Figure 7.

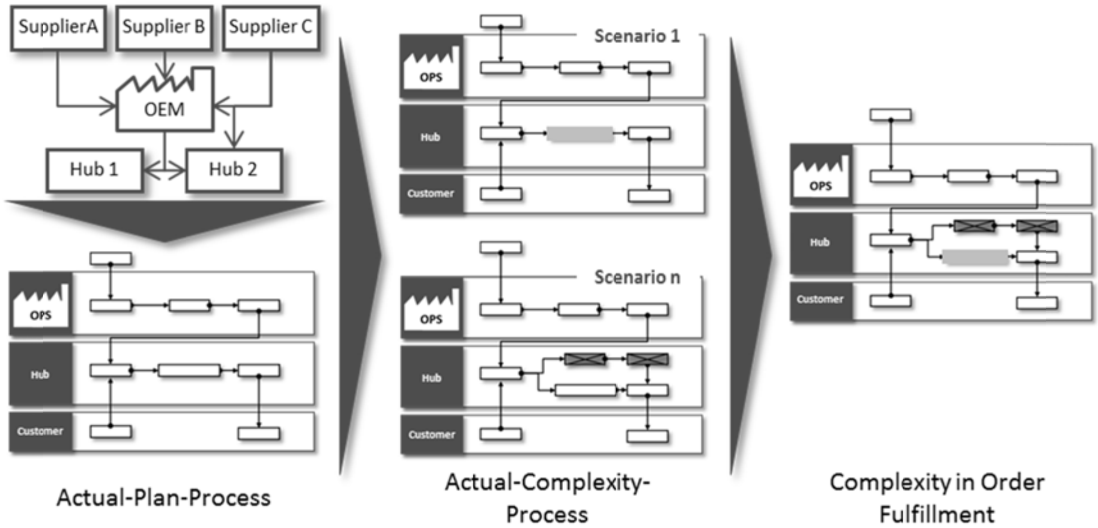

Figure 7. Ascertainment and visualization of the order fulfilment process

4.2 Identification of complexity drivers

The result of this analysis step is a structured collection of complexity drivers. If additional unplanned process steps are generated by the complexity drivers or planned process steps must be run several times, they are illustrated in a further swimlane diagram. The causes of this complexity and other complexity driver are structured using lists or mind maps (Figure 8). Examples of such complexity drivers are limited capabilities of computer systems or dynamically changing customer requirements.

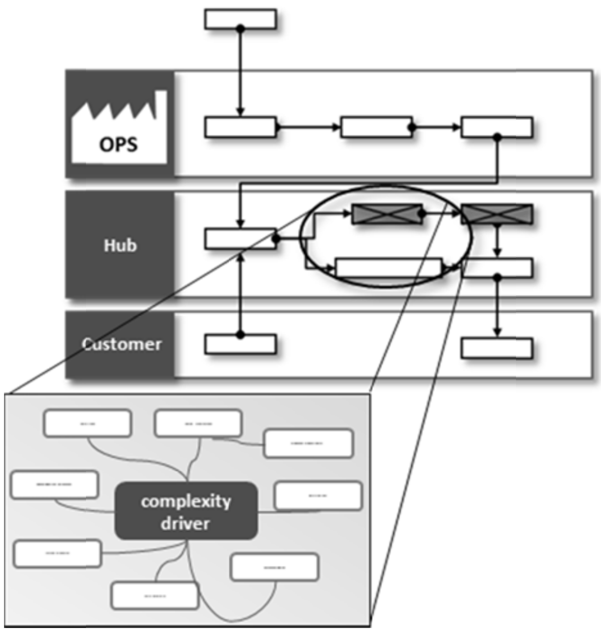

Figure 8. Identification of complexity drivers

4.3 Detection and visualization of the supply chain capabilities

Besides, the purely quantitative ascertainment of the value chain, the technical and capacitive capabilities of each supply chain station are recorded within this step of the Design for Supply chain Requirements approach. Especially within the product development, such information is highly relevant in deciding on the manufacturing strategy. If, for example, one hub is able to calibrate the electrical equipment or to conduct a separate testing on parts, but another hub is not able to do this, the product development needs this information to customize the product and the production structure. Even more when deciding on the modularization of a product, the knowledge of such capabilities is essential to identify module drivers or module restrictions and their specifications in the supply chain.

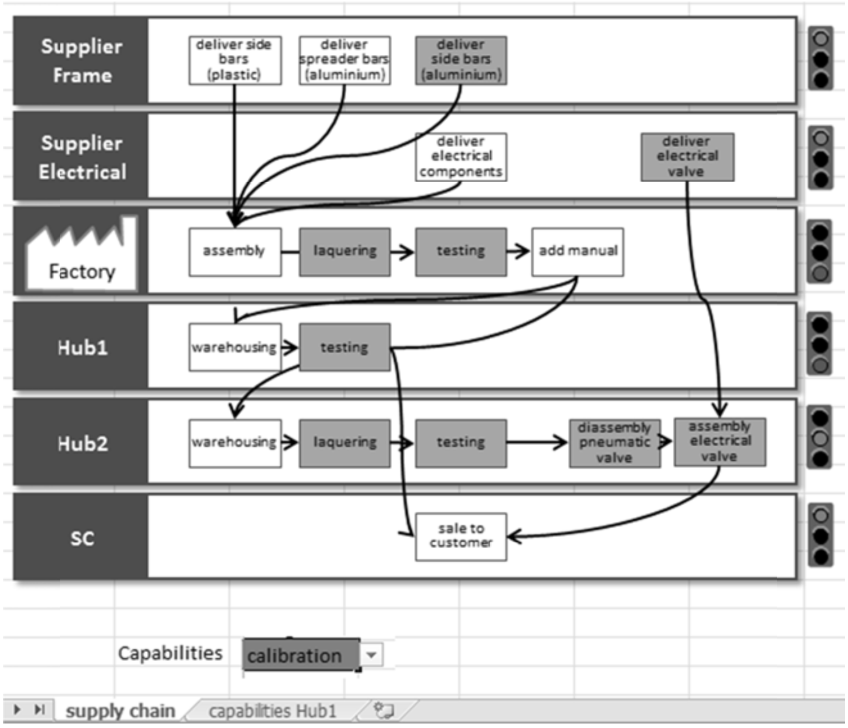

Figure 9. Capabilities of the supply chain stations

Figure 9 shows the capabilities of the supply chain stations using a traffic light display (reducing the subjective perspective of complexity). Currently this visual display is Excel based. Below is a selection field in which different capabilities can be selected. The traffic lights at the right edge of the swim lanes indicate whether this capability is available (green), whether certain conditions must be changed (orange) or whether the capability is not available (red) [Brosch 2011b].

4.4 Requirements of the requirements engineering

The goal of requirements engineering is generally the preparation of a contract specification as a basis for the future product development process. For this purpose the required properties by the customer have to be converted into specific characteristics of the product [Weber 2008].

These requirements are then assigned to the different hierarchical levels of the product, according to the V-model. To reduce the internal complexity further requirements have to be considered within the requirements engineering. The product has to pass through the existing or planned supply chain without increasing the complexity. Therefore, the requirements of the supply chain (that is an internal customer) and all the supply chain stations have to be taken into account at all levels (Figure 10). It is required to use an additional and internal supply chain specific V-model on each hierarchical level of the original V-model. In this case the following questions are relevant:

- In which countries should the product be sold?
- How are the internal requirements of the requirements engineering ascertained and prioritized?
- How is the transparency of the requirements engineering ensured?

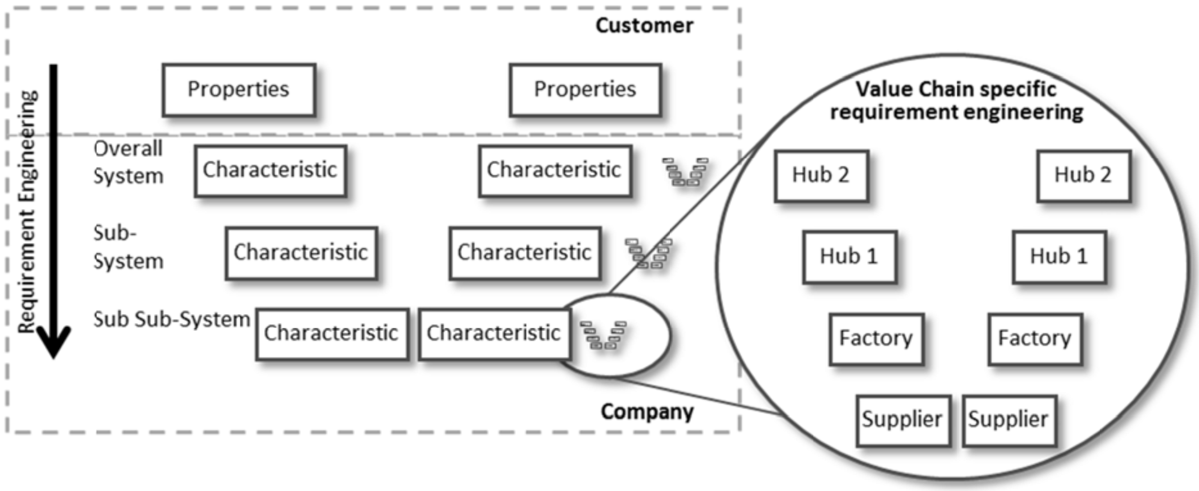

Figure 10. Internal supply chain specific V-model on each hierarchical level

4.5 Evaluation regarding the supply and value chain capabilities

The different methods and KPIs (Key Performance Indicator) to evaluate complexity in literature can be roughly divided into three groups. This subdivision is shown in Figure 11. There are cost-based evaluation methods, which show the positive or negative impact of complexity to the company's result; the implicit evaluation methods, which evaluate the complexity and diversity based on the number of elements, as well as the point of product differentiation and the entropy-based and in information theory used evaluation methods, which evaluate the density of information and the uncertainty of the system.

To evaluate the complexity of different product concepts, the question arises, which information is available, which information can easily be purchased and which information exceeds the value of the procurement effort. It may be questioned whether, the information is sufficient to work with exact figures within the early conceptual design phases. Based on these considerations, some factors of complexity within the supply chain need to be identified using the identified complexity driver (subsection 4.2.). An evaluation of the product concepts in the early stages of product development process is then realised by an interdisciplinary team based on the identified factors and the list of requirements.

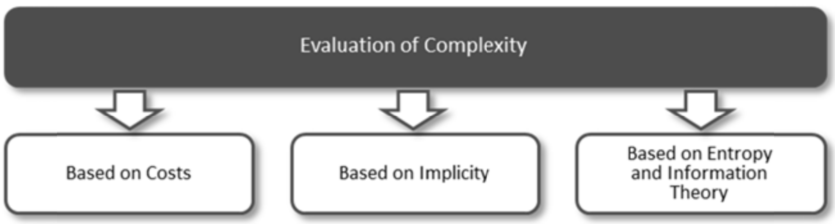

Figure 11. Subdivision of evaluation methods and KPIs

4.6 Future crosslinking of the support through knowledge management

The possible support of the Design for Supply Chain Requirements method using knowledge management is a subject of further research. Concepts are under development that supports a more directed knowledge allocation from the company to the Design for Supply Chain Requirements method. The employees working on the different stations of the value chain will get a possibility to continuously push their specific knowledge about requirements to the development department. This requires not only a sufficient infrastructure, but also the staffs' awareness of the relevance of knowledge. In addition knowledge will be gathered (pulled) from the supply chain stations at settled points in time. The recorded supply chain knowledge will be integrated into the development process after filtering and processing. This objective is the establishment of a continuous complexity improvement process within the companies (Figure 12). This requires continuing reflection of the success of implemented complexity management measure throughout the product life. Findings from comparing the set complexity management objectives with the achieved complexity reduction can then be used to improve the use of future products. A perquisite for this reflection is to ensure that the company and product specific concept to reduce complexity is communicated from the Design for Supply Chain Requirements project team to all supply chain stations in order to reach the desired improvements.

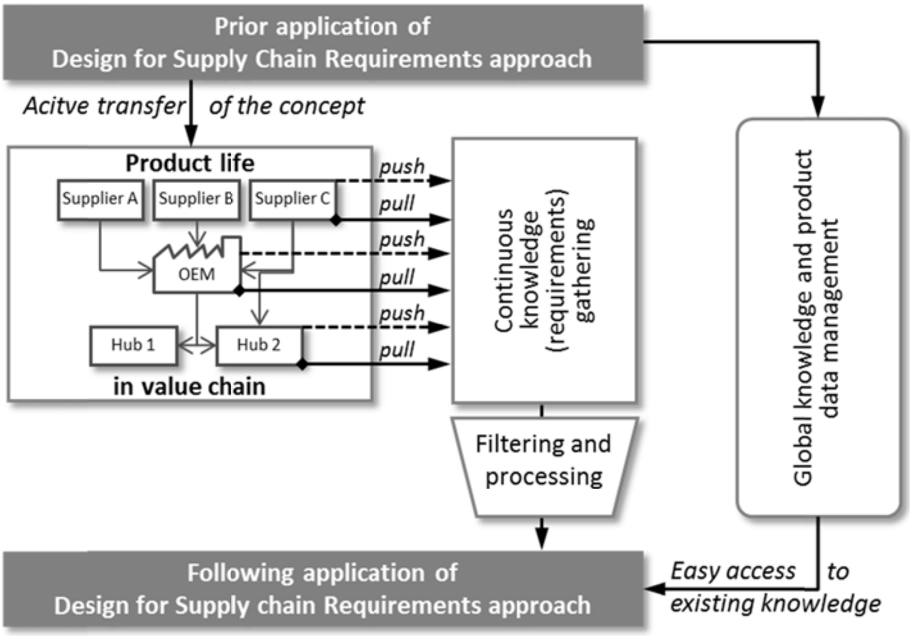

Figure 12. Knowledge based continuous complexity improvement process

Finally, knowledge management provides a link to the global knowledge and product data management. This offers the potential to make existing company knowledge easily accessible to the project team. On the other hand, knowledge is generated by applying the method and needs to be feed to the knowledge base of the company. For example, the created transparency of complexity could be of great value to other departments and needs to be shared.

5. Conclusion and prospect

The described approach Design for Supply Chain Requirements consists of the blocks analysis of the supply chain, identification of complexity driver, requirements of the requirements engineering, evaluation of the concepts, integration into the product development process and the support through knowledge management. Its aim is to extend the integrated PKT-approach to the level of supply chain and to reduce the internal supply chain complexity. From the analysis of the supply chain, the identification of the complexity and the complexity drivers, as well as the analysis of the capabilities of the supply chain stations, individual requirements to the requirements engineering are derived. Within this requirement engineering, the product requirements are identified at all levels of the V-model. These product requirements are needed within the task clarification phase of the product development process. However, requirement lists should be updated constantly. Therefore, the requirements management and engineering is also taken into account during the other phases of the product development process. Evaluating the different product concepts take place during the conceptual design phase. Design for Supply Chain Requirements is framed by the knowledge management (not shown in the picture).

The first three blocks of the approach have already been implemented successfully in an industrial project. The details of this extension need to be elaborated in more detail in the future and its utility need to be verified in future studies in the industry.

References

Abdelkafi, N. (2008), Variety-induced complexity in mass customization, Dissertation, Techn. Univ., Inst. für Logistik und Unternehmensführung, Berlin, Hamburg-Harburg.

Brosch, M., and D. Krause (2011a), Complexity from the Perspective of the Design for Supply Chain Requirements, in GIC-PRODESC Proceedings, edited by T. Blecker, and M. Pero, TuTech Innovation. Hamburg.

Brosch, M., and D. Krause (2011b), Design for Supply Chain Requirements. An approach to detect the capabilities to postpone, in International Design Engineering Technical Conferences & Computers and Information in Engineering Conference. IDETC/CIE , edited by ASME.

Brosch, M., G. Beckmann, Griesbach Marc, J. Dalhöfer, and D. Krause (2011), Design for Value Chain. Ausrichtung des Komplexitätsmanagements auf globale Wertschöpfungsketten, ZWF , 11, 855–860.

Ebert, C. (2008), Systematisches Requirements Engineering und Management. Anforderungen ermitteln, spezifizieren, analysieren und verwalten, 2nd ed., 417pp., dpunkt-Verl, Heidelberg.

Krause, D., and S. Eilmus (2011), A Methodical Approach for Developing Modular Product Families, in Proceedings of the 18th International Conference on Engineering Design (ICED 11), Impacting Society through Engineering Design, DS / Design Society, vol. 68, edited by S. J. Culley, pp. 299–308, Design Society. Glasgow.

Lindemann, U. (2009), Methodische Entwicklung technischer Produkte. Methoden flexibel und situationsgerecht anwenden, VDI-Buch, 3rd ed., Online-Ressource, Springer-Verlag Berlin Heidelberg, Berlin, Heidelberg.

Pahl, G., W. Beitz, L. Blessing, J. Feldhusen, K.-H. Grote, and K. Wallace (2007), Engineering Design. A Systematic Approach, Online-Ressource, Springer-Verlag London Limited, London.

Ulrich, K. T., and S. D. Eppinger (2011), Product design and development, 5th ed., XVI, 415 S., McGraw-Hill Irwin, New York, NY.

Weber, C. (2008), How to Derive Application-specific Design Methodologies, in 10th International Design Conference Design 2008, May 19 - 22, 2008, Cavtat - Dubrovnik, Croatia. [proceedings], edited by D. Marjanović, pp. 69–80. Zagreb.

M.Sc. Max Brosch
Research Assistant
Hamburg University of Technology, Institute of Product Development and Mechanical Engineering Design
Denickestr. 17, 21073 Hamburg, Germany
Telephone: +49 40 42878 2661
Telefax: +49 40 42878 2296
Email: max.brosch@tuhh.de
URL: http://www.tu-harburg.de/pkt