Vogel, Wolfgang; Lasch, Rainer

**Conference Paper**

# Approach for Complexity Management in Variant-rich Product Development

Proceedings of the Hamburg International Conference of Logistics (HICL) – 22

**Wolfgang Vogel and Rainer Lasch**

# Approach for Complexity Management in Variant-rich Product Development


Published in: Operational Excellence in Logistics and Supply Chains
Thorsten Blecker, Wolfgang Kersten and Christian M. Ringle (Eds.), August 2015, epubli GmbH
ISBN (online): 978-3-7375-4058-2, ISBN (print): 978-3-7375-4056-8
ISSN (online): 2365-5070, ISSN (print): 2635-4430

# Approach for Complexity Management in Variant-rich Product Development

*Wolfgang Vogel and Rainer Lasch*

During the last years, companies in high-technology marketplaces were confronted with technology innovations, dynamic markets, changing customer requirements and uncertainty. Manufacturing companies can't escape these trends. To cope with these trends, companies try to develop new product variants, which lead to increased complexity. Product development is characterized by different factors such as product, product portfolio and the development process. Complexity management in product development is a strategic issue for companies to be competitive. A systematic literature review was performed to identify and analyze the existing approaches for complexity management in all fields. Based on this, a new approach for managing complexity in variant-rich product development was developed. It encourages the reader to manage product development's complexity. In this approach, complexity is systematically analyzed and evaluated to create conditions for a target oriented managing and controlling of complexity in product development.

Keywords: Complexity, Complexity Management, Approach, Product Development

# 1 Introduction

Developing and producing individual and complex products for diversified marketplaces at minimum cost is the challenge of the 21st century. Within the last decades, complexity in the company has increased continuously in many industries (Schuh, Arnoscht and Rudolf, 2010, p.1928; Lübke, 2007, pp.2-4; Krause, Franke and Gausemeier, 2007, pp.3-4; ElMaraghy, et al., 2012, p.797). Companies in high-technology marketplaces are confronted with technology innovation, dynamic environmental conditions, changing customer requirements, market globalization and uncertainty. These are trends that manufacturing companies can´t escape (Miragliotta, Perona and Portioli-Staudacher, 2002, p.382; Gerschberger, et al., 2012, p.1016). In today's highly competitive environment it is fundamental for a company's success to bring new products to the market quickly and with customized settings (Augusto Cauchick Miguel, 2007, p.617; Lübke, 2007, pp.2-3). As a reaction, the companies are present in the market with a diversified product portfolio (Haumann, et al., 2012, p.107; ElMaraghy and ElMaraghy, 2014, pp.1-2). Product development is one of the most complex and nontransparent tasks and uncertain processes in the company (Bick and Drexl-Wittbecker, 2008, p.20; Davila, 2000, p.386; Specht and Beckmann, 1996, p.25-26). Product development process is confronted with several complexity factors such as demand variety, uncertain objectives, environmental dynamics, high time pressure and restricted resources (Wildemann, 2012, p.202). Dehnen (2004, pp.33-35) argues that complexity in product development comes generally from a variety of internal and external sources, called complexity drivers. Complexity drivers describe a system's complex-

ity and help to evaluate and handle it. Complexity management is a strategic issue for companies to be competitive (Miragliotta, Perona and Portioli-Staudacher, 2002, p.383).

The purpose of this paper is to present a praxis-oriented approach for managing complexity in variant-rich product development. The approach was developed based on literature and encourages the reader to manage product development's complexity. Section 2 gives a literature overview about complexity management, their properties, requirements and objectives. Furthermore, an overview of existing complexity management approaches in different fields is presented. As a result of the existing complexity management approaches, a new approach for complexity management in variant-rich product development is described in section 3 and is applied on a recent development project in the automotive industry. Section 4 and 5 conclude the paper and close the research gap with implications for future research.

# 2 Literature Review

## 2.1 Complexity Management

The origin of the term complexity comes from the Latin word "complexus", which means "entwined, twisted together" (Miragliotty, Perona and Portioli-Staudacher, 2002, p.383). Based on systems theory, complexity is characterized by the amount and diversity of a system's elements, the amount and type of dependencies and the variation of the elements and their dependencies over time (Kersten, 2011, p.15). Thus, complex systems are characterized by the variety of their states (Schuh, 2005, pp.34-35).

Generally in literature, increasing complexity is related to increasing costs (Meyer, 2007, p.94). For example, modifications in product design or process are responsible for product or process variety and generate additional costs. Furthermore, such modifications may have unpredictable effects on the whole development process (Aggeri and Segrestin, 2007, p.38).

Managing a system's complexity requires an optimum fit between internal and external complexity. Managing complexity comprises designing the necessary variety, handling variety-increasing factors, reducing variety and controlling complex systems (Schuh, 2005, pp.34-35). Generally, complexity management has several objectives. In literature, the main objectives are reducing, mastering and avoiding complexity (Wildemann, 2012, p.69; Lasch and Gießmann, 2009a, p.198; Schuh and Schwenk, 2001, pp.32-40; Kaiser, 1995, p.102). Wildemann (2012, p.69) defines these objectives as the three main strategies for complexity management. In addition to the three complexity strategies, Krause, Franke and Gausemeier (2007, pp.15-16) argue that complexity identification, complexity evaluation and the determination of the optimum complexity degree are also important objectives for complexity management and to improve transparency.

Complexity management requires approaches for understanding, simplification, transformation and evaluation of complexity (Hünerberg and Mann, 2009, p.3). A successful complexity management approach enables a balance between external market's complexity and internal company's complexity (Rosemann, 1998, p.61; Kaiser, 1995, p.17). Therefore, it is necessary to implement complexity management in company's management process as an integrated concept (Kersten, 2011, pp.17-18).

Product development is mainly characterized by three categories: product, product portfolio and product development process. Based on these categories, the complexity drivers product complexity, product portfolio complexity and process complexity are derived. Complexity drivers are factors or indicators, which influence a system's complexity (Puhl, 1999, p.31; Perona and Miragliotta, 2004, p.104). Thus, managing complexity in product development requires a detailed complexity analysis in these categories (Dehnen, 2004, p.9). Beyond the mentioned categories, Ponn and Lindemann (2008, p.7) argue that the applied methods and instruments in product development are also important aspects.

Product complexity is characterized by product design, the number of elements or materials and their interdependencies as well as the dynamics of products activity. Product activity consists of the rate at which new products are introduced or existing products are changed (Edersheim and Wilson, 1992, pp.27-33; Kirchhof, 2003, p.40). Product portfolio complexity is determined by the product range or the variant range, the number of their elements and the dynamics of product portfolio's variability (Kirchhof, 2003, p.40; Lübke, 2007, p.173; Schoeller, 2009, p.50). Process complexity is mainly characterized by process design, process dynamics and multidimensional target expectation. Process design contains of the number of direct and indirect process steps, their interdependencies, the design of process interfaces, the level of difficulty as well as the controllability and consistency of each step. Process dynamics refer to the rate at which processes or product design and operational parameters are changing. Operational parameters could be tolerances (Edersheim and Wilson, 1992, pp.28-34;

Klabunde, 2003, p.8; Kirchhof, 2003, p.40). Furthermore, process complexity describes the multidimensional demand for a structural coordination between different interfaces (Dehnen, 2004, p.34). According to complexity management's objectives and product development's characteristics, the requirements for a complexity management approach in variant-rich product development must be defined. In literature, several requirements for a complexity management approach exist. According to Lasch and Gießmann (2009a, pp.203-206), we defined eleven main requirements and assigned them to the following three main categories:

- ¾ Structural: Recurring cycle, modular structure.
- ¾ Functional: Practicability and transparency, identifying the complexity problem, methods for complexity management, application of key figures, approach for capability planning.
- ¾ Cause related: Identifying complexity drivers, identifying complexity drivers' interdependencies, evaluation of complexity drivers, evaluation of complexity (degree).

## 2.2 Research Methodology and Results

This paper's purpose is to develop a praxis-oriented approach for managing complexity in variant-rich product development. Before developing a new approach, existing literature must be identified, analyzed and evaluated. For this literature review, we determined two research questions:
RQ1: What different approaches currently exist in scientific literature?
RQ2: What structure and focuses do the existing approaches have?
The first step in conducting a literature research is to define the right search terms based on the research questions. In literature, the terms "approach",

"model", "method", "concept", "procedure" and "framework" are often used synonymously for describing a complexity management approach. Thus, all terms were used for this literature research. Furthermore, to extend the results and to prevent the elimination of important articles, the research was performed in English and German by using the following six databases, specialized in science and economics: Emerald, ScienceDirect, IEEE Xplore, Google Scholar, GENIOS/WISO and SpringerLink. No restrictions were made regarding the research period. The researched literature sources were synthesized based on the aforementioned research questions. This resulted in forty-seven relevant approaches in the time period between 1992 and 2014 (see Table 1 and 2). Fifty-seven percent of the existing approaches are focused on general in manufacturing companies. The remaining forty-three percent are separated in other fields such as product development (6.1 percent), procurement (2.0 percent), production (10.2 percent), logistics (4.1 percent), internal supply chain (16.3 percent) and distribution (4.1 percent). Only three approaches are focused on product development. In the next step, the identified approaches are analyzed and described according to their structure and targets (see Table 1 and 2). Furthermore, the existing approaches are evaluated based on the described requirements to identify deficits (see Table 3 and 4). The evaluation is based on the following three criteria:

- ¾ Fulfilled (+ +): Content and precise methods are described
- ¾ Partial fulfilled (+): Content are described without precise methods
- ¾ Not fulfilled (-): Content and methods are not described

Table 1 Overview about existing approaches (Part 1)

| **Explanation for focus:**<br>G General in manufacturing companies<br>PD Product Development<br>PC Procurement<br>PR Production<br>L Logistics<br>SC Internal Supply Chain<br>D Distribution<br>**Explanation for evaluation criteria:**<br>++ fulfilled<br>+ partial fulfilled<br>- not fulfilled<br>**Author(s)** | **Focus** | **Approach's structure** | | | | | | | **Target** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Complexity analysis | Complexity evaluation | Determine complexity strategy | Determine complexity instruments | Complexity planning | Implement complexity management | Complexity controlling | Product complexity | Process complexity | Product portfolio complexity |
| Grossmann (1992) | G | ● | | | ● | | ● | | - | - | - |
| Wildemann (1995) | PR | | | ● | ● | | | | - | - | - |
| Fricker (1996) | G | ● | ● | | | | | | - | - | - |
| Warnecke and Puhl (1997) | G | ● | ● | ● | | | | | - | + | - |
| Bliss (1998) | G | | | ● | | | | | ++ | - | - |
| Bohne (1998) | G | ● | ● | ● | | | | ● | - | - | - |
| Rosemann (1998) | G | | | ● | | | | | - | - | - |
| Puhl (1999) | G | ● | | | | ● | | ● | - | + | - |
| Wildemann (1999) | PC | | | ● | | | | | - | - | - |
| Bliss (2000) | G | | | ● | | | | | ++ | - | - |
| Westphal (2000) | L | | | ● | | | | | - | - | - |
| Miragliotta, Perona and Portioli-Staudacher (2002) | G | ● | ● | ● | ● | | | | - | - | - |
| Kim and Wilemon (2003) | PD | | ● | ● | | | ● | | - | - | - |
| Kirchhof (2003) | G | ● | | | | ● | | | - | - | - |
| Dehnen (2004) | PD | | | ● | | | | | ++ | ++ | ++ |
| Hanenkamp (2004) | PR | | | ● | | ● | ● | ● | + | + | - |
| Meier and Hanenkamp (2004) | SC | ● | | ● | ● | | | | - | - | - |
| Perona and Miragliotta (2004) | PR, L | ● | | ● | | | | | - | - | - |
| Blecker, Kersten and Meyer (2005) | G | ● | ● | | | | | | - | - | - |
| Geimer (2005) | SC | ● | | ● | | | ● | | - | - | - |
| Geimer and Schulze (2005) | SC | ● | | ● | | | ● | ● | - | - | - |
| Anderson et al. (2006) | G | ● | ● | ● | | | | | - | - | - |
| Greitemeyer and Ulrich (2006) | G | ● | | ● | | ● | | ● | + | + | - |
| Denk (2007) | G | ● | | ● | | | | | - | - | - |

Table 2 Overview about existing approaches (Part 2)

| **Explanation for focus:** | | **Approach's structure** | | | | | | | **Target** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G General in manufacturing companies<br>PD Product Development<br>PC Procurement<br>PR Production<br>L Logistics<br>SC Internal Supply Chain<br>D Distribution<br>**Explanation for evaluation criteria:**<br>++ fulfilled<br>+ partial fulfilled<br>- not fulfilled | **Focus** | Complexity analysis | Complexity evaluation | Determine complexity strategy | Determine complexity instruments | Complexity planning | Implement complexity management | Complexity controlling | Product complexity | Process complexity | Product protfolio complexity |
| **Author(s)** | | | | | | | | | | | |
| Marti (2007) | G | | ● | ● | | | | | ++ | - | - |
| Meyer (2007) | D | ● | | ● | | | | ● | - | - | - |
| Bick and Drexl-Wittbecker (2008) | G | | | ● | | | | | ++ | ++ | - |
| Schuh et al. (2008) | G | ● | | | | | | | ++ | - | - |
| Denk and Pfneissl (2009) | G | ● | | ● | | | | | - | - | - |
| Lasch and Gießmann (2009b) | G | ● | ● | ● | | ● | ● | ● | + | + | + |
| Lindemann, Maurer and Braun (2009) | PD | ● | | ● | | | | | + | - | - |
| Blockus (2010) | G | ● | | ● | | ● | | ● | - | - | - |
| Warnecke (2010) | G | ● | ● | ● | | | | | - | - | - |
| Isik (2011) | SC | ● | ● | ● | | | | ● | - | - | - |
| Kersten (2011) | SC | ● | ● | ● | | | | | - | - | - |
| Schawel and Billing (2011) | G | ● | | ● | | | | | - | - | - |
| Fabig and Haasper (2012) | G | ● | | ● | ● | | ● | | + | - | + |
| Koch (2012) | G | ● | ● | ● | | | | | - | - | - |
| Lammers (2012) | D | ● | ● | | ● | | | | - | - | - |
| Aelker, Bauernhansl and Ehm (2013) | SC | ● | ● | ● | | | | | - | - | - |
| Boyksen and Kotlik (2013) | G | ● | | ● | | | | | - | - | - |
| Jäger et al. (2013) | PR, SC | ● | ● | ● | ● | | | | - | - | - |
| Meier and Bojarski (2013) | G | ● | ● | | | | | | ++ | ++ | - |
| Serdarasan (2013) | SC | ● | ● | ● | ● | | | | - | - | - |
| Grimm, Schuller and Wilhelmer (2014) | G | ● | | ● | ● | | ● | ● | - | - | - |
| Schöttl et al. (2014) | PR | ● | ● | | ● | | | | - | + | - |
| Wassmus (2014) | G | ● | | ● | | | ● | ● | ++ | - | - |

Table 3 Overview about existing approaches (Part 3)

| **Explanation for evaluation criteria:**<br>++ fulfilled<br>+ partial fulfilled<br>- not fulfilled | **Evaluation criteria** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Author(s)** | Recurring cycle | Modular structure | Practicability | Transparency | Identifying the complexity problem | Methods for complexity management | Application of key figures | Approach for capability planning | Identification of complexity drivers | Complexity drivers' interdependencies | Evaluation of complexity drivers | Evaluation of complexity (degree) |
| Grossmann (1992) | - | - | ++ | + | ++ | ++ | + | - | - | - | - | - |
| Wildemann (1995) | - | ++ | - | - | - | ++ | - | - | - | - | - | ++ |
| Fricker (1996) | - | - | + | ++ | ++ | ++ | - | - | + | - | - | - |
| Warnecke and Puhl (1997) | ++ | + | ++ | + | - | ++ | - | - | ++ | - | ++ | ++ |
| Bliss (1998) | ++ | - | ++ | + | - | ++ | - | - | - | - | - | + |
| Bohne (1998) | + | - | + | ++ | + | ++ | - | - | - | - | - | - |
| Rosemann (1998) | - | - | + | - | - | ++ | - | - | - | - | - | - |
| Puhl (1999) | ++ | ++ | ++ | ++ | + | ++ | + | - | + | + | + | ++ |
| Wildemann (1999) | - | - | ++ | - | - | ++ | - | - | - | - | - | - |
| Bliss (2000) | ++ | - | ++ | + | - | ++ | - | - | - | - | - | + |
| Westphal (2000) | - | - | - | - | - | ++ | - | - | - | - | - | - |
| Miragliotta, Perona and Portioli-Staudacher (2002) | + | - | + | ++ | - | - | - | - | + | + | - | + |
| Kim and Wilemon (2003) | + | - | + | ++ | + | - | + | - | + | - | + | - |
| Kirchhof (2003) | + | + | - | ++ | - | + | - | - | ++ | ++ | + | - |
| Dehnen (2004) | - | + | + | - | - | + | - | - | - | - | - | + |
| Hanenkamp (2004) | + | + | - | ++ | - | + | - | - | ++ | ++ | + | - |
| Meier and Hanenkamp (2004) | ++ | + | ++ | + | - | ++ | - | - | ++ | - | ++ | - |
| Perona and Miragliotta (2004) | - | - | + | ++ | - | - | - | - | - | - | - | - |
| Blecker, Kersten and Meyer (2005) | + | + | ++ | ++ | - | - | - | - | ++ | ++ | - | - |
| Geimer (2005) | - | - | - | ++ | + | ++ | - | - | + | - | - | - |
| Geimer and Schulze (2005) | - | - | + | ++ | + | ++ | - | - | + | - | - | - |
| Anderson et al. (2006) | - | - | - | + | - | - | - | - | - | - | - | - |
| Greitemeyer and Ulrich (2006) | - | - | + | ++ | - | - | + | - | - | - | - | + |
| Denk (2007) | - | + | - | ++ | - | - | - | - | - | - | - | - |

Table 4 Overview about existing approaches (Part 4)

| **Explanation for evaluation criteria:**<br>++ fulfilled<br>+ partial fulfilled<br>- not fulfilled | **Evaluation criteria** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Author(s)** | Recurring cycle | Modular structure | Practicability | Transparency | Identifying the complexity problem | Methods for complexity management | Application of key figures | Approach for capability planning | Identification of complexity drivers | Complexity drivers' interdependencies | Evaluation of complexity drivers | Evaluation of complexity (degree) |
| Marti (2007) | - | - | ++ | ++ | - | + | - | - | - | - | - | + |
| Meyer (2007) | ++ | ++ | ++ | ++ | - | ++ | + | - | ++ | ++ | + | - |
| Bick and Drexl-Wittbecker (2008) | - | - | + | + | + | + | - | - | - | - | - | - |
| Schuh et al. (2008) | - | + | - | + | + | - | - | - | - | - | - | - |
| Denk and Pfneissl (2009) | - | + | - | ++ | - | - | - | - | - | - | - | - |
| Lasch and Gießmann (2009b) | ++ | - | + | - | + | ++ | + | - | ++ | ++ | + | + |
| Lindemann, Maurer and Braun (2009) | - | - | - | + | + | + | - | - | - | - | - | - |
| Blockus (2010) | - | - | + | ++ | - | + | + | - | - | - | - | - |
| Warnecke (2010) | - | - | + | + | - | + | - | - | - | - | - | + |
| Isik (2011) | - | - | + | ++ | + | - | - | - | + | + | - | - |
| Kersten (2011) | - | - | + | + | - | + | - | - | ++ | + | - | - |
| Schawel and Billing (2011) | - | - | + | ++ | - | ++ | - | - | ++ | ++ | + | - |
| Fabig and Haasper (2012) | + | - | - | - | - | + | - | - | - | - | - | - |
| Koch (2012) | - | - | - | + | - | - | - | - | - | - | - | - |
| Lammers (2012) | - | - | + | ++ | + | ++ | - | - | ++ | ++ | ++ | - |
| Aelker, Bauernhansl and Ehm (2013) | - | - | - | + | - | - | - | - | + | - | - | + |
| Boyksen and Kotlik (2013) | ++ | - | + | + | - | - | - | - | + | - | + | + |
| Jäger et al. (2013) | + | - | - | + | - | - | + | - | + | - | - | + |
| Meier and Bojarski (2013) | + | + | + | ++ | - | + | - | - | - | - | - | - |
| Serdarasan (2013) | ++ | + | - | + | - | - | - | - | + | - | - | + |
| Grimm, Schuller and Wilhelmer (2014) | + | - | + | + | + | - | - | - | + | - | - | - |
| Schöttl et al. (2014) | - | - | + | + | ++ | + | - | - | + | - | ++ | - |
| Wassmus (2014) | ++ | + | - | + | - | + | - | - | - | - | - | - |

In the first step, the structure and the targets of all identified approaches are analyzed to identify commonalities and differences. Based on this analysis, seven stages of complexity management can be identified and were applied in literature: complexity analysis (N: 36; 77%), complexity evaluation (N: 19; 40%), determination of complexity strategies (N: 38; 81%), determination of appropriate complexity instruments (N: 10; 21%), complexity planning (N: 6; 13%), complexity management's implementation (N: 9; 19%) and complexity controlling (N: 11; 23%). The most applied stages are determination of complexity strategies, complexity analysis and evaluation. Thus, these stages are very important. However, there is no approach, which consists of all stages.

Complexity management in product development is determined by product complexity, process complexity and product portfolio complexity. This is the reason why we analyzed the literature according to these categories. Most of the existing approaches have no explicit target or focus. Only one approach exists with a focus on all mentioned complexity categories.

In the next step, the identified approaches are evaluated based on the defined eleven main requirements. As a result, there is no approach, which fulfills all requirements in total or partial. The evaluation criteria practicability (N: 31; 66%), transparency (N: 40; 85%) and methods for complexity management (N: 31; 66%) are the most fulfilled or partially fulfilled requirements. Thus, the existing approaches are mostly focused on these criteria. They can be defined as the approach's objectives.

In summary, an approach which consists of all stages and categories and fulfills all requirements in total or partially does not exist yet. With our complexity management approach we cover this research gap.

# 3 Complexity Management in Variant-rich Product Development

In our literature review, we identified seven stages, which were applied for complexity management in the company.

Product development is characterized by variety, dynamics, complex and nontransparent tasks and uncertain processes (Wildemann, 2012, p.202; Bick and Drexl-Wittbecker, 2008, p.20; Davila, 2000, p.386; Specht and Beckmann, 1996, pp.25-26). This leads to an increasing risk in product development (Specht and Beckmann, 1996, p.25). For risk management, four stages are described in literature: analysis, evaluation, regulation and controlling of risks (Ahrendts and Marton, 2008, p.14; Schawel and Billing, 2011, p.165). Complexity and risk are closely connected because of their characteristics (Specht and Beckmann, 1996, pp.25-26). Thus, risk management's four stages can also be applied for complexity management.

Considering product development's characteristics, we developed a four stages complexity management approach for variant-rich product development based on the existing literature and the risk management strategies (see Figure 1). The approach is focused on product development's three main dimensions product complexity, product portfolio complexity and process complexity (Dehnen, 2004, p.9) and comprises the seven stages. The approach is designed as a recurring cycle with a modular structure to fulfill the structural requirements of a complexity management approach. Furthermore, different methods and tools for complexity management are described to gain practicability.

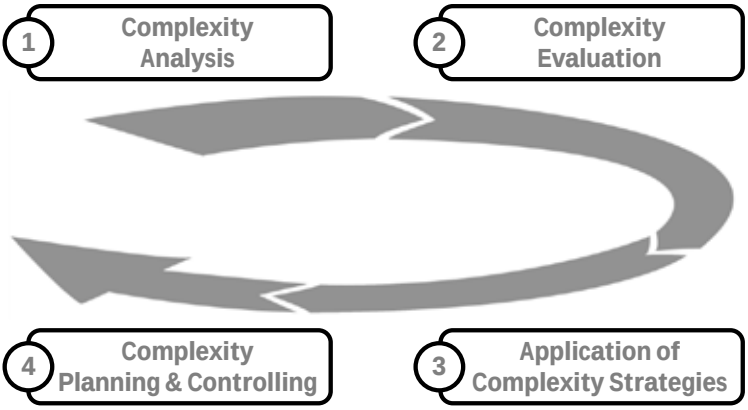


Figure 1 Four stage complexity management approach

The new approach was applied on a recent development project in the automotive industry to verify the scientific results. Cars are probably the most complex mass-produced industrial products in the market, because they combine many different parts, components, technologies and functions. The development process takes between three to four years and involves hundreds of engineers, technicians and partners (Moisdon and Weil, 1996, cited in Aggeri and Segrestin, 2007, p.38). In the last years, automotive companies increased their product portfolio successively to gain market shares and to be competitive. Complex products such as cars consist not only of mechanical and electrical parts and components but also of software, control modules and human-machine interfaces (ElMaraghy, et al., 2012, p.793), which influence each other and lead to an increasing complexity.

## 3.1 Complexity Analysis

Complexity in a project, especially in product development, requires a detailed complexity analysis (Warnecke, 2010, p.640) to increase transparency and to fulfill the functional requirements (see chapter 2.1). The first step is to formulate and distinguish the tangible problem and to derive the demand for action (Grossmann, 1992, p.209; Fricker, 1996, p.113; Schöttl, et al., 2013, p.258). Hauschildt (1977, p.127) argues that problem complexity is related to a problem's structure, its parts and uncertainty. For analyzing the complexity problem, Schöttl, et al. (2013, p.258) use individual questionnaires. The second step is to identify and analyze the complexity drivers. Complexity driver's analysis and understanding is the basis for developing a clear strategy for managing complexity (Serdarasan, 2013, p.533). In literature, several approaches for complexity driver's identification exist. The most applied approaches are expert interviews, process or systems analysis and influence analysis. In the third step, product variants are analyzed in detail to identify product's commonalities and differences and to identify the main attributes, which characterize a product variant. Variant's analysis and the main attributes are the basis for generating a variant derivation matrix in terms of an effective variant management (Nurcahya, 2009, pp.59-68). Variants are products with a high proportion of identical components in the categories geometry, material or technology (Lingnau, 1994, p.24). DIN 199 (1977 cited in Schwenk-Willi, 2001, pp.22-23) defines variants as objects with similar form or function and a high proportion of identical groups or components.

In our case study, the investigated object was the powertrain of a car. To identify the complexity problem in the product development department,

we used expert interviews and questionnaires. The result was that the product portfolio increased in the last years continuously to gain market shares. However, the available budget and the development time for projects are decreasing successively. Another problem is that the variants are characterized by different complexity levels. Thus, the management is faced to develop an increased powertrain product portfolio in less time with the same or less input and resources.

For a detailed problem and complexity analysis, the powertrain was abstracted to a product model (see Figure 2) (Nurcahya, 2009, pp.59-62). The product model is an abstraction of a real product and contains all relevant elements or modules for product's characterization (Nurcahya, 2009, pp.54-61). This model is the basis for complexity driver's identification, analysis and evaluation. In our case study, the product model of a powertrain is divided into five main modules (engine, induction system, fuel injection system, exhaust system and drivetrain) and contains forty-eight relevant elements (turbocharger, injection valve, catalytic converter, etc.).

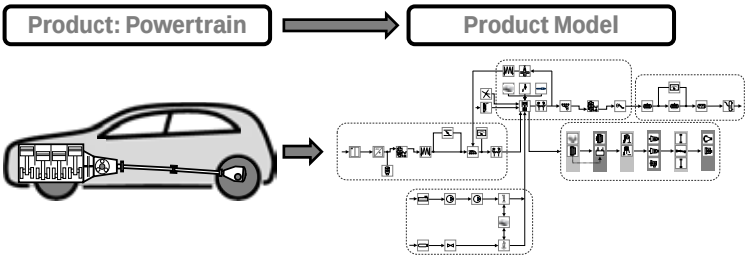


Figure 2 Powertrain product model

Next, the complexity drivers were identified and analyzed by using different approaches in the three categories product, product portfolio and process.

- ¾ Product: Literature, expert interviews, questionnaires, workshop, influence analysis.
- ¾ Product portfolio: Expert interviews, workshops, variant tree
- ¾ Process: Process analysis, expert interviews, workshops

In the third step, the product portfolio is analyzed to identify commonalities and differences. Based on product and complexity driver's analysis, the main attributes, which characterize a product variant, were defined.
Product portfolio can be divided in reference variants, product variants, product groups and product families. The reference variant is the most complex variant within a product family and the basis for variant's derivation. Product variants are derived from reference variants and clustered within the product family. A product group consists of several product families. Within a product family, the variants are similar with respect to specified criteria (Nurcahya, 2009, pp.52-55). Next, all reference and product variants within a product family are compared according to their characteristics to identify commonalities and differences (Nurcahya, 2009, pp.66-67). Nurcahya developed a matrix for variants' comparison. The matrix shows, which variants have the same characteristics and can be derived from another.
In our case study, a powertrain variant can be described by twenty different attributes (e.g. engine; transmission; time to market; etc.). Within the attributes, different product variants exist (e.g. 3.0l, 2.5l or 2.0l engine; auto-

matic or manual transmission; etc.). According to product complexity, development effort and time to market, the most complex and expensive product in the product portfolio, launched first in market is the reference variant, called lead. Product variants which can be derived from a lead-variant are called derivates. According to their complexity, development effort and time to market, derivates can be further separated in different sizes such as large, middle and small. As a result of this classification, a product portfolio can be clustered into four different groups: lead, derivate large, derivate middle and derivate small. Based on the described attributes, we analyzed and evaluated the product portfolio to identify commonalities and differences. Furthermore, we clustered the variants according to the product classification and developed a derivation matrix with expert's cooperation. Basically, the derivation matrix is similar to an influence matrix and shows, which variant can be derived from another. Figure 3 shows a derivation matrix for the main attributes "engine" (3.0l, 2.5l or 2.0l) and "transmission" (automatic or manual) and an example for clustering a product portfolio consisting of five variants with different market launches. With the derivation matrix, the powertrain portfolio can be analyzed and clustered into the four different groups. In the example, the reference variant, called lead variant (L), is the powertrain with a 3.0l engine and an automatic transmission. The lead is the most complex variant, launched first in the market at the time of T0. All other variants are derivates from the lead with different sizes and launched after T0.

**Attributes**

Engine

Transmission
AT: Automatic
MT: Manual

Time to Market

**Product Classification**

| | |
|---|---|
| L | LEAD |
| DL | Derivate large |
| DM | Derivate medium |
| DS | Derivate small |
| - - - | No Derivation |

Direction of Derivation

| | | 3.0l AT | 3.0l MT | 2.5l AT | 2.5l MT | 2.0l AT | 2.0l MT |
|---|---|---|---|---|---|---|---|
| 3.0l | AT | | - - - | - - - | - - - | - - - | - - - |
| 3.0l | MT | DM | | - - - | - - - | - - - | - - - |
| 2.5l | AT | DS | DM | | DM | DM | DL |
| 2.5l | MT | DM | DS | DM | | DL | DM |
| 2.0l | AT | DS | DM | DS | DM | | DM |
| 2.0l | MT | DM | DS | DM | DS | DM | |

**Example**

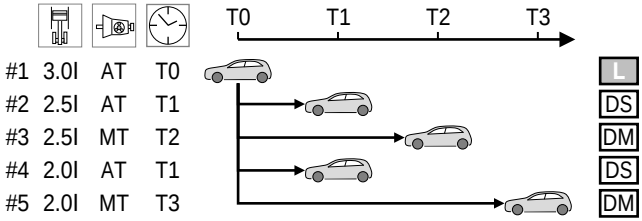


Figure 3 Derivation matrix and example

## 3.2 Complexity Evaluation

The second stage of our complexity approach comprises the complexity evaluation in the three categories product, product portfolio and process. The objective of evaluation in general is to emphasize commonalities and differences between relating object's properties (Kieser and Kubicek, 1983, p.174). Beyond, complexity evaluation is the basis for application of the right complexity strategy in the next stage of our approach.

Complexity management's objective is to achieve a company's optimum complexity degree, where internal and external complexity are equal (Schuh, 2005, p.43; Boyksen and Kotlik, 2013, p.49; Reiß, 1993, pp.133-134). In product development, internal complexity is characterized by product, product portfolio and process complexity (Dehnen, 2004, pp.33-35). External complexity is characterized by environmental, demand and competitive complexity (Dehnen, 2004, pp.33-35). Thus, company's optimum complexity degree can be achieved by evaluating and managing internal complexity. According to systems theory, a system's complexity degree is characterized by the amount of elements, their dependencies and the amount of system's conditions, so called variety (Curran, Elliger and Rüdiger, 2008, p.162; Malik, 2002, p.186). Malik (2002, p.186) argues that complexity can be quantified by variety. In literature, no uniform definition and measuring scale for a complexity degree exists. Höge (1995, pp.31-32), Greitemeyer and Ulrich (2006, p.8) state that the optimum complexity degree and measuring scale must be planned company-specific according to each company's strategy. To achieve a company's optimum complexity, internal complexity must be analyzed and evaluated. In our case study, we developed

three complexity indices on the basis of variety to evaluate product development's internal complexity in the categories product, process and product portfolio. According to Kieser and Kubicek, the objective is to compare different development projects in the categories to identify complexity trends over time.

### 3.2.1 Product Complexity Index (PDCI)

ElMaraghy and ElMaraghy (2014, p.5) described a product complexity index to characterize a product and to measure, how complex a product is. The measurement is based on variety. According to ElMaraghy and ElMaraghy, we also developed a PDCI, based on the product and the difference of variety ($\triangle\ Cn$) within the identified product complexity driver's categories. In our evaluation, the complexity drivers were weighted according to development effort, costs and time ($WF_{Cn}$), because some drivers are more complex than others. The most complex drivers have the weighting factor 1.0. The weighting factors of other drivers are defined in comparison to the most complex driver.

The PDCI is formulated as the weighted average of variety difference in all product complexity driver's categories ($Cn$). N is the maximum amount of product complexity driver's categories and n is the category's number.

$$PDCI = \frac{\sum_{n=1}^{N}(\Delta Cn * WF_{Cn})}{N} \quad (1)$$

The PDCI represents the percentage increase or decrease of development effort or costs, in comparison to the basis. Figure 4 shows an example for calculating a PDCI of two powertrain development projects. Project #1 is

already completed while project #2 is currently developed. For comparison, we use seven complexity driver's categories (C1-C7): engine (C1), turbocharger (C2), valve controlling (C3), fuel injection system (C4), ignition system (C5), catalytic converter (C6) and transmission (C7). In the first step, the variety in the categories C1-C7 is identified for project #1 and #2. Next, the differences of variety ($\triangle\ Cn$) between project #1 and #2 are calculated, using project #1 as the basis. Then, the PDCI is calculated percentual considering different weighting factors. As a result, the new project #2 has a complexity increase of forty percent in comparison to project #1. In category two (C2) the variety of turbochargers in project #1 and #2 is identified. The finished project #1 had one turbocharger and the current project #2 has two different turbochargers. The difference ($\triangle\ Cn$) between project #2 and #1 is one. The basis is project #1, thus the variety in project #2 increased by 100 percent. The categories turbocharger (C2) and valve controlling (C3) have a weighting factor of 1.0, because they are the most complex drivers.

| | Product Complexity Driver's Categories Cn | | | | | | |
|---|---|---|---|---|---|---|---|
| | C1  | C2  | C3  | C4  | C5  | C6  | C7  |
| Variety in Cn Project #1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 |
| Variety in Cn Project #2 | 2 | 2 | 3 | 1 | 1 | 1 | 2 |
| $\triangle\ Cn_{Project\#1\ à\ \#2}$ | 0% | +100% | +200% | -50% | 0% | -50% | +100% |
| Weighting factor $WF_{Cn}$ | 0.8 | 1.0 | 1.0 | 0.6 | 0.7 | 0.9 | 0.6 |

**PDCI: +40%**

Figure 4 Example PDCI

### 3.2.2 Process Complexity Index (PRCI)

In literature, no process complexity index exists. Thus, we developed a PRCI analogously to PDCI. PRCI is based on the development process and the difference of variety within the identified process complexity driver's categories ($\Delta\ PrCn$). The complexity drivers were also weighted according to development effort and time ($WF_{PrCn}$). The PRCI is formulated as follows:

$$PRCI = \frac{\sum_{n=1}^{N}(\Delta \mathrm{Pr}Cn * WF_{PrCn})}{N} \quad (2)$$

Figure 5 shows an example for calculating a PRCI of two powertrain development projects. In this case, the process complexity drivers are the amount of different process steps (PrC1) and their conjunctions (PrC2) and the amount of interfaces to other subsections within the value chain (PrC3). The PRCI is calculated analogously to PDCI. As a result, the development process of project #2 has a complexity increase of twenty-six percent in comparison to project #1.

| | Process Complexity Driver's Categories PrCn | | |
|---|---|---|---|
| | PrC1 | PrC2 | PrC3 |
| Variety in PrCn Project #1 | 6 | 2 | 5 |
| Variety in PrCn Project #2 | 7 | 3 | 6 |
| $\Delta$ $PrCn_{Project\#1\ à\ \#2}$ | +17% | +50% | +20% |
| Weighting factor $WF_{PrCn}$ | 0.7 | 1.0 | 0.8 |
| | | **PRCI: +26%** | |

Figure 5 Example PRCI

### 3.2.3 Product Portfolio Complexity Index (PPCI)

Product portfolio complexity is another important part when evaluating product development's complexity. However, in literature no index for measuring product portfolio complexity exists. Based on product attributes (e.g. engine or transmission), product classification (e.g. lead or derivates) and derivation matrix, the product portfolio can be analyzed and clustered into different groups (leads and derivates) according to their characteristics. Next, the groups with equal product classifications are evaluated by the assignment of weighting factors. The weighting factors are also defined according to development effort, costs and time and represent single efforts. The lead variant is the most complex and expensive variant with the highest single effort and has the weighting factor 1.0. The weighting factors of the derivates (large, medium and small) are defined in comparison to the lead variant.

The PPCI is calculated by summing up the weighting factors ($WF_{Variant\ n}$), which were assigned to all variants in the product portfolio. N is the total amount of product variants in the product portfolio and n is the product variant's number. PPCI's unit are effort points (EP).

$$PPCI = \sum_{n=1}^{N} WF_{Variant\ n} \tag{3}$$

PPCI facilitates product portfolio's standardization to one measured value under consideration of product and process complexity and provides an overview about complexity in the product portfolio. Furthermore, PPCI describes the total effort, which is dedicated to develop a specific product portfolio. To quantify product portfolio complexity in our case study,

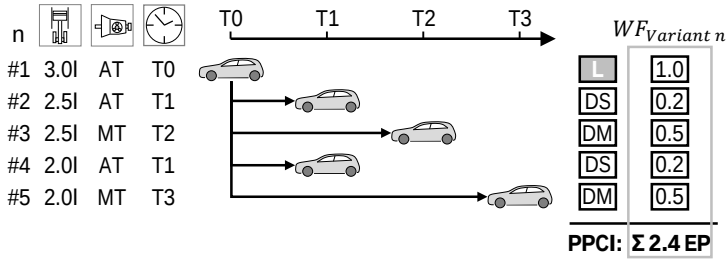


Figure 6 Example PPCI

we developed four weighting factors for our product classifications according to their complexity, development time and effort. The Lead-variant is the most complex variant in the portfolio and has the highest factor 1.0. The Derivates have weaker factors. Figure 6 shows an example for calculating the PPCI for a product portfolio with five powertrains.

In the next step, the product's development effort is identified and evaluated over product's launch time. The PPCI and the evaluated product portfolio are the basis for calculation. Therefore, the development efforts over time for the different product classifications (Lead or Derivate) were described. In our case study, the development efforts of a Lead-variant was separated consistently over a period of three years. The time period is determined by the company's experts. They divide the development efforts in different periods according to their development plan. The development efforts for our derivates were specified analogously. However, the periods were one year for small and two years for medium and large derivates. For calculation of the total development effort in a period, the particular efforts were summed up. Figure 7 shows an example for calculating the development effort over time for a product portfolio consisting of five powertrains.

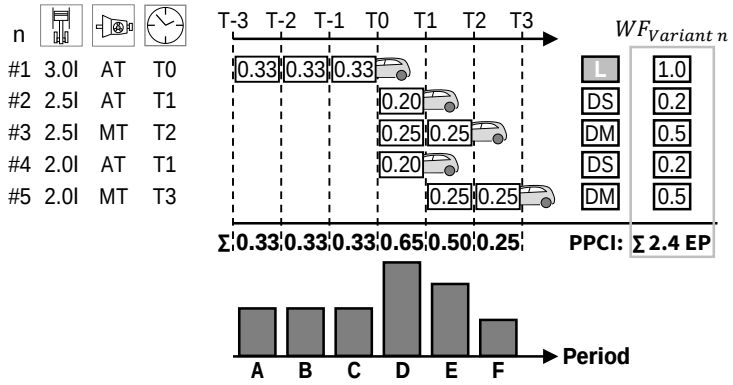


Figure 7 Calculating project's development effort over time

It can be seen that the maximum is achieved in period D because of the amount of variants, which were developed simultaneously. Furthermore, the PPCI can also be calculated as a number, called effort points.

## 3.3 Application of Complexity Strategies

In the third stage, the complexity strategies are presented for a company's complexity optimization. In literature, a vast number of different single approaches for managing complexity are described (Gießmann, 2010, pp.57-70). However, there is no specific instruction which approaches are the most effective for managing a specific complexity problem. An approach's application depends on the particular situation and must be planned company-specific. Generally, the approaches can be divided in four categories according to their focus: product, product portfolio, process and organization (Gießmann, 2010, pp.57-70).

Table 5 Applied single approaches for complexity management

| Focus | Approaches | Reduction | Mastering | Avoidance |
|---|---|---|---|---|
| Product | Modular concept | ✓✓✓ | ✓✓ | ✓ |
| | Modular system | ✓✓✓ | ✓✓ | ✓ |
| | Standardization | ✓✓✓ | ✓ | ✓✓ |
| | Using same parts | ✓✓✓ | ✓ | ✓✓ |
| | Platform concept | ✓✓✓ | ✓✓ | ✓ |
| | Differential construction | ✓✓✓ | ✓✓ | ✓ |
| | Integral construction | ✓✓✓ | ✓✓ | ✓ |
| Product portfolio | Packaging | ✓✓✓ | ✓✓ | |
| | Reducing product range | ✓✓✓ | | ✓✓ |
| | Reducing of customers | ✓✓✓ | | |
| Process | Postponement concept | ✓✓✓ | ✓✓ | ✓ |
| | Standardization of | ✓✓✓ | | ✓✓ |
| | Modularity of processes | ✓✓✓ | ✓✓ | ✓ |
| Organization | Delayering | ✓✓✓ | | |
| | Empowerment | ✓✓✓ | | |

✓✓✓ Priority 1 ✓✓ Priority 2 ✓ Priority 3

The approaches were mainly used for complexity reduction, mastering and avoidance. Table 5 presents an overview about the different approaches and their main purposes. The basis for Table 5 was our literature analysis.

In our research project we applied different single approaches for complexity reduction, mastering and avoidance in the categories product, product portfolio and process. The effects resulting of an approach's application are evaluated with our three indices to identify the approach's effectivity. The Figures 8-10 show three examples from our research project. In the first example (Figure 8), we use product standardization to reduce the variety in the categories turbocharger (C2) and valve controlling (C3) in project #2.

| **PDCI** | Product Complexity Driver's Categories Cn | | | | | | |
|---|---|---|---|---|---|---|---|
| Product standardization in C2 and C3 | C1 | C2 | C3 | C4 | C5 | C6 | C7 |
| Variety in Cn Project #1 | 2 | 1 | 1 | 2 | 1 | 2 | 1 |
| Variety in Cn Project #2 | 2 | ~~1~~ **1** | ~~2~~ **2** | 1 | 1 | 1 | 2 |
| $\Delta$ $Cn_{Project\#1 \text{ à } \#2}$ | 0% | 0% | +100% | -50% | 0% | -50% | +100% |

**PDCI: +~~40~~% è +12% Complexity Reduction**

Figure 8 Application of product standardization

| **PRCI** | Process Complexity Driver's Categories PrCn | | |
|---|---|---|---|
| Process standardization and modularization in PrC1 | PrC1 | PrC2 | PrC3 |
| Variety in PrCn Project #1 | 6 | 2 | 5 |
| Variety in PrCn Project #2 | ~~6~~ **5** | 3 | 6 |
| $\Delta$ $PrCn_{Project\#1 \text{ à } \#2}$ | -17% | +50% | +20% |

**PRCI: +~~26~~% è +18% Complexity Reduction**

Figure 9 Application of process standardization and modularization

After product standardization the current development project has one turbocharger and two valve controlling systems. Thus, the PDCI was reduced from forty to twelve percent.

Next, process standardization and modularization was applied in category PrC1 (see Figure 9). Different process steps were standardized and modularized to reduce the number from seven process steps to five. The PRCI was reduced from twenty-six percent to eighteen percent.

In the third example, we reduced product portfolio's complexity, development efforts and costs by reducing the product range (see Figure 10). Based on a cost-benefit analysis, company's experts decided to remove the variants #3 and #4 with weighting factors of 0.5 and 0.2 from the portfolio. The

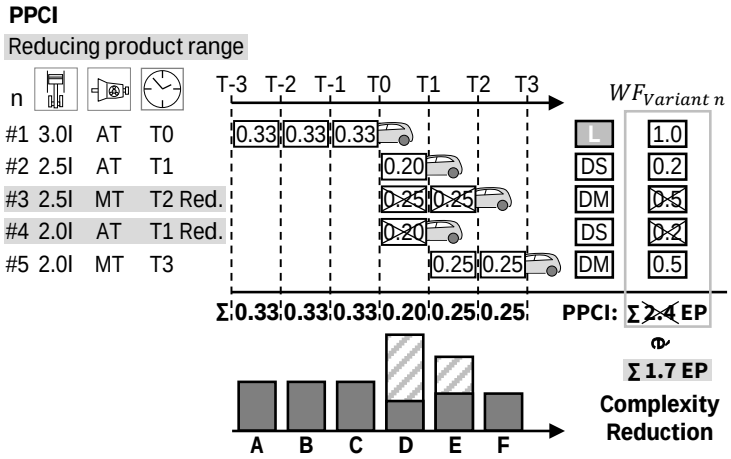


Figure 10 Application of reducing product range

PPCI was decreased from 2.4 to 1.7 effort points. In period D and E, the development effort also decreased from 0.65 EP (period D) and 0.5 EP (period E) to 0.20 EP (period D) and 0.25 EP (period E).

## 3.4 Complexity Planning and Controlling

Complexity planning and controlling are important elements for a target oriented complexity management. They provide a leverage point for an active complexity adjustment and help the company to prevent costs (Kirchhof, 2003, pp.166-167). Company's capacity planning contains of planning of resources (Schuh, Millarg and Göransson, 1998, p.49) and is an important factor for company's competitiveness (Krüger and Homp, 1997, p.10). Furthermore, it is the basis for complexity controlling (Jania, 2004, p.16). Re-

sources can be separated in tangible (e.g. equipment, facility) and intangible (e.g. technology, image) resources (Hungenberg, 2001, p.116). To reduce costs and time, it is necessary to apply the resources effectively. In product development, resources have a particular relevance, because the amount of available resources is restricted. Based on our research, product development's complexity has a high influence on the required resources and their planning. A detailed complexity planning increases transparency and enables the management to simulate different development scenarios to identify the optimum.

Complexity costs can be separated into direct and indirect costs. Direct costs consist of continuous (e.g. costs for serial supervision) and nonrecurring costs (e.g. test vehicle, test engine). Indirect costs are costs which generate no benefit growth (e.g. costs for increasing product range have no benefit because of product cannibalization) (Gießmann, 2010, p.39).

In our research project, we developed a complexity planning model based on literature and the results of complexity analysis and evaluation. The complexity indices are particularly important for this.

Kersten, Lammers and Skirde (2012, pp.28-30) developed a complexity vector with two dimensions for complexity driver's visualization and operationalization. The dimensions describe different points of view regarding complexity's occurrence and can be weighted. Different complexity drivers can be visualized in the vector space and thereby they can be compared with each other. The visualization can be used as a starting point for different strategies in complexity management. According to Kersten, Lammers and Skride, we developed a complexity vector $\overrightarrow{CI}$ with the two dimensions

product (PDCI) and process complexity index (PRCI). The two dimensions have the same weighting.

$$\overrightarrow{CI} = \begin{pmatrix} PDCI \\ PRCI \end{pmatrix} \tag{4}$$

Vector $\overrightarrow{CI}$ is visualized in the vector space. The vector's length $\left|\overrightarrow{CI}\right|$ represents development's project complexity. The distance between two complexity vectors describes the proportion for complexity reduction. The distance is calculated with Pythagoras' theorem.

$$\left|\overrightarrow{CI_{12}}\right| = \sqrt{(PDCI_1 - PDCI_2)^2 + (PRCI_1 - PRCI_2)^2} \tag{5}$$

In the first step of our complexity evaluation, we identified a $PDCI_1$ with forty percent and a $PRCI_1$ with twenty-six percent (see chapter 3.2) and generated the vector $\overrightarrow{CI_1}$ (see Figure 9). After complexity evaluation, we applied different single approaches to reduce the complexity indices (see chapter 3.3). $PDCI_2$ (twelve percent) and $PRCI_2$ (eighteen percent) are the basis of vector $\overrightarrow{CI_2}$. The distance between $\overrightarrow{CI_1}$ and $\overrightarrow{CI_2}$ is the proportion of complexity reduction. In our case study, the application of different single sources resulted in a complexity reduction of twenty-nine percent in total. For complexity planning, the length of $\overrightarrow{CI_2}$ is important, because it is directly associated to development project's complexity, development efforts and the amount of required resources (see Figure 11). Thus, the amount of required resources is directly proportional to the length of $\overrightarrow{CI_2}$ and the PPCI. The length of $\overrightarrow{CI_2}$ is twenty-two percent, thus the amount of resources in the periods A until F is also increased by this percentage.

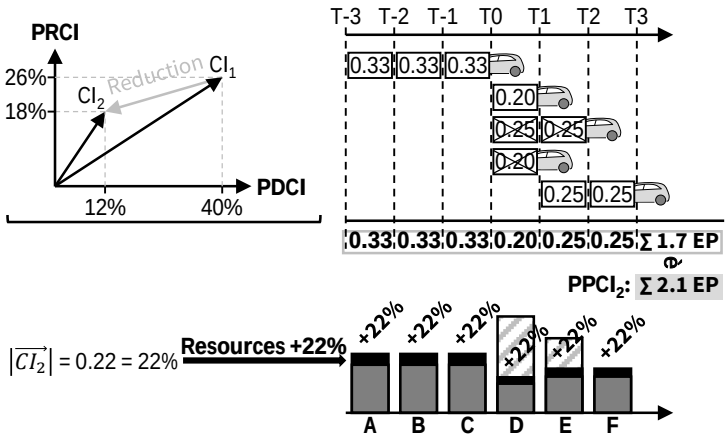


Figure 11 Complexity vector's influence on development effort

For calculating the precise amount of required resources (e.g. test vehicles), we determined a resource factor (RF) based on process analysis, expert interviews and workshops (e.g. 7 test vehicles per effort point). The resource factor represents the amount of resources which are required for a specific development effort. With the resource factor, the development efforts (EP) in each period can be translated in a precise amount of required resources. In Figure 12 we calculated the amount of test vehicles in period A based on the amount of effort points in period A and the RF for test vehicles. Calculation is based on Figure 11. This procedure was used analogously to develop cost factors for calculating development costs.

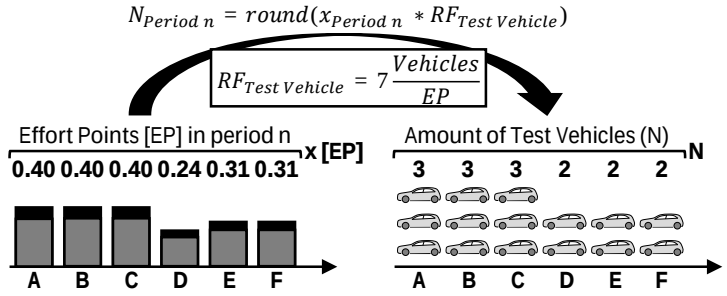


Figure 12 Calculating required resources based on resource factor

In product development, complexity controlling enables the management to compare the actual development efforts or costs of different projects with the planned values to identify weakness, potentials, and to influence company's development activities. The objective is to develop a complexity controlling system to fulfill this requirements and to provide a methodically principle (Jania, 2004, pp.15-17). For complexity controlling, key performance indicators (KPI) were used to gain transparency and to apply specific strategies in product development. KPI in different projects or function levels can be compared with reference values to identify discrepancy and increasing complexity (Gleich and Klein, 2013, pp.49-53). Furthermore, KPI are used to achieve company's objectives and are defined company specific (Kersten, 2011, p.17). KPI can be defined by comparison of costs and benefits (Gleich and Klein, 2013, p.53). Based on Kersten, Gleich and Klein, we developed project KPI ($KPI_{Project\ n}$) by comparing the applied amount of resources ($N_{Resources\ Project\ n}$) and project's PPCI. KPI are compared with reference values to identify discrepancies.

$$KPI_{Project\ n} = \frac{N_{Resources\ Project\ n}}{PPCI_{Project\ n}} \tag{6}$$

Figure 13 shows an example with two projects (A, B) in period A. The projects have different PPCIs, but the amount of applied resources (test vehicle) is equal. To compare the projects, the project KPIs for A and B are determined and compared with the reference value. In our case study, the reference is the resource factor for test vehicle. As comparison's result, project A is more efficient than project B ($KPI_{Project\ A} < KPI_{Project\ B}$). However, both projects show differences according to the reference. If the reasons for the differences are unclear, a further complexity analysis in stage one can be started. With this method, other KPIs can be developed analogously, such as for test engines or development costs.

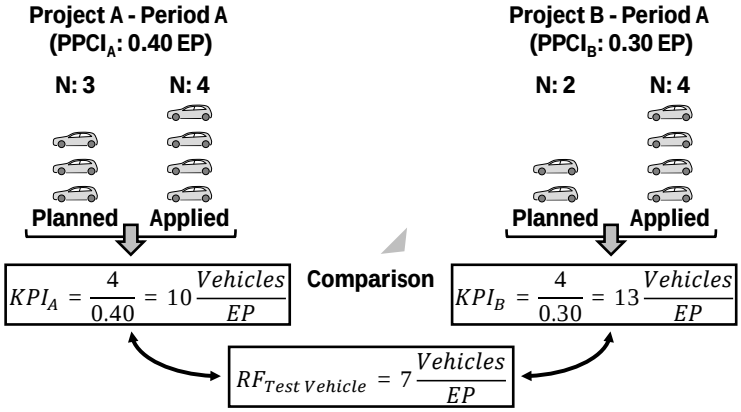


Figure 13 Calculating KPIs and comparison with planned values

## 4 Results and Discussion

The result of this paper is a four stage praxis-oriented approach for managing complexity in variant-rich product development. The approach was developed based on a detailed literature analysis and applied on a recent development project in the automotive industry. This paper describes the objectives and requirements of complexity management approaches and characterizes product development by three categories: product, product portfolio and process. Based on these categories, the complexity drivers are derived and described. For this research paper, we determined two research questions, which will be answered in the following manner. Before developing a new approach, the existing literature must be identified, analyzed and evaluated systematically. The identified approaches are analyzed according to their structure and focuses. In literature forty-seven complexity management approaches exist. However, an approach which fulfills all requirements in total or partially does not exist yet.

In summary, our approach applies all steps and categories and fulfills all requirements in total (see Table 6). In all stages we described different methods, which can be applied easily by the user. The new approach consists of a modular structure and a recurring cycle. The approach is focused on the three categories product, product portfolio and process and enables a detailed complexity analysis by identifying the complexity problem, the complexity drivers and their interdependencies (see chapter 3.1). After complexity analysis, complexity is evaluated and optimized by applying different complexity single approaches (see chapter 3.2 and 3.3). In the last stage, we developed an approach for capability and resource planning as well as complexity controlling by application of key figures (KPIs).

Table 6 Evaluation of our new complexity management approach

| Approach's structure | | | | | | | Target | | | Evaluation criteria | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Complexity analysis | Complexity evaluation | Determine complexity strategy | Determine complexity instruments | Complexity planning | Implement complexity management | Complexity controlling | Product complexity | Process complexity | Product portfolio complexity | Recurring cycle | Modular structure | Practicability | Transparency | Identifying the complexity problem | Methods for complexity management | Application of key figures | Approach for capability planning | Identification of complexity drivers | Complexity drivers' interdependencies | Evaluation of complexity drivers | Evaluation of complexity (degree) |
| ● | ● | ● | ● | ● | ● | ● | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ | ++ |

## 5 Conclusion

This paper's purpose was to close the research gap by analyzing existing literature and developing a praxis-oriented complexity management approach for variant-rich product development. In literature, such an approach does not exist yet. The existing approaches are focused on specific issues and do not fulfill all requirements in total or partial. This paper covers this literature gap. It provides a four stage complexity management approach and encourages the reader to manage product development's complexity. The approach was first applied in the automotive industry and verified in toy industry. Future research may include other sectors.

## References

Aelker, J., Bauernhansl, T. and Ehm, H., 2013. Managing complexity in supply chains: A discussion of current approaches on the example of the semiconductor industry. Procedia CIRP, 7, pp.79-84.

Aggeri, F. and Segrestin, B., 2007. Innovation and project development: an impossible equation? Lessons from an innovative automobile project development. R&D Management, 37(1), pp.37-47.

Ahrendts, F. and Marton, A., 2008. IT-Risikomanagement leben: Wirkungsvolle Umsetzung für Projekte in der Softwareentwicklung. Berlin: Springer Verlag.

Anderson, B., Hagen, C., Reifel, J. and Stettler, E., 2006. Complexity: customization's evil twin. Strategy & Leadership, 34(5), pp.19-27.

Augusto Cauchick Miguel, P., 2007. Innovative new product development: a study of selected QFD case studies. The TQM Magazine, 19(6), pp.617-625.

Bick, W. and Drexl-Wittbecker, S., 2008. Komplexität reduzieren: Konzept, Methode, Praxis. Stuttgart: LOG_X Verlag.

Blecker, T., Kersten, W. and Meyer, C., 2005. Development of an Approach for Analyzing Supply Chain Complexity, Hamburg University of Technology. Available at: <http://mpra.ub.uni-muenchen.de/5284/1/MPRA_paper_5284.pdf> [Accessed 18 March 2015].

Bliss, C. A., 1998. Komplexitätsreduktion und Komplexitätsbeherrschung bei der Schmitz-Anhänger Fahrzeugbau-Gesellschaft mbH. In: D. Adam, ed. 1998. Komplexitätsmanagement: Schriften zur Unternehmensführung. Wiesbaden: Gabler Verlag. pp.145-168.

Bliss, C. A., 2000. Management von Komplexität: Ein integrierter, systemtheoretischer Ansatz zur Komplexitätsreduktion. Wiesbaden: Betriebswirtschaftlicher Verlag.

Blockus, M.O., 2010. Komplexität in Dienstleistungsunternehmen: Komplexitätsformen, Kosten- und Nutzenwirkungen, empirische Befunde und Managementimplikationen. Wiesbaden: Gabler Verlag.

Bohne, F., 1998. Komplexitätskostenmanagement in der Automobilindustrie: Identifizierung und Gestaltung vielfaltsinduzierter Kosten. Wiesbaden: Gabler Verlag.

Boyksen, M. and Kotlik, L., 2013. Komplexitätscontrolling: Komplexität erkennen, bewerten und optimieren. Controller Magazin, November/Dezember 2013, pp.48-52.

Curran, C.S., Elliger, C. and Rüdiger, S., 2008. Komplexitätsmanagement: Wann ist viel schon zu viel?. Nachrichten aus der Chemie, 56(2), pp.160-162.

Davila, T., 2000. An empirical study on the drivers of management control systems' design in new product development. Accounting, Organizations and Society, 25, pp.383-409.

Dehnen, K., 2004. Strategisches Komplexitätsmanagement in der Produktentwicklung. Hamburg: Verlag Dr. Kovac.

Denk, R., 2007. Die 5α des Komplexitätsmanagements. CFO aktuell, February, pp.19-22.

Denk, R. and Pfneissl, T., 2009. Komplexitätsmanagement. Wien: Linde Verlag.

Edersheim, E. H. and Wilson, J., 1992. Complexity at Consumer Goods Companies: Naming and Taming the Beast. Journal of Cost Management, 6(36), pp.26-36.

ElMaraghy, W. H., ElMaraghy, H. A., Tomiyama, T. and Monostori, L., 2012. Complexity in engineering design and manufacturing. CIRP Annals - Manufacturing Technology, 61, pp.793-814.

ElMaraghy, H. A. and ElMaraghy, W. H., 2014. Variety, Complexity and Value Creation. In: M. F. Zaeh, ed. 2014. Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 5th International Conference on Changeable, Agile, Reconfigurable and Virtual Production (CARV 2013). Cham: Springer Verlag. pp.1-7.

Fabig, C. and Haasper, A., 2012. Komplexitätsmanagement im 21. Jahrhundert. In: C. Fabig, A. Haasper, eds. 2012. Complexigence: Komplexität verstehen und aktiv managen. Norderstedt: Books on Demand. pp.7-26.

Fricker, A. R., 1996. Eine Methodik zur Modellierung, Analyse und Gestaltung komplexer Produktionsstrukturen. Aachen: Verlag der Augustinus Buchhandlung.

Geimer, H., 2005. Komplexitätsmanagement globaler Supply Chains. HDM Praxis für Wirtschaftsinformatik, 42, pp.38-46.

Geimer, H. and Schulze, F., 2005. Die Beherrschung der Komplexität. Jahrbuch der Logistik, 19, pp.98-102.

Gerschberger, M., Engelhardt-Nowitzki, C., Kummer, S. and Staberhofer, F., 2012. A model to determine complexity in supply networks. Journal of Manufacturing Technology Management, 23(8), pp.1015-1037.

Gießmann, M., 2010. Komplexitätsmanagement in der Logistik - Kausalanalytische Untersuchung zum Einfluss der Beschaffungskomplexität auf den Logistikerfolg. Lohmar: Josef Eul Verlag.

Gleich, R. and Klein, A., 2013. Komplexitätscontrolling: Komplexität verstehen und beherrschen. Freiburg: Haufe Verlag.

Greitemeyer, J. and Ulrich, T., 2006. Komplexitätsmanagement im Mittelstand. Scope, April, pp.8-9.

Grimm, R., Schuller, M. and Wilhelmer, R., 2014. Portfoliomanagement in Unternehmen: Leitfaden für Manager und Investoren. Wiesbaden: Springer Gabler.

Grossmann, C., 1992. Komplexitätsbewältigung im Management: Anleitungen, integrierte Methodik und Anwendungsbeispiele. St. Gallen: Verlag GCN.

Hanenkamp, N., 2004. Entwicklung des Geschäftsprozesses Komplexitätsmanagement in der kundenindividuellen Serienfertigung: Ein Beitrag zum Informationsmanagement in mehrdimensional modellierten Produktionssystemen. Aachen: Shaker Verlag.

Haumann, M., Westermann, H.H., Seifert, S. and Butzer, S., 2012. Managing complexity - A methodology, exemplified by the industrial sector of remanufacturing. In: M. Björkman, ed. 2012. Proceedings of the 5th International Swedish Production Symposium SPS 12. Linköping: The Swedish Production Academy. pp.107-114.

Hauschildt, J., 1977. Entscheidungsziele: Zielbildung in innovativen Entscheidungsprozessen - theoretische Ansätze und empirische Prüfung. Tübingen: Mohr Verlag.

Höge, R., 1995. Organisatorische Segmentierung: Ein Instrument zur Komplexitätshandhabung. Wiesbaden: Deutscher Universitäts Verlag.

Hungenberg, H., 2001. Strategisches Management in Unternehmen: Ziele, Prozesse, Verfahren. 2nd ed. Wiesbaden: Gabler Verlag.

Hünerberg, R. and Mann, A., 2009. Komplexität und Ressourceneinsatz als Herausforderungen an die Unternehmensführung. In: R. Hünerberg and A. Mann, eds. 2009. Ganzheitliche Unternehmensführung in dynamischen Märkten. Wiesbaden: Gabler Verlag. pp. 1-14.

Isik, F., 2011. Complexity in Supply Chains: A New Approach to Quantitative Measurement of the Supply-Chain-Complexity. In: P. Li, ed. 2011. Supply Chain Management. Shanghai: InTech. pp. 417-432.

Jania, T., 2004. Änderungsmanagement auf Basis eines integrierten Prozess- und Produktdatenmodells mit dem Ziel einer durchgängigen Komplexitätsbewertung. Available at: <http://digital.ub.uni-paderborn.de/hs/content/titleinfo/3567> [Accessed 1 March 2015].

Jäger, J. M., Kluth, A., Sauer, M. and Schatz, A., 2013. Komplexitätsbewirtschaftung: Die neue Managementdisziplin in Produktion und Supply Chain. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 108(5), pp.341-343.

Kaiser, A., 1995. Integriertes Variantenmanagement mit Hilfe der Prozesskostenrechnung. Hallstadt: Rosch-Buch.

Kersten, W., 2011. Je komplexer, desto teurer und risikoreicher. io management, September/October, pp.14-19.

Kersten, W., Lammers, T. and Skirde, H., 2012. Komplexitätsanalyse von Distributionssystemen. Available at: <https://www.bvl.de/files/ 441/481/Sachbericht_16164.pdf > [Accessed 10 March 2015].

Kieser, A. and Kubicek, H., 1983. Organisation. 2nd ed. Berlin: De Gruyter.

Kim, J. and Wilemon, D., 2003. Sources and assessment of Complexity in NPD projects. R&D Management, 33(1), pp.15-30.

Kirchhof, R., 2003. Ganzheitliches Komplexitätsmanagment: Grundlagen und Methodik des Umgangs mit Komplexität im Unternehmen. Wiesbaden: Deutscher Universitäts-Verlag.

Klabunde, S., 2003. Wissensmanagement in der integrierten Produkt- und Prozessgestaltung: Best-Practice-Modelle zum Management von Meta-Wissen. Wiesbaden: Deutscher Universitäts-Verlag.

Koch, D., 2012. Wissensmanagement und der Umgang mit Komplexität. In: C. Fabig, A. Haasper, eds. 2012. Complexigence: Komplexität verstehen und aktiv managen. Norderstedt: Books on Demand. pp.40-61.

Krause, F.L., Franke, H.J. and Gausemeier, J., 2007. Innovationspotenziale in der Produktentwicklung. München: Carl Hanser Verlag.

Krüger, W. and Homp, C., 1997. Kernkompetenz-Management: Steigerung von Flexibilität und Schlagkraft im Wettbewerb. Wiesbaden: Gabler Verlag.

Lammers, T., 2012. Komplexitätsmanagement für Distributionssysteme. Lohmar: Josef Eul Verlag.

Lasch, R. and Gießmann, M., 2009a. Ganzheitliche Ansätze zum Komplexitätsmanagement - eine kritische Würdigung aus Sicht der Beschaffungslogisitk. In: R. Bogaschewsky, et al., eds. 2009. Supply Management Research: Aktuelle Forschungsergebnisse 2008. Wiesbaden: Gabler Verlag. pp.194-231.

Lasch, R. and Gießmann, M., 2009b. Qualitäts- und Komplexitätsmanagement: Parallelitäten und Interaktionen zweier Managementdisziplinen. In: R. Hünerberg and A. Mann, eds. 2009. Ganzheitliche Unternehmensführung in dynamischen Märkten. Wiesbaden: Gabler Verlag. pp.93-124.

Lindemann, U., Maurer, M. and Braun, T., 2009. Structural Complexity Management: An Approach for the Field of Product Design. Berlin: Springer Verlag.

Lingnau, V., 1994. Variantenmanagement: Produktionsplanung im Rahmen einer Produktdifferenzierungsstrategie. Berlin: Erich Schmidt Verlag.

Lübke, E., 2007. Lebenszyklusorientiertes Produktstrukturmanagement: Eine theoretische Untersuchung. München: Transfer-Centrum-Verlag.

Malik, F., 2002. Strategie des Managements komplexer Systeme: Ein Beitrag zur Management-Kybernetik evolutionärer Systeme. 7th ed. Bern: Haupt Verlag.

Marti, M., 2007. Complexity Management: Optimizing Architecture of Industrial Products. Wiesbaden: Deutscher Universitäts-Verlag.

Meier, B. and Bojarski, S., 2013. Ganzheitliches Modell zur Bewältigung vielfaltsinduzierter Komplexität. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 108(7-8), pp.547-551.

Meier, H. and Hanenkamp, N., 2004. Komplexitätsmanagement in der Supply Chain. In: A. Busch and W. Dangelmaier, eds. 2004. Integriertes Supply Chain Management: Theorie und Praxis effektiver unternehmensübergreifender Geschäftsprozesse. 2nd ed. Wiesbaden: Gabler Verlag. pp.111-130.

Meyer, C. M., 2007. Integration des Komplexitätsmanagements in den strategischen Führungsprozess der Logistik. Bern: Haupt Verlag.

Miragliotta, G., Perona, M. and Portioli-Staudacher, A., 2002. Complexity Management in the Supply Chain: Theoretical Model and Empirical Investigation in the Italian Household Appliance Industry. In: S. Seuring, ed. 2002. Cost Management in Supply Chains. Berlin: Springer Verlag. pp.381-397.

Nurcahya, E. Z., 2009. Ein Produktdatenmodell für das rechnerunterstützte Variantenmanagement. Aachen: Shaker Verlag.

Perona, M. and Miragliotta, G., 2004. Complexity management and supply chain performance assessment: A field study and a conceptual framework. International Journal of Production Economics, 90, pp.103-115.

Ponn, J. and Lindemann, U., 2008. Konzeptentwicklung und Gestaltung technischer Produkte: Optimierte Produkte - systematisch von Anforderungen zu Konzepten. Berlin: Springer Verlag.

Puhl, H., 1999. Komplexitätsmanagement: Konzept zur ganzheitlichen Erfassung, Planung und Regelung der Komplexität in Unternehmensprozessen. Kaiserslauten: Foto-Repro-Druck.

Reiß, M., 1993. Komplexitätsmanagement (I). In: G. Sieben and A. Woll, eds. 1993. WISU - Das Wirtschaftsstudium. Düsseldorf: Werner & Lange Verlag, pp.132-137.

Rosemann, M., 1998. Die Komplexitätsfalle. Logistik Heute, 20(9), pp.60-62.

Schawel, C. and Billing, F., 2011. Top 100 Management Tools: Das wichtigste Buch eines Managers. Wiesbaden: Gabler Verlag.

Schoeller, N., 2009. Internationales Komplexitätsmanagement am Beispiel der Automobilindustrie, RWTH Aachen University. Available at: < http://publications.rwth-aachen.de/record/51376/files/ Schoeller_Nicolas.pdf> [Accessed 23 March 2015].

Schöttl, F., Herrmann, N., Maurer, M. and Lindemann, U., 2014. Systematic Procedure for Handling Complexity in the Automotive Production. In: M. F. Zaeh, ed. 2014. Enabling Manufacturing Competitiveness and Economic Sustainability. Heidelberg: Springer Verlag. pp.255-260.

Schuh, G., 2005. Produktkomplexität managen: Strategien, Methoden, Tools. München: Carl Hanser Verlag.

Schuh, G., Millarg, K. and Göransson, A., 1998. Virtuelle Fabrik: Neue Marktchancen durch dynamische Netzwerke. München: Carl Hanser Verlag.

Schuh, G. and Schwenk, U., 2001. Produktkomplexität managen - Strategien, Methoden, Tools. München: Carl Hanser Verlag.

Schuh, G., Arnoscht, J. and Rudolf, S., 2010. Integrated Development of Modular Product Platform. In: D. Kocaoglu, T. Anderson and T. Daim, eds. 2010. Proceedings of International Center for Management of Engineering and Technology PICMET. Portland: IEEE. pp.1928-1940.

Schuh, G., Monostroi, L., Csáji, B. C. and Döring, S., 2008. Complexity-based modeling of reconfigurable collaborations in production industry. CIRP Annals - Manufacturing Technology, 57, pp.445-450.

Schwenk-Willi, U., 2001. Integriertes Komplexitätsmanagement: Anleitung und Methodik für die produzierende Industrie auf Basis einer typologischen Untersuchung. Bamberg: Difo Druck.

Serdarasan, S., 2013. A review of supply chain complexity drivers. Computers & Industrial Engineering, 66, pp.533-540.

Specht, G. and Beckmann, C., 1996. F&E-Management: Kompetenz im Innovationsmanagement. Stuttgart: Schäffer-Poeschel Verlag.

Warnecke, G., 2010. Komplexität: mit Kompetenz bewältigen, mit Technik beherrschen. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 105(7-8), pp.639-641.

Warnecke, G. and Puhl, H., 1997. Komplexitätsmanagement: Mit Systemdenken zur Beherrschung der Komplexität. wt Werkstattstechnik, 87, pp.359-363.

Wassmus, A., 2014. Serviceorientierung als Erfolgsfaktor und Komplexitätstreiber beim Angebot hybrider Produkte. Wiesbaden: Springer Gabler.

Westphal, J. R., 2000. Komplexitätsmanagement in der Produktionslogistik, Technische Universität Dresden. Available at: <http://tu-dreden.de/die_tu_dresden/fakultaeten/vkw/iwv/diskuss/2000_4_diskusbtr_ivw.pdf> [Accessed 14 March 2015].

Wildemann, H., 1995. Komplexitätsmanagement in der Fabrikorganisation. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb, 90(1-2), pp.21-26.

Wildemann, H., 1999. Ansätze für Einsparpotentiale. Logistik Heute, 21(4), pp.64-67.

Wildemann, H., 2012. Komplexitätsmanagement in Vertrieb, Beschaffung, Produkt, Entwicklung und Produktion. München: Transfer-Centrum-Verlag.