

# **Risk Management in Complex New Product Development Projects – the Automotive Industry Perspective**

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## ABSTRACT

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This dissertation integrates three papers on risk management in complex new product development projects (NPD) with an integrated perspective on the automotive industry. It seeks to provide a comprehensive access to the topic by highlighting the most relevant risk management aspects in NPD – processes and methods (chapter 2), organization and coordination (chapter 3) as well as culture and strategy (chapter 4).

The focus of chapter 2 lies on the identification and assessment of risks as the initial and most critical risk management steps. It illustrates the application of the analytic hierarchy process (AHP) method as an established multi-criteria decision analysis method to create transparency on the overall risk position of a selected highly complex NPD in the automotive industry. Chapter 2 confirms the AHP method as a suitable approach for stronger preventive risk management in complex NPD with stakeholders with conflicting functional perspectives. This sets the stage for chapter 3 and a subsequent consideration of organization and coordination.

Chapter 3 considers an issue of organization and coordination in complex NPD that is mainly based on the fact that the involved stakeholders have individual targets and rely on concurrent processes. The selected automotive industry example illustrates the resulting managerial challenge of balancing the overall NPD requirements such as product characteristics and development lead time (system perspective) and the targets of single stakeholders in NPD (individual perspective). The NK model as an important setting for search builds the methodical basis to solve this issue and results in optimized organizational and coordination setups.

The implications on risk management in complex NPD as a result of newly emerging NPD types in the automotive industry are subject to chapter 4. These implications are in line with profound industry changes that include changes in the requirements of customers and markets. Chapter 4 uses complexity theory and deploys the lens of complex adaptive systems (CAS) to NPD to outline the emerging NPD types and their implications on risk framing activities. An extended risk framework is derived as basis that addresses the cultural and strategic shift in the automotive industry with regard to managing risk in emerging NPD types.

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## ABBREVIATIONS

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AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
CAS	Complex Adaptive Systems
NK	Main parameters of the NK model (where N stands for the elements of any complex system and K expresses the degree of element interaction)
NPD	New Product Development Project(s)
w/	With
w/o	Without

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## ADDITIONAL NOTES

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The three chapters of this dissertation are in different stages of the publication process:

- Chapter 2: unpublished working paper by Martin Vu and Stefan Spinler (2016) [in journal submission process: Technovation]
- Chapter 3: unpublished working paper by Martin Vu and Stefan Spinler (2016) [under journal review: Journal of Engineering and Technology Management, submission date: June 12<sup>th</sup> 2016]
- Chapter 4: unpublished working paper by Martin Vu and Stefan Spinler (2016) [in journal submission process: Technovation]

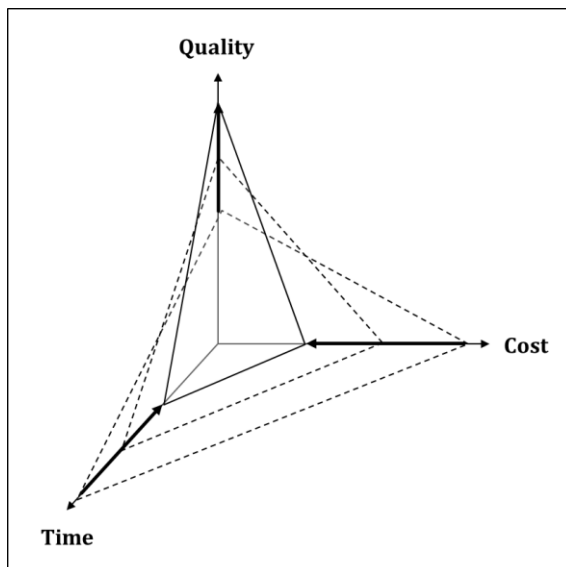
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# 1 INTRODUCTION

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## 1.1 Research Relevance

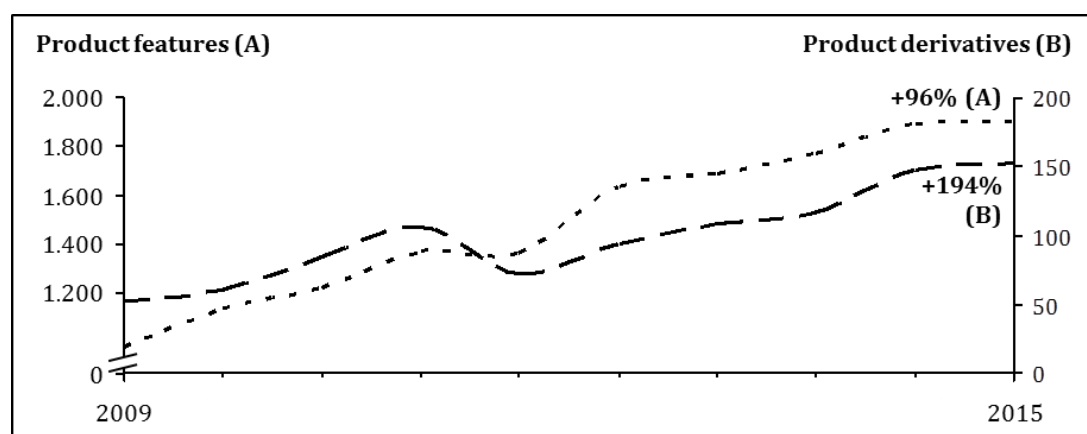
The automotive industry finds itself in a phase of transition. Megatrends such as urbanization, digitalization and environmental awareness are transforming the demand side. Customers and markets ask for new mobility solutions and the automotive industry is forced to intensify the efforts regarding topics as for instance autonomous driving, connected vehicles and e-mobility. The “buzz words” of yesterday have long become reality and a radical change in the automotive industry becomes increasingly apparent. The intensification of megatrends results in two challenges that will sustainably change the automotive industry. On the one hand, the automotive industry has to quickly react to the changes on the demand side and provide solutions to the new mobility understanding of customers and markets. On the other hand, the automotive industry has to find ways to become more efficient in realizing existing products in order to release resources for upcoming topics and stay competitive in the longer term. Both challenges combined lead to a transition from the current product portfolio to the product portfolio of the future. The vehicle that enables this transition for firms is new product development.



**Figure 1:** Trend in new product development in the automotive industry (own figure based on OEM, 2015)

As illustrated in Figure 1, new product development in the automotive industry underlies a trend towards more requirements at higher standards (quality), lower product costs (cost) due to the intensive competition in a still consolidating industry and reduced time-to-market (time) in line with ever shorter product cycles. The transition between product portfolios is an ongoing process that is intensifying. As a result, the number of new product development projects (NPD) have sharply increased over the past few years.

As existing and new products are realized in parallel in the transitional phase, firms in the automotive industry are facing an increasing number of NPD. Figure 2 gives exemplary insights into the development of the amount of product features and derivatives that are addressed through NPD at a selected automotive manufacturer. The illustrated development is mainly driven by customer requirements such as comfort, safety and efficiency as well as market requirements as for instance stated by CO<sub>2</sub> fleet emission regulations.



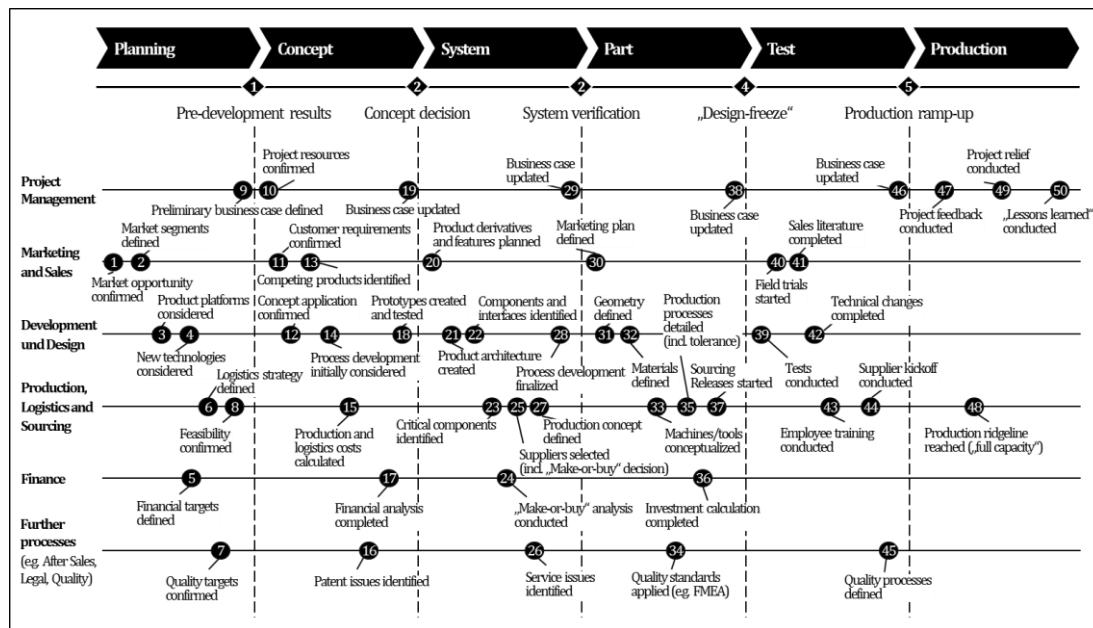
**Figure 2:** Exemplary development of product features and derivatives between 2009 and 2015 (own figure based on OEM, 2015)

The success in accomplishing the transition phase depends on the automotive industry's ability to conduct NPD according to customer and market requirements, at competitive product cost points and in fast development cycles. At least one of these targets was not achieved in 36% of all NPD at a selected automotive manufacturer in 2015 (OEM, 2015). Further intensifying NPD with regard to aspects of quality, cost and time coupled with increasing numbers of conducted NPD lead to complexity levels that are new to the automotive industry and a potential threat to NPD targets. This development assumes that there is a tendency that even more NPD may not achieve their targets in the future. As there is no other option for the automotive industry than actively driving change, approaches towards efficient and effective project management in NPD

have to be considered. In turn, this puts increasing pressure on the project management function in NPD. Managing risk is at the core of project management in NPD and risk management in NPD becomes inevitable in realizing NPD targets and bringing products successfully to the market place.

## **1.2 Research Scope**

The focus of this dissertation lies on managing risk in complex NPD from the automotive industry perspective. In the following, the terminologies NPD and risk management are briefly introduced as point of departure. NPD is extensively used in the business and management literature but a common understanding does not exist. The definition of NPD as a process is widely spread and illustrates the narrow focus on this topic. Shankar et al. (2012) define NPD as an iterative process of gathering creating and evaluating information for developing new and defect-free products. Ulrich and Eppinger (2003) refer to a process sequence that a firm employs to conceive, design, and commercialize a product. And Florén and Frishammer (2012) as well as Frishammer et al. (2013) define NPD as a process that starts with ideation activities. Although, the majority of NPD definitions seems to agree that NPD follow a process that focuses at the early product stage, a consistent distinction of this process for instance with regard to specific start and end points does not exist in the established literature base. Overall, the majority of existing NPD definitions can be summarized by referring to NPD as the sum of all activities that are needed to introduce new products to the market based on feasible concepts and according to customer requirements. The relevant phases, milestones and activities in NPD can be exemplarily extracted from Figure 3.



**Figure 3:** Exemplary illustration of phases, milestones and activities in NPD (own figure, 2014)

The illustration of NPD as process varies depending on the level of detail. Whereas Unger and Eppinger (2011) apply a spiral illustration, Ulrich and Eppinger (2003), Kim (2013) as well as Tabatabai et al. (2014) use some form of process sequence. The latter is widely established in the field and offers a higher level of detail (Malz et al., 2014). This illustration further allows the illustration of a stage-gate-model (Sethi et al., 2012). Despite different illustrations, the process contents can be considered rather similar. The development of new products follows a defined scheme from concept, system and parts development to integration and test as well as production. Though, two aspects make the prevailing definition of NPD very narrow. First of all, as the main focus lies on defining NPD as a process, a consideration of further aspects is widely neglected (Young 2010; Thamain, 2013 and Teller et al., 2014). Although, the process is a central aspect in developing new products, the contribution of further aspects as for instance organization and coordination as well as communication and decision-making are widely neglected. Second of all, the term NPD implies a focus on the development of new products, thus puts the Engineering functional area in the center of much of the research work. But it is important to highlight the cross-functional nature of NPD. Although, the Engineering functional area is important as main guidelines of a new product venture and about 80% of the total costs are determined by the Engineering functional area in the early concept phase, all functional areas have to be equally considered in NPD (Gidel et al., 2005).

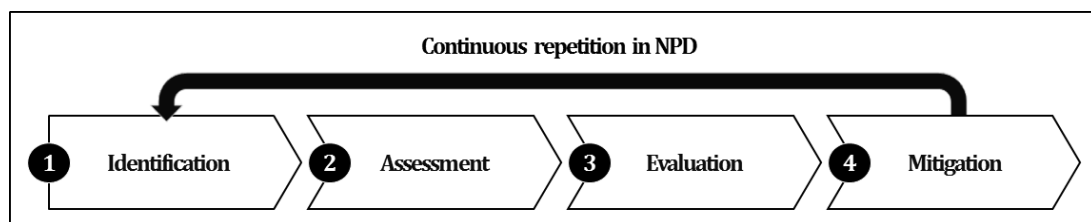
The second terminology of importance in this dissertation is risk management. The idea of risk has to be considered at first. Multiple definitions for risk exist in the literature. Traditional definitions focus on the “uncertainty of loss” (Crowe and Horn, 1957; Mehr and Cammack, 1961 and Denenberg et al., 1964). Here, risk is related to negative consequences of certain events based on the inability to forecast their outcome. Recent definitions also include the possibility of positive outcomes as a result of such events (Carpenter, 2014). In sum, there is an uncertainty of loss or gain. Risk is considered relative and relies strongly on given expectations. Nevertheless, it is important to focus preventively on the events that carry risks and may result in positive or negative outcomes rather than treating the results or symptoms. Risk may therefore be defined as an uncertain event regarding loss or gain dependent on existing expectations. According to Sharma (2013), these uncertain events may result from firm-internal and firm-external sources and can either be controllable or uncontrollable. In this regard, the management of uncertain events in NPD is a core activity of the project management function and crucial for securing the expected project target achievement (Smith and Merritt, 2002; Gosnik, 2011 and Otniel et al., 2012). Although, the importance of risk management in NPD is well-known, risk management activities are perceived to remain widely neglected (Elahi, 2013). As a legal obligation for risk management standards does not exist overall, the landscape of risk management practices varies among industries and firms (Bock and Chwolka, 2014). Risk management is generally interpreted as operational problem solving in the course of NPD and may lead to reactive and cost-consuming “firefighting” activities. Ineffectiveness and inefficiency of risk management result in unsuccessful NPD and non-achievement of NPD targets with regard to requirements fulfillment, budget conformity and time-to-market (Schulz, 2014). The practical relevance for risk management is especially high in NPD as the market success of new products over the product lifetime business case starts at this point. NPD define the product outcome and may lead to sustainable competitive advantage (Soerensen, 2006). The ability to create market-oriented products in ever shorter periods of time is a focal point of market competition (Ahmadi and Wang, 1999). This requires risk management and coping with complexity (Lakemond et al., 2013). Figure 4 illustrates the general steps in managing risk in NPD as proposed by Schawel and Billing (2011) as well as Holzmann (2012). Four basic steps are included, namely identifying, assessing evaluating and mitigating risks. The first two steps are considered crucial in terms of path dependency as they support risk evaluation and

mitigation by creating risk transparency and a first risk understanding without an initial cash flow.

Although, risk management in NPD follows a simple and structured process and therefore seems a straightforward task, numerous negative industry examples in line with a quite high number of “failed” NPD in the automotive industry indicate that the task is rather challenging. Managing risk in NPD already states a challenging project management task and has the potential become even more challenging in the light of increasing NPD complexity.

### 1.3 Research Benefit

The main target of this dissertation is to be of practical relevance and support to the project management function in NPD in the automotive industry. There seems to be agreement in the field as well as in the literature that risk management in NPD is generally underdeveloped. From the perspective of this dissertation, this is neither a result of the unwillingness to manage risk in NPD in the field nor a result of lacking impulses from the literature base. Instead, the underdevelopment of risk management in NPD rather results from the large availability of different approaches to risk management that are available to project managers. This oversupply of risk management approaches leads to paralysis and possibly even to the negligence of risk management in NPD. The final result are mixed-method approaches to risk management in NPD that indeed satisfy the formal demand for risk management in NPD in many cases but often do not lead to the desired outcomes. Managing risk is particularly critical in consideration of complex NPD.



**Figure 4:** Risk management steps in NPD (own figure based on Schawel and Billing, 2011 and Holzmann, 2012)

This dissertation aims to provide particular insights in managing risk in complex NPD in the automotive industry. Instead of simply expanding the literature base on risk management in NPD, this dissertation has a narrow focus to allow for clear statements and thus general guidance in the field. This dissertation incorporates primary qualitative and quantitative data from the field to clarify the relationship between high complex NPD and risk. Risk theory and

complexity theory are two very mature research streams. Though, the combination of these two research streams is in a nascent stage and has not yet resulted in distinct outcomes. This dissertation focuses on testing the relationship between complex NPD and risk from the perspective of the automotive industry and with support of specific NPD data from the field. In addition to this formal relationship testing, this dissertation seeks include industry-specific developments that affect the effectiveness of current risk management thinking with regard to the implications of emerging new NPD types.

Finally, including the most relevant aspects of risk management in NPD, namely processes and methods, organization and coordination as well as culture and strategy, this supports the rather small existing literature base on some aspects of NPD. Applying the extended definition of NPD by considering the cross-functional nature of NPD instead of focusing on single functions such as engineering, logistics or production, this research work considers NPD from the holistic product perspective and includes all functional perspectives. This approach addresses a perceived literature gap and supports the illustration of complexity in NPD.

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## **2 MANAGING RISK IN HIGHLY COMPLEX NEW PRODUCT DEVELOPMENT PROJECTS (NPD) WITH THE ANALYTIC HIERARCHY PROCESS (AHP) METHOD<sup>1</sup>**

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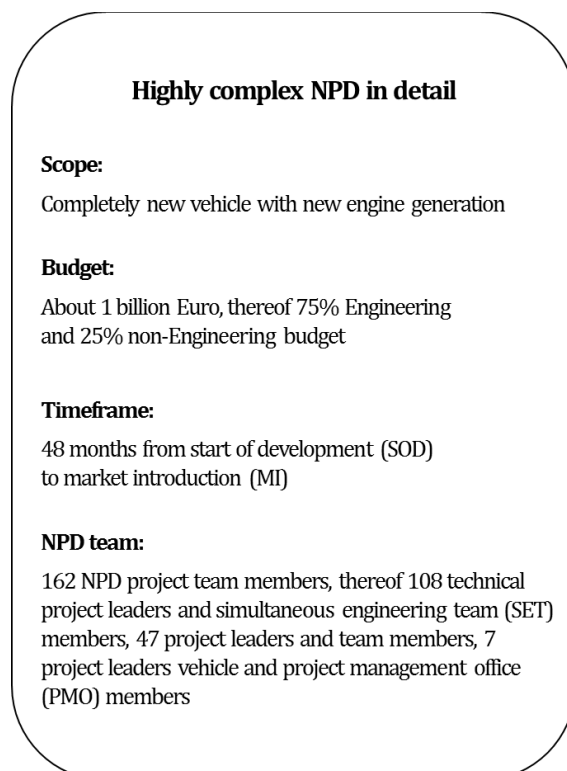
### **2.1 Introduction**

Automotive manufacturers engage in new product development to achieve competitive advantages (Ahmad et al., 2013). New product development projects (NPD) state the framework to conduct new product development in a formal and structured team approach (Tabatabai et al., 2014). The conduction of NPD involves uncertainty and risk that has a potential negative effect on the performance of new product ventures with regard to quality, cost and time targets (Griffin, 1997 as well as Tatikonda and Rosenthal, 2000). High technical hurdles, escalating product costs and decomposed project schedules are well-known side effects in the development of new products (Tabatabai et al., 2014). This research work regards the initial two steps in managing risk in NPD, namely risk identification and assessment (Schawel and Billing, 2011 and Holzman, 2012). The aim of this research work is to create

<sup>1</sup> Vu, M. and Spinler, S. (2016). Managing Risk in Highly Complex New Product Development Projects (NPD) with the Analytic Hierarchy Process (AHP) Method. Unpublished working paper.



transparency on the overall risk position of a selected highly complex NPD by the application of the analytic hierarchy process (AHP) method as an established multi-criteria decision analysis method as first introduced by Saaty (1980). The AHP method has been widely applied by practitioners and academics for the purpose of risk management in the project management field (Sharma, 2013). Though, the advantages of the AHP method have not yet been used in highly complex NPD in the automotive manufacturer area. The existing literature base is particularly vague with regard to the relationship between risk and complexity (Thamain, 2013). This research work seeks to draw on this shortcoming with the application of the AHP method to a current and industry-specific example. The selected NPD aims at the development of a completely new vehicle. Figure 5 illustrates the NPD environment in detail. The new vehicle states an important product to maintain the competitiveness of an automotive manufacturer. The NPD is highly complex particularly due to the large amount of development contents and the high degree of technical innovation. The new vehicle is supposed to combine the latest technical innovations and future-relevant legal requirements. The NPD scope includes a new vehicle and engine generation that reflects upon the large amount of interfaces and respective synchronization need.



**Figure 5:** Highly complex NPD in detail (own figure based on OEM, 2015)

The management of risk starts with the transparency over possible influence factors on the overall NPD performance. The identification of risks takes place with a group of 14 selected NPD team members. They identify a total number of 23 risks that are categorized in the three risk categories product, process and project. The subsequent risk assessment is supported by expert judgment. The benefit of the AHP method resolves from the involvement of experience and knowhow paired with a structured stepwise methodology. The result indicates that the NPD has a high risk degree with a probability of almost 70%. The decomposition of the NPD risk position allows for risk transparency with regard to specific influence factors. The highest influence on the overall risk position results from the product category with a relative importance of over 60%. The process and project category follow on rank two and three respectively. Particularly the product development scope and innovation degree have a high relative importance. Thus, NPD complexity is associated with risk in this case. The specification of key influence factors enables risk evaluation and mitigation in the light of the subsequent risk management steps. Thus, the project management function is capable of defining specific and objective measures to reduce key risks and balance NPD targets. This research work starts with a review of the current literature regarding the application of the AHP method for risk management purposes in the project management field. Furthermore, current literature with regard to complexity as a main challenge in NPD is addressed. Subsequently, this research work leads through the AHP method. The results are then discussed and managerial implications are derived.

## **2.2 Literature Review**

### *2.2.1 Analytic Hierarchy Process (AHP) Method Application in the Project Management Field*

Automotive manufacturers conduct countless NPD each year and spend large amounts of financial resources to bring new vehicles to the market. An important management task is the evaluation and selection of suitable NPD to allocate resources to NPD with the most promising outcome in accordance to the overall targets of the firm. These decisions involve uncertainty to some degree. Here, risk becomes an inherent part of managerial decision-making and NPD conduction (Lam, 2014). Thus, in order to enable decision-making by the management and support reasonable resource allocation, it is crucial to understand the underlying risk position of the NPD landscape. The challenge lies in the selection of suitable risk management methods

to secure NPD performance (Bakhtiari, 2014). The industry does not follow an established risk management standard and legal requirements with regard to risk management practices do not exist (Bock and Chwolk, 2014). It is finally the decision of automotive manufacturers to select suitable approaches for risk management in NPD from a large variety of existing methods. According to Elahi (2013), effective risk management has become increasingly important but is perceived to remain widely neglected. Firms apply informal and mixed-method approaches based on the variety of risk management methods (Kaplan and Mikes, 2012 as well as Marle and Vidal, 2014).

This research work focuses on the identification and analysis of risk in a selected highly complex NPD. Thus, this research work addresses the initial two phases in risk management according to (Schawel and Billing, 2011 as well as Holzmann, 2012). Namely, identifying NPD-specific risks as a first risk inventory and analyzing these risks by categorizing and assessing them to understand their character. These first phases in risk management are crucial according to (Marle and Vidal, 2014). They find out that shortcomings in the coordination of risks and risk owners appear in the subsequent risk management phases particularly due to an insufficient systematical identification and categorization of risks. Goh et al. (2013) state the existence of different methods to identify risks and present the workshop as one approach to collect risks in a constructive environment. The main benefit of using a workshop environment in NPD is that different functional perspectives come together, develop a common understanding for risk consequences as well as interrelationships and receive immediate feedback. This is an advantage over decentralized risk identification approaches within the single functional areas. Multiple frameworks for risk categorization exist (Sharma, 2013; Tah and Carr, 2000 as well as Lakemond et al., 2013). The frameworks have in common that risk categorization is firm-specific to allow for a consistent internal understanding of the nature of the identified risks. Subsequent to the categorization of risks, this research work seeks to apply the AHP method as a risk management method to assess the identified and categorized risks of a specific NPD. As a multi-criteria decision analysis method, the AHP method has been widely applied in the project management field (Table 1). According to Martin (2007), its success relies on a major disadvantage of other existing methods. Many methods rely on historical data inputs. In case of NPD and completely new product ventures respectively, such past data is often not available.

The success of the AHP method is further based on the structured assessment of risks without compromising the knowledge and experience of experts (Saaty, 1980). Instead of focusing on system-based approaches, the AHP method involves human judgment. This makes the AHP method equally interesting for practitioners and academics. Table 1 summarizes recent publications on the application of the AHP method for risk management purposes in the project management field.

No.	Description	Industry	Source
1	Risk management in Indian oil refinery project	Raw materials	Dey, 2012
2	Risk management in NPD for electronic product	Electronics	Salgado and Salomon, 2012
3	Safety risk assessment in project manufacturing system	Manufacturing	Silvestri et al, 2012
4	Identification of critical criteria in new green NPD in Taiwan	Electronics	Tsai, 2012
5	Decision support in electricity infrastructure project in Spain	Construction	Alvarez et al, 2013
6	Safety risk assessment in Turkish construction project	Construction	Aminbakhsh et al, 2013
7	Risk management in Canadian underground mining project	Raw materials	Badri et al, 2013
8	Risk management in subway construction project in China	Construction	Li et al, 2013
9	Risk assessment for construction project in India	Construction	Sharma, 2013
10	Risk management in NPD under uncertainty	Multiple	Song et al, 2013

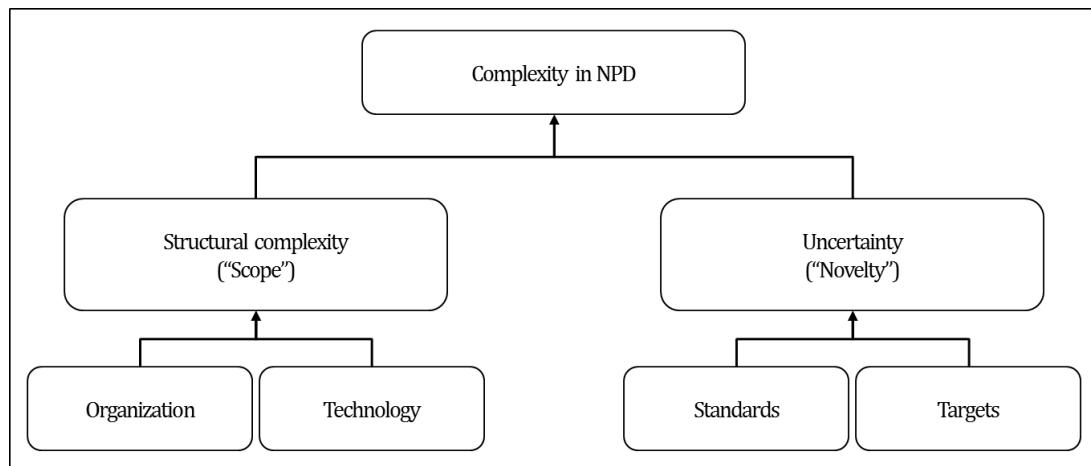
No.	Description	Industry	Source
11	Identification of critical factors in construction project in Lithuania	Construction	Gudiene et al, 2014
12	Safety risk assessment in Chinese bridge project	Construction	Peng et al, 2014
13	Risk management in NPD for food industry product	Food	Porananond and Thawesaengskulthai, 2014
14	Risk identification and assessment in tunnel construction project	Construction	Xuexian et al, 2014
15	Risk evaluation for wind power project in China	Energy	Yang et al, 2014

**Table 1:** Relevant AHP method publications (2012-2014) (own table, 2015)

Table 1 illustrates a large recent literature base with regard to the application of the AHP method for risk management purposes in the project management field. A remarkable proportion of the publications focuses on heavy industries such as construction and raw materials. According to Alvarez et al. (2013) the pressure regarding risk management in these industries has increased due to the risen amount of deadly incidences. Additionally, projects in these industries often involve governmental constitutions and contractual compensation clauses with high fines in case of non-compliance to project targets as for instance late project completion. The share of recent publications regarding new product ventures is relatively low. The automotive industry is not covered at all. Risk management in the automotive industry becomes increasingly important. A NPD defines the lifecycle costs of a new product, about 80% of the total costs are determined in the early design phase and product characteristics are defined Gidel et al, 2005. Product recalls and deadly incidents based on functionality issues as seen by automotive manufacturers in the middle of 2014 are partly referring to risk management in NPD (GM, 2015). The lacking application of the AHP method in the automotive industry can be seen as a chance to extend the application of the proven AHP method in a new environment.

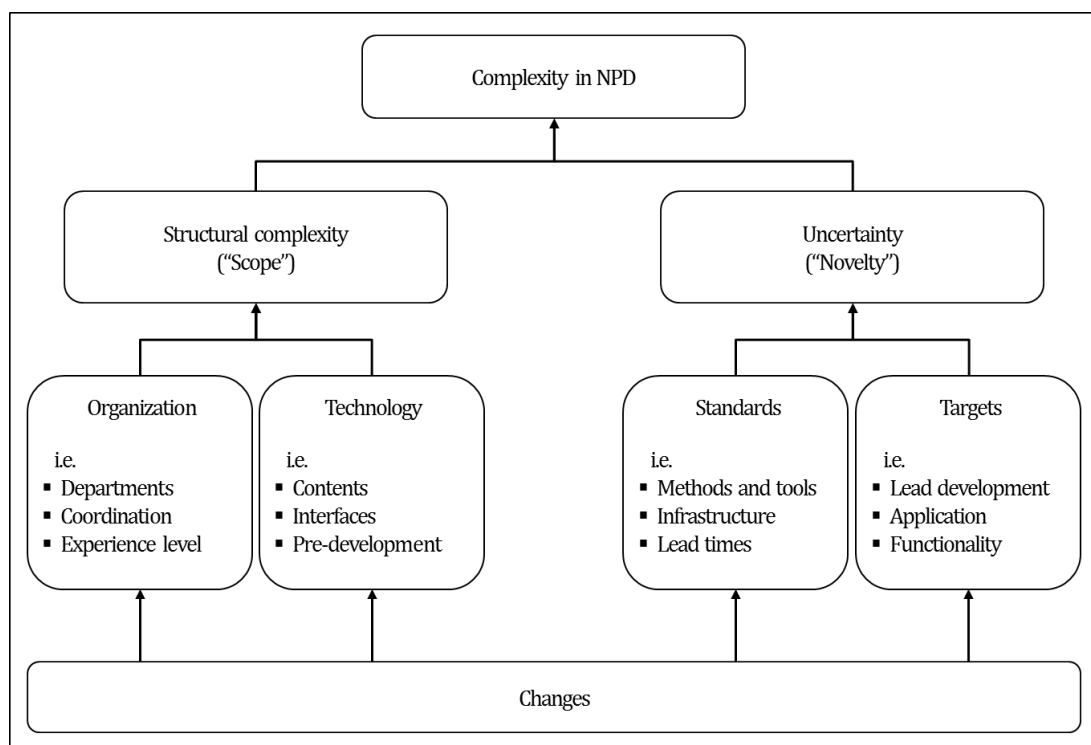
### *2.2.2 Complexity as Challenge in New Product Development Projects (NPD)*

The existing literature regarding complexity in NPD is fairly large and heterogeneous. Although, numerous definitions and various examples exist, most of the current literature agrees that complexity in NPD is defined by more than just the plain scope of a project (Tatikonda and Rosenthal, 2000 as well as Williams, 1999). Whereas a few years earlier, complexity in NPD is solely defined by the extent to which a new product is based on in-house developed parts, the definition is now continuously changing in line with a deeper understanding of the drivers behind complexity in NPD (Clark, 1989). In fact, it proves to be particularly true with regard to the automotive industry that complexity in NPD does not simply result from the plain scope of a project. Almost all automotive manufacturers are applying modular kits ("Baukasten"), often called standard, transverse or longitudinal modular kits (OEM, 2015). These modular concepts are used to handle NPD with a fairly large scope through the universal use of existing parts, modules and systems across different model lines. Despite the large scope, the complexity degree that comes along with these NPD can generally be considered quite low (OEM, 2015). Lebcir (2006) confirms this perspective. He conducts a comprehensive meta-analysis and finds out that high complexity in NPD results from a high level of structural complexity in combination with a high level of uncertainty as illustrated in Figure 6. Whereas structural complexity regards NPD in relation to the organizational and technological complexity ("scope"), uncertainty considers the availability and existence of concrete standards and targets in a NPD ("novelty"). It is agreed that new product development is complex per se and has become more complex over time (Lakemond et al., 2013). Therefore, this topic still receives much attention in the current literature and further definitional approaches keep emerging.



**Figure 6:** NPD complexity (own figure based on Lebcir, 2011)

Though, it is obvious that these new definitions are similar and rather add new detail than completely new aspects to the prevailing perspective that is summarized by Lebcir (2006). This research work uses the definition for complexity in NPD as illustrated in Figure 6 as a basis. Further details from the latest definitional approaches are added to complement this basic definition. The resulting synthesis is illustrated in Figure 7.



**Figure 7:** NPD complexity in detail (own figure based on Ahmad et al, 2013; Lakemond et al, 2013; Lebcir, 2006; Lebcir, 2011 as well as Grussenmeyer and Blecker, 2013)

Figure 7 illustrates an extended definition of complexity in NPD for the purpose of this research work. This definition for instance also considers changes to the factors organization, technology, standards and targets as crucial for the overall evaluation of complexity in NPD and therefore accounts for the fact that NPD become more and more volatile with regard to specified requirements (Grussenmeyer and Blecker, 2013). Though, this perspective on complexity in NPD can only be considered of temporary nature. Industry-specific trends indicate that new topics will have to be taken stronger into account in the future as well. For instance, the trend towards increasing external value creation states a new topic that will further influence the view on complexity in NPD (OEM, 2015). Nowadays, automotive manufacturers have increased their outsourcing rate to up to 85% depending on the specific functional area (OEM, 2015). Although, the focus shifts for instance from parts construction and functions development towards setting product targets and steering product realization through suppliers, complexity in NPD has not reduced (OEM, 2015). Instead, complexity has become a large challenge based on the fact that fewer new parts are developed in-house. For instance, the average outsourcing rate for parts construction and functions development at an automotive manufacturer amounts to 76% on average (OEM, 2015). The integration of the single external supplier results and their subsequent steering overcompensates the outsourcing effect of the basic construction and development tasks (OEM, 2015). In fact, complexity in NPD steadily increases as organizational boundaries between automotive manufacturers and suppliers disappear and synchronization needs increase. The literature base widely agrees that complexity is an enormous challenge in new product ventures. The need for the application of an effective and efficient risk management method in NPD increases in the light of high complexity. According to Ahmad et al. (2013), the degree of complexity can be considered the main influence factor on the performance of new product ventures, thus constitutes a source of multiple risks. Thaimain (2013) as well as Kim and Wilemon (2013) add that increasing complexity generally leads to a higher risk position but points out that the evidence in the existing literature is rather vague. Indeed, the complexity in new product ventures is ever growing and needs to be understood by modern project management (Vidal et al., 2011). An automotive manufacturer states that about 36% of all NPD finish above budget due to increasing complexity and risk positions (OEM, 2015). As NPD have not been conducted in a similar form before and internal references are therefore not available, their underlying risk

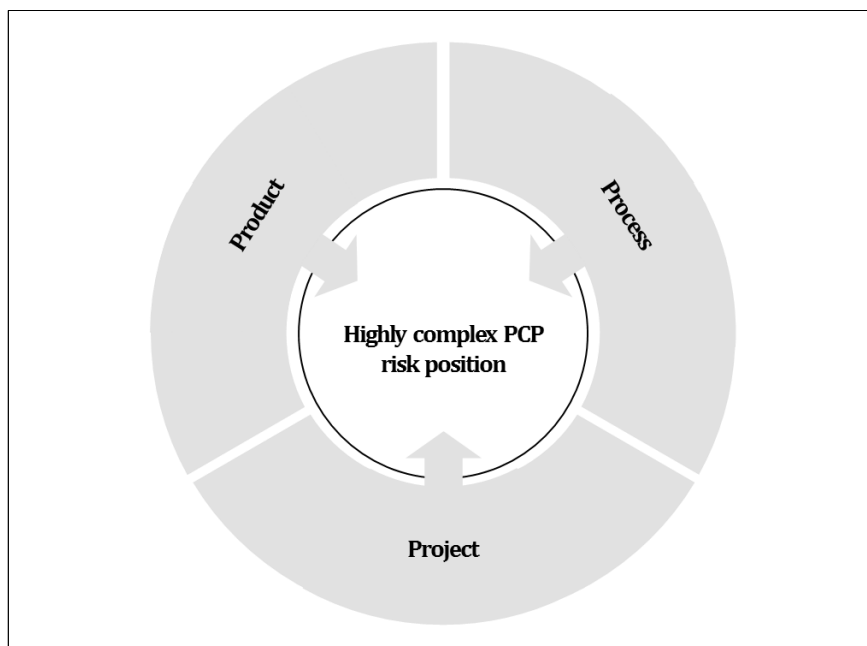


position posts a challenge to the project management function. Risk management requires special attention during the entire timeframe of the NPD conduction. This research work intends to use an exemplary NPD in accordance to the characteristics stated above and apply the AHP method to manage risks effectively.

## 2.3 Research Methodology

### 2.3.1 General Analytic Hierarchy Process (AHP) Method Application

This research work seeks to illustrate how the AHP method can be applied to assess the risk position of a specific NPD. In the following, the single AHP method steps for the risk identification and analysis of the NPD at an automotive manufacturer are described. The underlying research methodology is based on Saaty (1980) and modified for the purposes of this research work.



**Figure 8:** Risk categorization framework (own figure based on OEM, 2015)

#### Step 1: Identify and categorize risks

The identification and categorization of risks is performed firm-specific. Figure 8 illustrates a specific risk categorization framework in accordance to an automotive manufacturer. The categorization of risks aims at structuring the identified risks and supporting the risk consolidation. Thus, risks can be merged, re-defined or removed based on the initial risk categorization. This research work applies a total of three risk categories, namely product,

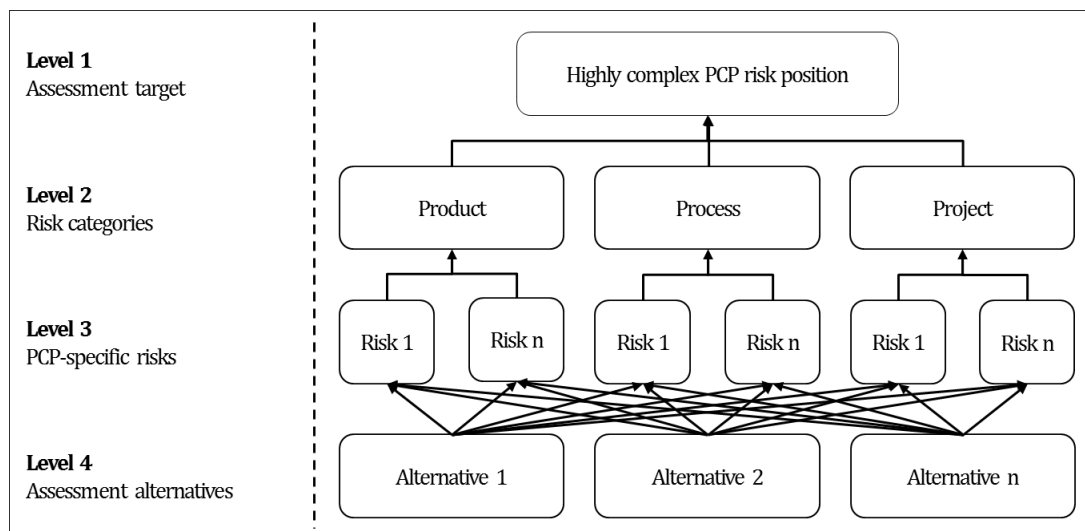
process and project. A general rule of thumb with regard to the number of risk categories does not exist. According to (Lasch and Janker, 2005 as well as Hair et al., 2006), the number of risk categories should be kept small to reduce data without losing relevant information. The product category is related to the output of the specific NPD and summarizes risks that refer to the technical product scope as for instance in terms of product contents, product variants and product novelty degree. The process category relates to the necessary functional area processes (competences) to develop a product. Furthermore, this category links to applied methods, standards and resources within specific functional areas, thus indirectly also includes for instance the multi-project perspective. The project category is related to the specific NPD in terms of time deadlines and the adherence degree to the defined new product development process. In extraordinary cases, the generically defined new product development process is not adhered to in specific NPD. Late product changes and time limitations due to a late NPD start and outstanding pre-development results are exemplary reasons. These specific risks fall into the project category.

The assignment of single risks to one of the three risk categories is conducted as a discrete choice. This requires a distinct definition of each specific risk prior to the risk assignment. In turn, this distinct risk definition is further necessary to avoid risk overlaps and thus create ambiguity in the ownership of single risks (Marle and Vidal, 2014). Also, the dependencies among risks as well as among risk categories are then neglected as illustrated in Figure 8. As a result, risk identification and categorization become a simpler exercise at the expense of a complete risk picture. Sipahi and Timor (2010) consider this fact as the main weakness of the AHP method. From the perspective of this research work, this fact is rather a strength than a weakness as risk management in NPD must be kept efficient in the light of scarce project management resources and a predominantly low affinity towards risk management (OEM, 2015). Thus, a simple way to identify and categorize risks as with the use of the AHP method is a prerequisite for the success in the field. Omkarprasad and Sushil (2006) predict that the application of the AHP method as a decision support tool will continuously increase due to the fact that its application qualifies for a simple and practical application in the field. Although, there are other methods as for instance the value analysis or the analytic network process (ANP) method, the AHP method meets the requirements of this research work best (Saaty, 2001). On

the one hand, the value analysis regards an unstructured and exclusively subjective approach towards risk identification and assessment and therefore posts a too simple form of a decision support tool. On the other hand, the ANP method as a generalization of the AHP method states a too complex approach due to the consideration of all risk interrelationships within a system such as a NPD. In comparison to these approaches, the AHP method is balanced and promotes an in-between solution that incorporates expert judgment (subjectivity) in a structured way and is simple to apply in the field.

#### Step 2: Decompose NPD risk position

Based on the identified risks and their allocation in defined risk categories, the risk position is completely structured through decomposition in single components as illustrated in Figure 9. The resulting hierarchical structure incorporates all influence factors of the NPD risk position. The levels in this hierarchical structure are interrelated as the subordinate level influences the next higher level. Whereas the first level represents the overall risk position as the target of the assessment, the second level comprises of the three risk categories (influence factors of level one), the third level states the NPD-specific risks (influence factors on level two) and the fourth level depicts the possible assessment alternatives for level three. The NPD risk position on the first level of the hierarchical structure describes a possible NPD target deviation based on the nature and relative importance of NPD-specific risks. The NPD target deviation will ultimately lead to an increase in the planned costs of the specific NPD.



**Figure 9:** General hierarchical structure (own figure, 2015)

Each level of the hierarchical structure influences the next higher level. This influence is expressed through a pairwise comparison. The pairwise comparison among the single components of the hierarchical structure creates transparency on the overall risk position. According to (Saaty, 1980), the hierarchical structure shall optimally contain about seven components for the pairwise comparison. According to Miller (1956), the human capacity for effective information processing is limited to about this amount of components.

### Step 3: Conduct pairwise comparison

The pairwise comparison starts at the top of the hierarchical structure and is then conducted on each level of the hierarchical structure. Prior to performing the pairwise comparison, the compared influence factors are arranged in a matrix (A) on each level of the hierarchical structure. Each influence factor is compared once to all other influence factors in the matrix. Experts assess on each hierarchical level which influence factor is more important with regard to the component on the next higher level. The knowledge and experience of the experts contribute to the assessment of one influence factor over another. The Saaty scale is a nine-point scale and serves as general guidance in the qualitative expert assessment (Appendix 2.1). Saaty (1980) proposes to focus on the values 9, 7, 5, 3 and 1 in the qualitative expert assessment. The intermediate values 8, 6, 4 and 2 shall be used in the case of assessment conflicts as for instance if compromise between the experts is necessary to derive a shared solution. This exemplifies a major strength of the AHP method in involving expert judgment. It seeks to facilitate a shared solution between the involved parties in the assessment of influence factors. The number of necessary expert judgments (Ej) depends on the number of influence factors in the matrix as illustrated in (2.1).

$$(2.1) \quad E_j = \frac{n(n-1)}{2}$$

where n is the total number of influence factors  
in the matrix

### Step 4: Determine importance of influence factors

The subsequent step determines the importance of the single influence factors by calculating their respective relative weights. Thus, the relative influence of one factor over all other factors

in the matrix with regard to the component on the next higher level is assessed. Saaty (1980) applies the concept of eigenvector to estimate the relative weights of influence factors. The normalization of the eigenvector values (NE) in the rows of the matrix is illustrated in (2.2).

$$(2.2) \quad NE_j = \frac{a_{i/j}}{\sum_{i=1}^n a_{n/j}}$$

where  $a_{i/j}$  is the result of pairwise comparison between influence factors i and j

The normalization of each matrix further ensures the consistent weighting of the single branches from the overall hierarchical structure perspective. Based on the normalized matrix, relative weights for the influence factors can be derived to reveal their importance and derive statements on the influence on the next higher level component. The relative weights (W) arise as a result of (2.3).

$$(2.3) \quad W_j = \frac{1}{n} \sum_{j=1}^n NE_j$$

where  $NE_j$  is the normalized eigenvector value and n is the total number of  $NE_j$

#### Step 5: Validate consistency of results

The consistency of the results is validated with the application of the consistency ratio (CR) as illustrated in (2.4).

$$(2.4) \quad CR = \frac{CI}{CIR}$$

where CI is the consistency index and CIR is a random consistency index (values for  $n \leq 10$  used from Saaty (1980) as illustrated in Appendix 2.2)

According to Saaty (1980), the results are considered consistent if the CR is less than or equal to 0.1. In case the CR is higher than 0.1, a revision of the pairwise comparison in step 3 is necessary. The underlying CI is raised as illustrated in (2.5).

$$(2.5) \quad CI = \frac{\lambda_{max} - n}{n - 1}$$

where  $\lambda_{max}$  is the largest eigenvalue of the matrix  
and n is the total number influence factors

#### Step 6: Analyze assessment results

The final step in the AHP method includes the analysis of the assessment results. At this point, the relative importance of influence factors is used to identify key drivers for the NPD risk position. Furthermore, the synthesis of the available information enables the subsequent steps in risk management and states the value of the AHP method from a managerial perspective.

#### *2.3.2 Analytic Hierarchy Process (AHP) Method Data Collection*

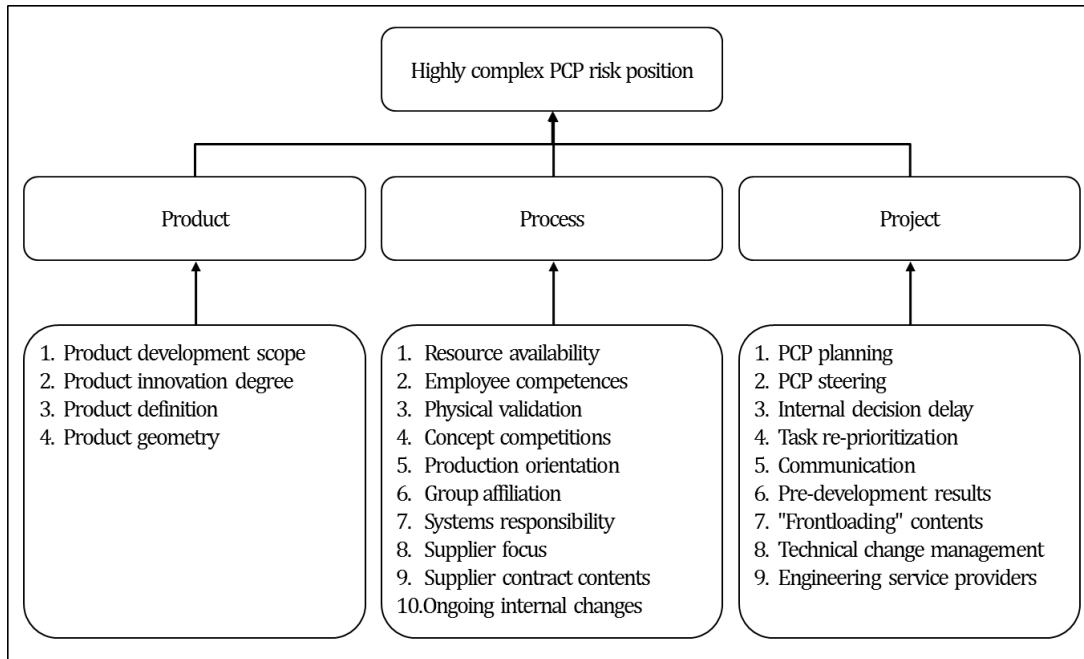
This research work requires data in the form of identified risks as well as expert judgment based on the AHP method. In order to increase time efficiency in the collection of data, this research work applies explorative procedures and embeds the AHP method into a workshop and interview environment. According to Goh et al. (2013), the workshop has proven to be a constructive environment for the purpose of risk identification. The main benefit is the creation of a common understanding of risks between the involved parties as well as the reception of immediate feedback. Whereas the initial risk identification and categorization is conducted in a workshop with a group of 14 selected NPD team members (Table 2), an unstructured interview is applied with the project leader for the subsequent assessment of risks. Here, the workshop duration is planned to be three hours and the risk assessment interview lasts another two hours. The 14 NPD team members state the NPD core team and represent the functions involved in the new product development venture. Their workshop participation supports a complete risk transparency. The NPD is in an early phase at quality gate product definition (PD) where technical, sales and financial targets are set. Risks are considered for the first time and risk identification and risk assessment are thus based on primary data.

No.	Workshop team	Work experience
1	Project leader Vehicle	15 years
2	Leader Project Management Office	12 years
3	Project leader Purchasing	N/A [undisclosed]
4	Project leader Production and Logistics	9 years
5	Project leader Sales	5 years
6	Project leader After Sales	6 years
7	Project leader Quality	12 years
8	Project leader Controlling	N/A [undisclosed]
9	Technical project leader Body	8 years
10	Technical project leader E/E	8 years
11	Technical project leader Chassis	N/A [undisclosed]
12	Technical project leader Engine	N/A [undisclosed]
13	Technical project leader Complete Vehicle	11 years
14	Product Manager	5 years

**Table 2:** Workshop team (own table, 2015)

### *2.3.3 Analytic Hierarchy Process (AHP) Method Sample and New Product Development Project (NPD) Application*

The workshop team identified a total of 23 risks as sample for the NPD. Whereas four risks (17%) are specific to the product category, ten risks (44%) belong to the process category and nine risks (39%) are related to the project category. The risk distribution indicates that the NPD primarily incorporates risks related to the process and project category. In absolute terms, the conduction of the NPD depends more on functional area processes (competences) and time factors than on the scope of the NPD with regard to the general risk position. Figure 10 illustrates the decomposition of the NPD risk position. The NPD risk position finally results as the sum of the risk degrees of all NPD-specific risks (Figure 10).



**Figure 10:** Hierarchical structure for NPD risk position (own figure, 2015)

A description of the 23 identified risks is referred to in Appendix 2.3. The distribution of the single risks to the three risk categories in Figure 10 provides general insights to the risk position of the NPD. The process and project risk categories play a predominant role in the overall risk position of the NPD in absolute terms. In order to assess the risk position and the relative importance of single risks in detail, pairwise comparisons are conducted.

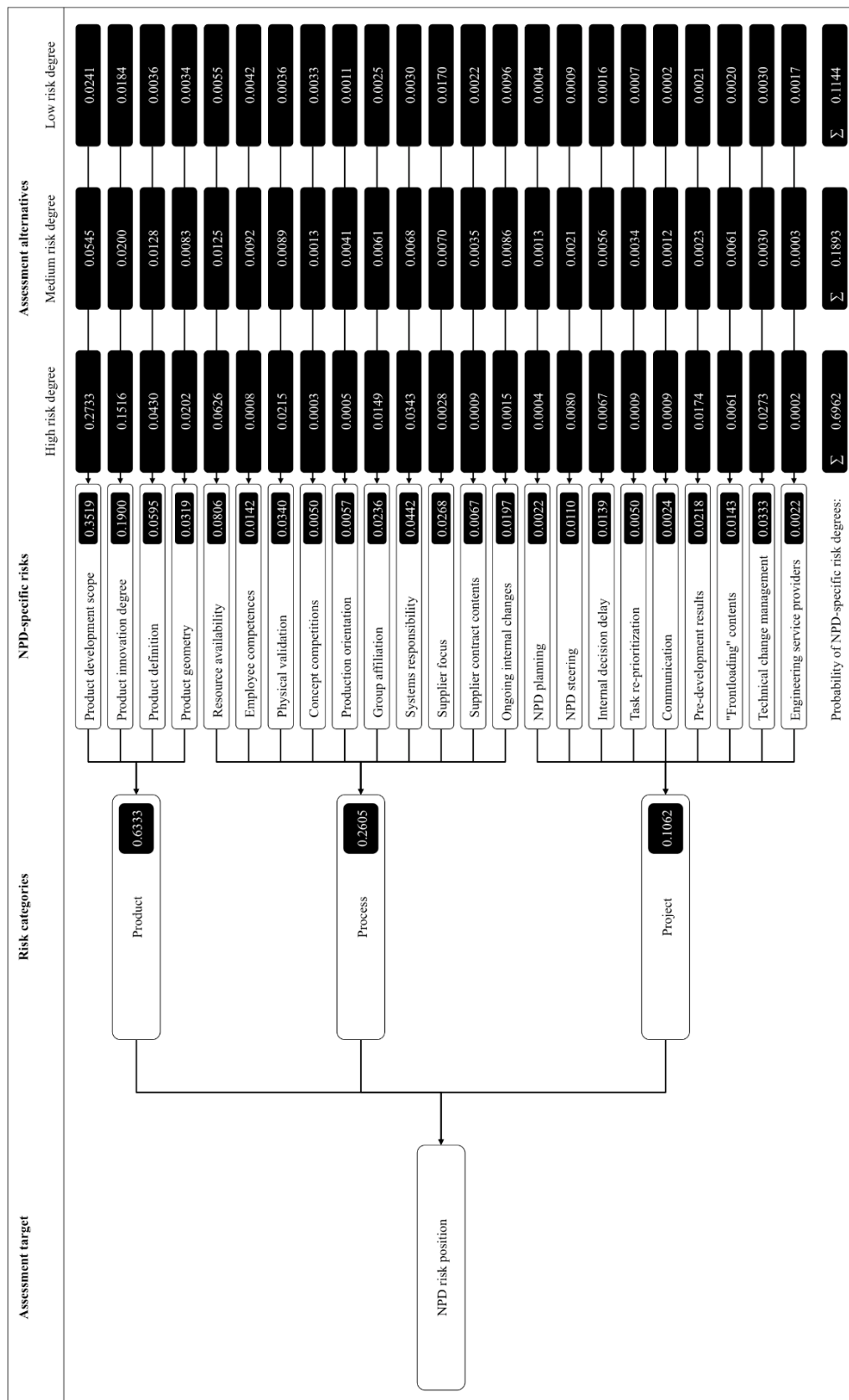
	Product	Process	Project	Relative weights
Product	1	3	5	0,6333
Process	1/3	1	3	0,2605
Project	1/5	1/3	1	0,1062

**Figure 11:** Pairwise comparison matrix on risk category level (own figure, 2015)

27 matrices are prepared with a total of 159 pairwise comparisons, namely one matrix on the risk category level with three pairwise comparisons, three matrices on the NPD-specific risk level with 87 pairwise comparisons and 23 matrices on the assessment alternative level with 69 pairwise comparisons. Figure 11 illustrates the matrix on the risk category level as an example. The matrix shows the pairwise comparisons between the three risk categories. Three pairwise comparisons are necessary to complete the matrix. The pairwise comparison between the risk categories product and process illustrates that the product category is moderately more important than the process category with regard to the NPD risk position.



Another pairwise comparison between the risk categories product and project favors the product risk category over the project risk category. The final pairwise comparison between the risk categories process and project assesses the process risk category as moderately more important than the project risk category. The relative weights for each of the three risk categories are a result of the normalization of the pairwise comparison matrix. Based on the relative weights, the product risk category (63.33%) is the most important influence factor with regard to the NPD risk position. The process risk category (26.05%) follows on the second rank and the project risk category (10.62%) on rank three. Although, the product risk category is underrepresented in absolute terms, its influence on the NPD risk position is relatively strong. The consistency of the result is validated with the application of the consistency ratio. The result is considered consistent as the consistency ratio equals 0.03 and is therefore lower than 0.1 as proposed by Saaty (1980). The demonstrated methodical chain is repeated for the remaining levels of the hierarchical structure. Figure 12 summarizes the relative importance of risk categories, NPD-specific risks and assessment alternatives for the NPD risk position.



**Figure 12:** Relative importance of risk categories, NPD-specific risks and assessment alternatives for NPD risk position (own figure, 2015)

## **2.4 Research Results**

The application of the AHP method for risk management purposes in the NPD supports the understanding of the overall risk position. The results of this research work illustrate that the selected NPD is characterized by a high risk degree with an underlying probability of almost 70% as illustrated in Figure 12. Therefore, it is highly probable that the specific NPD will deviate from its target based on the identified and evaluated risks. This means in turn that the NPD will ultimately not adhere to the planned costs if appropriate measures are not taken into account. The results for the single assessment alternatives per risk (high, medium and low relative risk degree) are added up to shift the perspective and result with the overall probability of the NPD-specific risk degrees. Furthermore, the decomposition of the NPD risk position allows for risk transparency with regard to the specific influence factors on the NPD. The outcome of this research work illustrates that the product risk category is relatively more important than the process and project risk categories. The NPD involves a large development scope particularly due to the high amount of planned body and engine derivatives. In addition, the product innovation degree itself is considered high based on new lead developments within the NPD as for instance in the case of infotainment systems. Table 3 ranks the NPD-specific risks according to their relative importance. The risk degrees stand in a relative relationship to each other that result from expert evaluations. Risks are internally delimited and evaluated in a qualitative relative system according to their risk degree. Here, it is more important to reach consensus between the experts and allow for direction and risk ownership than to have vague but quantified risk degrees in such an early phase of the NPD. Table 3 illustrates that the risks are highly concentrated. The top 5 risks account for over 70% of the total NPD risk position with regard to the relative importance.

Rank	NPD-specific risk	Relative importance	Relative risk degree	Risk category
1	Product development scope	0.3519	High	Product
2	Product innovation degree	0.1900	High	Product
3	Resource availability	0.0806	High	Process
4	Product definition	0.0595	High	Product
5	Systems responsibility	0.0402	High	Process
6	Physical validation	0.0340	High	Process
7	Technical change management	0.0333	High	Project
8	Product geometry	0.0319	High	Product
9	Supplier focus	0.0268	Low	Process
10	Group affiliation	0.0236	High	Process
11	Pre-development results	0.0218	High	Project
12	Ongoing internal changes	0.0197	Low	Process
13	“Frontloading” contents	0.0143	Medium	Project
14	Employee competences	0.0142	Medium	Process
15	Internal decision delay	0.0139	High	Project
16	NPD steering	0.0110	Medium	Project
17	Supplier contract contents	0.0067	Medium	Process
18	Production orientation	0.0057	Medium	Process
19	Concept competitions	0.0050	Low	Process
20	Task re-prioritization	0.0050	Medium	Project
21	Communication	0.0024	Medium	Project
22	NPD planning	0.0022	Medium	Project
23	Engineering service providers	0.0022	Low	Project

**Table 3:** Ranking of NPD-specific risks regarding relative importance (own table, 2015)

## **2.5 Managerial Implications**

### *2.5.1 General Managerial Implications*

In the case of the specific NPD in this research work, the responsibility of the AHP method results lies with the project leader vehicle. The recipient of the AHP method results is firstly the management of the specific model line as the responsible function for the overall NPD budget and secondly the general management of the functional areas. Based on the identification and assessment of the overall NPD risk position, the AHP method supplies the necessary transparency to either decide for or against the new product venture at this early NPD stage. Furthermore, as the specific NPD is located before quality gate product definition (PD), the actual cash outflow in relation to the overall budget of the NPD is still negligible, thus changes to the targets of the NPD are viable and probable. The underlying discussion regarding the completion of the specific NPD is supported by the results of the AHP method as a rational decision base and prevents the NPD from escalation or the firm as such from harm. Besides the creation of awareness for the increasing complexity in NPD at an automotive manufacturer in general, the AHP method makes an important contribution by the specification of single risks. Main NPD influence factors become tangible and decisions can be taken with a higher level of detail and certainty. This is also an incremental advantage for subsequent risk management steps and the mitigation of specific risks.

The following points reflect the main managerial implications. All three managerial implications focus on the main risks reflected by the large product development scope and high product innovation degree. The selected NPD shows high complexity that results in a high overall risk position. Influencing these two factors does not only lead to a reduction in the overall complexity of the NPD but also has a positive effect on all other identified risks to a certain degree as well. Some risks as for instance product geometry (rank 8) or supplier focus (rank 9) will be less affected (“weak”) than risks such as for instance resource availability (rank 3) or physical validation (rank 6) that will be strongly affected to the positive. Table 4 provides a general overview of the estimated effect per NPD-specific risk. Table 4 illustrates that a total number of six NPD-specific risks can be strongly influenced to the positive in the case that the overall risks from the product development scope and the product innovation degree are reduced.

Rank	NPD-specific risk	Relative importance	Relative risk degree	Estimated effect
1	Product development scope	0.3519	High	<i>Strong (implicit)</i>
2	Product innovation degree	0.1900	High	<i>Strong (implicit)</i>
3	Resource availability	0.0806	High	Strong
4	Product definition	0.0595	High	Intermediate
5	Systems responsibility	0.0402	High	Intermediate
6	Physical validation	0.0340	High	Strong
7	Technical change management	0.0333	High	Intermediate
8	Product geometry	0.0319	High	Weak
9	Supplier focus	0.0268	Low	Weak
10	Group affiliation	0.0236	High	Intermediate
11	Pre-development results	0.0218	High	Intermediate
12	Ongoing internal changes	0.0197	Low	Strong
13	“Frontloading” contents	0.0143	Medium	Intermediate
14	Employee competences	0.0142	Medium	Strong
15	Internal decision delay	0.0139	High	Strong
16	NPD steering	0.0110	Medium	Strong
17	Supplier contract contents	0.0067	Medium	Intermediate
18	Production orientation	0.0057	Medium	Intermediate
19	Concept competitions	0.0050	Low	Intermediate
20	Task re-prioritization	0.0050	Medium	Intermediate
21	Communication	0.0024	Medium	Intermediate
22	NPD planning	0.0022	Medium	Strong
23	Engineering service providers	0.0022	Low	Intermediate

**Table 4:** Estimated effect on NPD-specific risks by reducing product development scope and product innovation degree (own table, 2015)

Although, the overall NPD risk position benefits from optimizing the product development scope and the product innovation degree, it is important to find a balance between the

reduction of the risks and the corresponding changes in the financial result of the NPD. This business case perspective is in the responsibility of the project leader vehicle and decides over the lifecycle performance of the NPD.

### *2.5.2 New Product Development Project (NPD) Stakeholder Balance*

According to Table 4, the product development scope and the product innovation degree reflect by far the two most considerable risks in the specific NPD. The threat that is related to the large product development scope and the high product innovation degree (with a total relative importance of 0.5419) can be reduced by removing or deferring specific development contents. In this specific case, a reduction of the number of body (-12%) and engine (-15%) derivatives is decided by the top management. An intelligent reduction of NPD contents without compromising financial results with regard to sales figures is the key to the management of complexity. The conflict between different stakeholders in NPD becomes apparent at this point. Whereas the Sales and Marketing areas are in favor for a “most personalized vehicle” that further leads the way in terms of innovation, the Engineering and Production areas are facing resource shortages and processing issues in parallel. For instance, the construction, validation and ramp up efforts strongly increase. Some processes also rely on specific seasonal conditions as for instance in the case of the winter validation. Requirements from all functional areas have to be balanced in order to guarantee NPD target achievement.

### *2.5.3 Parallel vs. Sequential Product Development*

The second managerial implication focuses on separating vehicle and engine development and thus shifting from simultaneous or parallel product development to sequential product development. The resulting reduction of complexity through a decoupling of vehicle and engine development activities leads to a reduction of the overall NPD risk position. However, deferring development activities at this stage in NPD makes it necessary to update the cycle plan and more importantly the underlying technology roadmap as the lead development for certain development contents has to be transferred to another NPD. This may finally lead to conflicts with other model lines that are planning to use the development results from this new product venture for their own purposes.

#### *2.5.4 Carry-Over-Parts (COP) Quota*

The third managerial implication is based on the quota for carry-over-parts (COP) and therefore the reduction of newly developed contents in the NPD. The complexity with regard to the large product development scope and the high product innovation degree was recognized too late in the specific NPD. There is no central function established with a specific focus on product complexity. This central function could verify the complexity in specific NPD based on the product architecture and find ways to reduce this complexity without compromising functionality. An important measure is the application of COP in the scope of the group-wide modular system.

### **2.6 Conclusion**

This research work has illustrated for a specific NPD that complex NPD lead to a high overall risk position. This research work contributes to the still developing literature base on the relationship between risk and complexity in the project management field (Thamain, 2013 as well as Kim and Wicklemon, 2013). The high risk degree of a selected NPD is illustrated. The AHP method is applied as a structured and simple method to support the identification and assessment of risk in this NPD. The effectiveness of the AHP method for the purpose of risk management in a new product venture at an automotive manufacturer is confirmed. The AHP method is applicable for this complex problem where a mixture between subjectivity in the form of expert judgment and structure is needed to come to a final decision. The AHP method is used to justify preventive risk countermeasures and re-evaluate the initially planned NPD budget. From the perspective of the workshop team, the AHP method is particularly helpful in the solution finding process of a team. Defining a common solution that is ultimately accepted by everyone with minimal time effort is a large benefit of the method. This is mainly due to its transparent and stepwise approach in getting to a common solution that is finally also free of inconsistencies. The challenge for the management function lies in the translation of the key findings in all other NPD.

The management function draws an important side benefit from the application of the AHP method as shortcomings in functional area processes are uncovered. Table 4 illustrates for instance that systems responsibility (rank 5) posts a threat to the NPD. The knowhow of internal systems engineering and integration that is needed in the specific NPD due to the loss



of a systems supplier does not exist. The management function utilizes this specific information in a comparison with other new product ventures and decides upon firm internal optimizations to ensure new product development from the internal competence perspective. These general optimizations include for instance building up internal competences to define, develop, integrate and validate entire systems in-house.

The apparent main weakness of the AHP method is the negligence of interrelationships among the factors as for instance the interaction between the three risk categories product, process and project (Sipahi and Timor, 2010). It is stated that this leads to a less realistic depiction of the overall risk position (compare Analytic Network Process (ANP) method). From the perspective of this research work, this cannot be confirmed. In fact, the negligence of factor interrelationships is rather a strength of the AHP method than a weakness as neglecting these interrelationships ensures a simple application of the method and thus the acceptance in the field without compromising much of the result quality. Though, the AHP method also has a main weakness from the perspective of this research work. The application of the AHP method depends heavily on the quality of expert involvement and further requires a deeper quantitative understanding to translate their inputs. The AHP application is particularly recommendable for complex problem solutions. Less complex NPD as for instance facelifts of existing vehicle models (product updates) benefit from a transition of risks from previously conducted product ventures. In other words, the application of the AHP method is particularly valuable for risk management in the development of completely new products. Three main premises for this purpose result from the application of the AHP method in this research work.

First of all, the involvement of the most important project stakeholders must be ensured. Their presence in the course of the risk identification and assessment creates a complete picture of all involved risks. In this regard, this research work neglects the increasing responsibility of external suppliers. Where applicable, the further involvement of for instance key tier one suppliers is a chance to increase the quality of risk identification and assessment for automotive manufacturers. Second of all, the decomposition of the overall risk position must follow a lean structure. An increasing amount of levels in the hierarchical structure posts a challenge to the understanding of the involved experts. The additional benefit of further levels is negligible. In addition, the number of components in a matrix for pairwise comparison must be limited. Saaty

(1980) proposes to use between seven and nine components. A higher number of components carries the risk of inconsistency in the pairwise comparison (Miller, 1956). With regard to this research work, the matrix on the level of process category includes ten influence factors and results in a consistency ratio of exactly 0.1 (just acceptable) after pairwise comparisons have been corrected. And third of all, the relative importance and the relative risk degree of the specific risk must be considered as a valuable outcome of the AHP method. Although, the overall risk position of the NPD is the assessment target and the relative importance of the risk categories supports the understanding of the nature of the specific new product venture, the assessment of single risks is important for the subsequent risk management steps.

This research work opens the way for further research in the general field of risk management in NPD in terms of research content and methodology. In terms of research content, it is seen as valuable to consider the entire value chain of the NPD in risk management. This research work has only considered the automotive manufacturer NPD risk perspective. But about 85% of the value chain depends on the supplier and sub-supplier structure. This fact is not yet considered enough in order to create a deep understanding of the specific NPD risk position. From the automotive manufacturer perspective, all risks that belong to the supplier and sub-supplier structure are in the hand of their tier 1 suppliers. But in case of problems, these risks will disrupt the NPD progress on the level of the automotive manufacturer as well. Thus, it is recommendable to widen the scope in additional research towards a stronger consideration of the supplier and sub-supplier structure. Leaving the tier 1 suppliers with the problems may eventually lead to worst case scenarios where not just the NPD itself suffers but the series production cannot ramp up as initially planned and vehicles cannot be delivered to customers on time. In terms of methodology, further research can include a stronger connection between the risk categories. This research work has assumed independent risk categories to decrease the methodological complexity and increase the acceptance of the participants for the AHP method. A consideration of the dependence between the single risk categories (in line with the analytic network process (ANP) method) leads to a valuable addition to the provided picture of the overall NPD risk position.

Chapter 2 illustrates the potential efficiency of structured risk management processes and methods as one crucial aspect in managing risk in NPD. Risk management activities are often

neglected or at least depend highly on specific persons in the course of the NPD conduction. This may partly be due to the provided risk management processes and methods that have to be “served” despite the fact that they are large in number and may be considered as inefficient by the persons concerned. Though, it is not the amount of risk management processes and methods that provides NPD risk transparency but their practicability and acceptance within an organization. This is the basis that supports setting a central organizational standard that is thoroughly practiced and ensures a certain transferability to other NPD. The AHP method embedded in a sound risk management process landscape provides such a simple methodological approach. The following chapter focuses on organization and coordination as another crucial aspect of managing risk in NPD. All defined processes and methods are just as good as the execution quality of the persons within the organization. Different areas of the organization have to collaborate to conduct shared processes and methods. This concerns their organization and coordination as an important managerial activity. Here, the management function has to be held responsible for the gap between defined process and method conduction (desired target) and their actual execution (as-is status). This gap does not just illustrate the managerial ability to organize and coordinate a workforce in an efficient manner but also contains risk in the sense that desired targets are not met. The following chapter addresses this issue by considering a specific example where multiple perspectives have to be integrated in order to reach a desired overall target, namely the successful development of a first engine prototype.

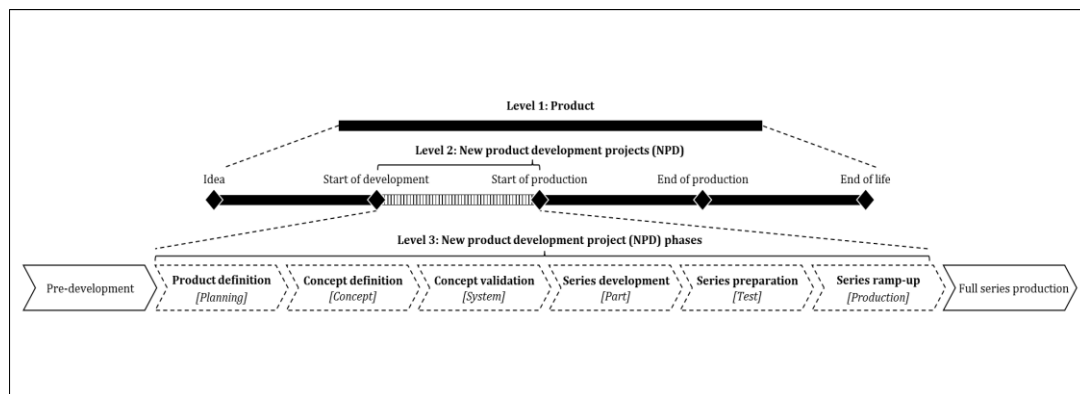
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## 3 COORDINATION IN NEW PRODUCT DEVELOPMENT PROJECTS (NPD) – THE NK MODEL APPROACH<sup>1</sup>

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### 3.1 Introduction

Many firms have to engage in continuous competitive interaction to achieve strategic targets and thrive in the long-term. The vehicle for this competitive interaction are new products that are created in a formal and structured environment, namely new product development projects (NPD) (Tabatabai et al., 2014). Figure 13 generically illustrates NPD (and its phases) as part of the overall product perspective.



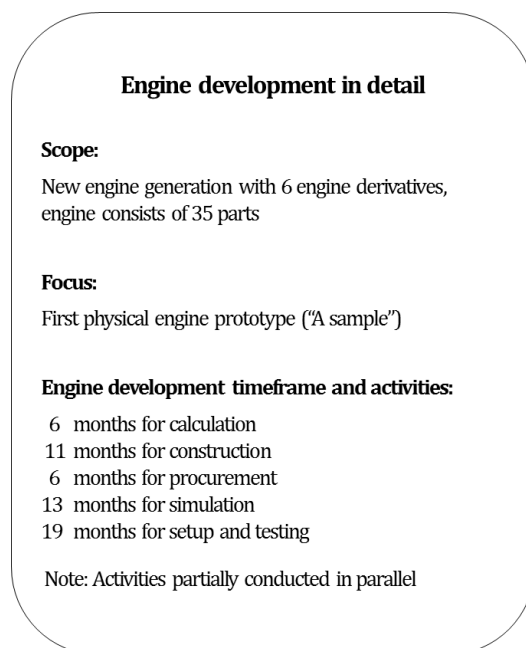
**Figure 13:** New product development projects (NPD) and new product development project (NPD) phases as part of the overall product perspective (own figure, 2018)

NPD aim at the market introduction of new products with specified requirements under given budget and time constraints (Tatikonda and Rosenthal, 2000). In the case of automotive manufacturers, the time-to-market for new products has strongly decreased over the past decades (Gil et al., 2005 and Becker, 2006). In turn, this leads to an increasing amount of conducted NPD. Although, product requirements are specified, automotive manufacturers find it increasingly difficult to achieve NPD targets (OEM, 2015). In this regard, automotive manufacturers pose a representable example for the challenge of how to reach anticipated NPD targets in an efficient manner. This question leads to coordination as a main managerial issue in NPD (Sting et al., 2011). Search theory provides the general framework to the coordination issue (Knudsen, 2014). This framework deals with the solution finding process for complex issues. Though, the focus on NPD in the scope of this research work poses a special case as the

1 Vu, M. and Spinler, S. (2016). Coordination in New Product Development Projects (NPD) – The NK Model Approach. Unpublished working paper.

solution finding process is only “open” to a certain degree as a general solution space is available from the beginning. The most important setting for search is the NK model (Sting et al., 2011). Initially applied in biological evolution, the NK model quickly finds its application in a variety of other research fields (Kauffman, 1993 as well as Kaul and Jacobson, 2006). The NK model proves to be particularly popular in the business management field. The existing body of literature reveals large evidence on the application of the NK model for coordination-related research in this field (Frenken, 2001 and Giannoccaro, 2013). Despite the large interest in coordination as a key element in organizational theory, the question of how coordination is achieved is not yet sufficiently answered (Mihm et al., 2010).

This research work considers coordination in the specific example of engine construction in the prototype phase as critical part of the engine development activities in the specific NPD of an automotive manufacturer as illustrated in Figure 14. The target of this research work is to examine the overall engine construction performance with varying coordination approaches for the construction of a first physical engine prototype (“A sample”) as well as to illustrate the impact on the required engine construction time as a central NPD target dimension. Engine construction posts a complex issue in the context of a NPD and involves a group of design engineers that construct the 35 parts of an engine. An overview of all 35 engine parts is provided in Appendix 3.1.



**Figure 14:** Engine development in detail (own figure based on OEM, 2015)

The construction results are subject to specific requirements regarding quality, budget conformity and completion time. The complexity of the engine construction arises particularly based on the fact that the single engine parts interact. A successful coordination among design engineers equally depends on the achievement of their own targets (individual perspective) and the performance of the overall engine construction (system perspective). These two challenges are at the core of the coordination task and have to be systematically managed to enable downstream processes as for instance the timely procurement of the single parts. The NK model is applied in the course of this research work. Three possible coordination approaches – simple, adapted and complex – with varying levels of interaction between the single design engineers are considered. They are examined with regard to the engine construction performance or fitness value ( $S_F$ ) on the one hand and the time to performance saturation on the other hand. These two indicators provide the basis for a comparison of the three coordination approaches. Furthermore, the role of communication and its effect on both, the engine construction performance or fitness value ( $S_F$ ) and the time to performance saturation is elaborated. With regard to the specific example, the research results suggest that the adapted coordination approach with lead clusters is the most balanced and suitable coordination approach, particularly under the effect of communication.

## **3.2 Literature Review**

### *3.2.1 Search in New Product Development Projects (NPD)*

Firms have to engage in both, routine tasks and none-routine tasks in everyday business. Whereas daily routines are encountered with formalized processes and procedures as well as standard rules and regulations, none-routine tasks pose complex issues to firms (Mihm et al., 2010). These complex issues involve a higher degree of uncertainty and have to be solved in an individual manner. New product development is a main process of many firms that aims at the market introduction of new products and states such a complex issue (Annacchino, 2003). The market introduction of new products is addressed in NPD (Tatikonda and Rosenthal, 2000). This project environment constitutes a complex issue as different functional areas, individual targets as well as various opportunities and options have to be continuously integrated and balanced (Tabatabai et al., 2014). According to Knudsen (2014), two main implications result from this constellation. First of all, a final solution that is acceptable for each individual

contributor in a NPD must be ensured. Second of all, the best overall result for a NPD must be strived for. These two challenges are multiplied on the various hierarchical levels of a NPD, namely from the overall product level perspective to the single perspectives on the levels of the components and parts of the product. In fact, this implies potential risks for the overall NPD target achievement as targets on the one hand and results on the other hand have to be aligned throughout the different stages of a NPD. Finally, product specifications may not be fulfilled, budgets may be overrun and market introduction deadlines may not be adhered to (Tatikonda and Rosenthal, 2000 as well as Tabatabai et al., 2014). Thus, the realization of NPD proves to be difficult on the basis of high uncertainty and complexity degrees (Kim and Wilemon, 2013 as well as Thaimain, 2013). Although, general guidelines such as generic NPD descriptions, product architectures and requirement specifications exist, the single components and parts of a product ask for individual decision-making outside the overall product perspective (Prencipe, 2005).

Search theory is the underlying framework that deals with the process of how complex issues such as new product development can be solved under a given level of uncertainty (Sting et al., 2011). Search in the context of NPD may be seen as an iterative process and an evolutionary movement of the organization towards a best solution (Sting et al, 2011 as well as Ulrich and Eppinger, 2012). This movement is equally supported by incremental and radical changes with respect to considered solutions to the complex issue. In this regard, search classically determines the organizational context that supports a firm in managing the entire solution finding process. Though, following Simon (1969) and Sting et al. (2011), finding the best solution to complex issues is elusive due to high degrees of uncertainty as well as existing time constraints in NPD. Also, the concept of bounded rationality and the associated limited cognitive abilities to find a best solution play an important role (Knudsen, 2014). Rivkin and Siggelkow (2002) further describe the concept of “sticking points” that supports these findings. Here, firms stick to suboptimal solutions due to personal interests of single individuals that do not accept other possible solutions despite an improvement of the overall result. Each contributor in a NPD may primarily focus on his individual piece of the complex issue and therefore neglects the “big picture” as the overall result is difficult to grasp (Knudsen, 2014). This distributed incremental search as Sting et al. (2011) term the isolated and parallel work focus of single

contributors to a complex issue, holds the premise that individual work packages do not overlap. In the case that this premise does not hold, overall solution quality may benefit more from collaborative search (Cohen et al., 1972 as well as Sing et al., 2011). Here, the focus shifts towards a combination of individual problem-solving skills. The concentration on a common target implies that individual targets are accepted to play a subordinate role (Frenken, 2001). The joint ownership of organizational outputs requires the search process to consider all other relevant information to enforce a common optimum instead of several local optima (Sing et al., 2011). In terms of NPD, this implies that project targets are placed before personal targets and individual ambitions of the line organization. A premise that often does not hold in the NPD practice (OEM, 2015). Thus, distributed incremental search is more commonly found in the NPD context than joint ownership. And although, the work packages here are free of overlaps, search in NPD still proves to be difficult as single work packages or local optima have to be merged into one final result. In order to overcome this challenge within the context of given NPD targets, a suitable search setting has to be regarded.

### *3.2.2 The NK Model as Search Setting in Business Management*

The NK model states the most important setting for search and enables the solution finding process for complex issues (Sing et al., 2011). Initially developed by Stuart A. Kauffman, a complex systems researcher in the field of biological evolution, the NK model quickly found its application in a wide variety of research areas (Kauffman and Weinberger, 1989 as well as Kauffman, 1993). Kauffman (1993) originally applies the NK model to study the evolution of genomes that comprise of interrelated genes. As these genes mutate and attain different forms, they exert an effect on dependent genes as well as on the overall performance of the genomes. The NK model enables Kauffman (1993) to examine the performance of complex systems (genomes) based on the changes (mutations) of their interacting elements (genes). It further supports for instance the determination of the time effort that is needed to reach a certain performance level and the measurement of the stability of different configurations that result from the underlying states of the elements. The NK model is named after its two main parameters N and K, where N stands for the elements of any complex system and K expresses the degree of interaction between these elements.



Kauffman emphasizes the application of the NK model in other research areas and sets the stage for the research of complex issues mainly in the fields of biology, physics and business management (Kaul and Jacobson, 2006). The NK model is especially used in the business management field to optimize complex decision-making problems (Giannoccaro, 2013). These complex decision-making problems can be separated into four main categories. Frenken (2010) describes three of these categories that aim at the translation of the properties of the NK model into business management. First of all, there are complex decision-making problems that are related to strategy. This first literature body is fairly large and puts either the finding of a corporate strategy (Levinthal, 1997; Gavetti and Levinthal, 2000; Rivkin, 2000; Winter et al., 2007 as well as Ganco and Hoetker, 2009) or the definition of organizational capabilities (Bruderer and Singh, 1996 as well as Gavetti, 2005) in the center of attention. The second literature body focusses on production technology (Auerswald et al., 2000 as well as Kauffman et al., 2000). According to Frenken (2001), this literature body examines the complexity that stems from interrelations of production-related activities and the performance of the respective production outputs. The third literature body deals with so called technological artefacts (Rivkin and Siggelkow, 2002). Simon (1969) defines technological artefacts as man-made systems comprising of single elements that collectively attain one or more common goals. Thus, technological artefacts are represented by the single elements that are integrated into a common design as for instance in the case of new product development. A fourth literature body with regard to business management is operations management. Giannoccaro (2013) refers to complex decision-making problems along the value chain of a firm that are addressed with the NK model. This includes for instance procurement (e.g. sourcing policy), engineering (e.g. reverse engineering), production (e.g. production site) and supply chain management (e.g. distribution network). Although, complex decision-making problems may vary with different research topics, the standard application of the NK model remains the same. Thus, the NK model is applicable for a variety of complex decision-making problems, regardless of whether the examined system refers to strategies, production outputs, technological artefacts or operations management-related topics.

### *3.2.3 Coordination of System Development in New Product Development Projects (NPD)*

The NK model has proven to be a valuable setting for search in complex decision-making problems (Frenken, 2001 as well as Sting et al., 2011). In this context, the underlying decision-making problem (that can be used interchangeably with the terms “technological artefact” or “system”) plays an important role in the overall solution finding process (Rivkin and Siggelkow, 2002 as well as Ethiraj, 2007). Such a complex decision-making problem is often too large to be managed by an individual and thus has to be decomposed into smaller and more tangible elements (Frenken, 2001). Frenken (2001) exemplarily refers to the technical components of an automobile, namely engine, gearbox, breaks, springs as well as tires, and concludes that the interrelations of these elements are at the source of complexity in a technological artefact such as an automobile. In this regard, managers have to cut through the complexity of a system and delegate single elements to specialists that in turn deliver solutions in their respective fields of specialization (Mihm et al., 2010). The decomposition of systems does not only allow for a stronger specialization but also decentralizes parts of a complex decision-making problem as an individual by itself is not capable of finding an optimal overall solution (Geisendorf, 2010). According to Simon (1969), the complexity of a system results from the large number of elements that interact in non-linear ways. Kauffman (1993) later refers to epistatic relations among the single elements. This implies that a change in the state of an element affects the element itself as well as all dependent elements and finally the performance of the entire system. These relations among the elements may further be characterized by conflicting constraints (Frenken, 2001). The combinatorial complexity that arises from this condition assumes that optimal solutions for the single elements are not necessarily sufficient to ensure the best solution from the overall system perspective (Simon, 1969).

Although, the elements of a system are processed independently, their interrelation asks for coordination in the light of epistatic relations. Therefore, coordination becomes a main managerial challenge and has an ultimate effect upon the performance of NPD (Knudsen, 2014). Although, the coordination of interrelated actors in NPD is known to be a main issue in organizational theory, it is still not completely transparent how coordination is achieved (Knudsen, 2014 as well as Mihm et al., 2010). Also, risk management with regard to the organizational perspective of NPD is considered to be underdeveloped in this context

(Thamain, 2013). The decomposition of a complex decision-making problem in its single elements, the respective solution finding process for these elements as well as the integration and balancing of the elements' solutions is at the core of the coordination task (Sting et al., 2011). According to Frenken (2001), specialists have to work on clearly defined and manageable tasks and complement each other through coordination to achieve a common target.

System development in new product development is particularly difficult as complex systems with specified requirements and a given budget are developed in a specified amount of time (Tatikonda and Rosenthal, 2000). The coordination of the development activities posts a central influence factor on the performance of system development in new product development. In the exemplary case of the automotive industry where product development times become ever shorter and development cycles are subject to increasing time constraints, automotive manufacturers are forced to overlap their development activities and expose themselves to high risks (Loch and Terwiesch, 1998). In order to reduce this risk exposure, automotive manufacturers complement the overlap of development activities with frequent information transfer. The literature body with focus on the role of communication in coordination is extensive (March and Simon, 1958; Lawrence and Lorsch, 1967; Loch and Terwiesch, 1998; Lazer and Friedman, 2007; Vidgen and Padget, 2009 as well as Knudsen, 2014). The effects of communication are particularly studied with regard to distributed incremental search where development activities are broken down and parallelized in order to reduce time-to-market (Knudsen, 2014). The concurrent engineering approach uses communication to outweigh possible negative effects as for instance rework as a result of parallel proceeding development activities with preliminary or immature information (Knudsen, 2014). Though, the reduction of negative effects such as possible rework results at the expense of communication time and synchronization efforts (Artmann, 2009). There are opposing views among experts regarding the benefits of communication for coordination (Brown and Eisenhardt, 1995). It is believed that shared knowledge among specialists is difficult to create. This view is specifically supported by the fact that bounded rationality based on high specialization complicates a mutual understanding (Knudsen, 2014). And the resulting loss of time through extensive communication may finally not outweigh the timely gains from concurrent engineering (Loch and Terwiesch, 1998). The coordination discussion in the

literature can be retraced over several decades and is ongoing. The extensive evidence in the literature indicates the challenges that come with this research area. The question of how system development in new product development can be coordinated must be answered in accordance to a specific situation or NPD and depending on the perspective regarding the various NPD levels of product, components and parts.

### **3.3 Research Methodology**

#### *3.3.1 Focus and Targets*

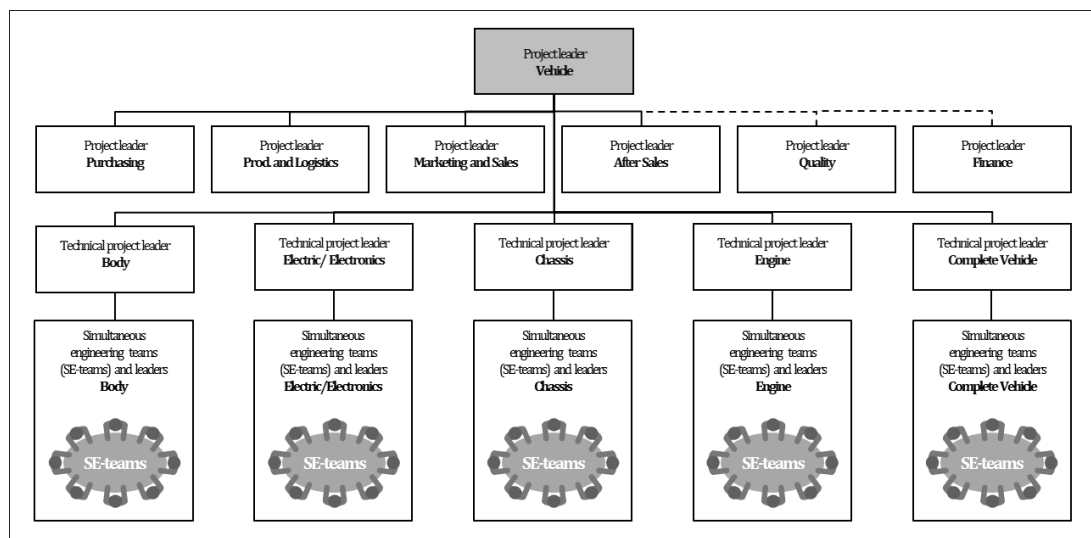
This research work addresses the coordination issue with regard to the engine development in a specific NPD of an automotive manufacturer. The focus lies on the engine construction in the prototype phase that is performed by a group of specialized design engineers and represents a particularly complex issue within the specific NPD. The engine states a large system that comprises of 35 parts. The coordination issue arises particularly based on the fact that these parts mainly interact in two specific ways (OEM, 2015). First of all, the interfaces of the parts have to be compatible with each other. Second of all, the parts share an overall construction space that is limited, thus the construction design of each part has a potential influence on all neighboring parts. The first physical engine prototype ("A sample") is created in the scope of a NPD and involves high costs. The range of functionality and the specific search space may not be fully specified at this point in time. The resulting uncertainty coupled with a high technical change frequency leaves space for various solutions in the course of the overall engine construction. This is accepted for the benefit of a rapid product maturity increase in the first stages of the NPD.

The target of this research work is to examine the overall engine construction performance with varying coordination approaches for the construction of a first physical engine prototype ("A sample") as well as to illustrate the impact on the required engine construction time as a central NPD target dimension. Furthermore, this research work investigates the role of communication in this actual coordination issue. This research work considers the prevailing approaches of distributed incremental search and concurrent engineering as initial situation (OEM, 2015). Namely, on the one hand, the overall engine design is separated into tangible parts that can be managed predominantly decentralized and independent by the responsible design

engineers to achieve individual targets (distributed incremental search). On the other hand, construction tasks are parallelized in order to rapidly increase the maturity degree of the product on the basis of the current work status (concurrent engineering). This approach is accompanied by regular communication among the different stakeholders, mainly in order to take changes in the current work status into ongoing consideration.

### 3.3.2 Initial Situation

The development of engines is characterized by high requirements for increasing performance, reduced weight, less energy consumption and emissions as well as higher quality and improved life expectation (OEM, 2015). All these requirements directly relate to the construction of an engine. This establishes the design engineer as a highly important role with regard to the fulfillment of NPD targets and equally creates work pressure based on the high expectations. The construction of an engine represents a major part of the overall engine development activities. The physical engine prototype (“A sample”) of an automotive manufacturer consists of 35 parts. These 35 parts must be compatible with each other and fulfill all specified NPD targets on the level of the engine component. In order to ensure the successful realization of these NPD targets on the component level, the responsibility of the engine parts construction is assigned to a simultaneous engineering team (SE-team) Engine as illustrated in Figure 15.



**Figure 15:** Standard NPD organization (vehicle) (own figure based on OEM, 2015)

The construction responsibility is with the design engineers. Although, they represent specialists in their specific areas of expertise, they are affiliated to the same engine development main department and thus share a common background in terms of corporate culture as well as general know-how and qualification. Despite the fact that the responsibility of each design engineer refers to a different set of engine parts, their general task is the same. They transfer requirements into a product design in order to ensure NPD target achievement on the part and component level. This is followed by a high degree of uncertainty as the search space may not be initially given in the context of NPD. The SE-teams conduct the operational work and are generally cross-functional in nature. They are standardized organizational units that function widely independent ("firm-in-firm" approach). The SE-team leader is at the top of this organizational unit and has full responsibility for the respective development scope. In turn, the single subordinated design engineers are responsible for the parts under their supervision in terms of requirements fulfillment, budget and development time plan adherence. This specific premise is central to the coordination issue as the engine parts are partly interrelated but have split responsibilities, follow individual targets and are progressed in parallel. Although, the single design engineers are almost exclusively dedicated to one NPD and communication is institutionalized over the NPD organization (project communication) as well as over the engine development main department (line organization communication) to synchronize the work status and dissolve difficulties, the coordination of the overall engine construction activities remains a challenge.

In order to improve the coordination of the construction activities for a first engine prototype ("A sample") in the specific NPD of an automotive manufacturer, different coordination approaches are considered. Here, the overall engine construction performance states the most essential sign for success. First general indications for coordination improvement potential are existent. Mihm et al. (2010) as well as Loch and Terwiesch (1998) indicate that a more sequential coordination approach may be beneficial. Though, Knudsen (2014) sees this central question as unsolved. This research work applies the NK model to solve this question for a specific example.

### 3.3.3 NK Model Procedure

The NK model as setting for search builds the framework for this research work. In the following, the general steps of the standard NK model application are described in accordance to (Kauffman, 1993; Frenken, 2001 and Giannoccaro, 2013). Although, the standard application of the NK model is similar, the level of detail varies. Whereas Kauffman (1993) and Frenken (2001) illustrate four almost similar steps, Giannoccaro (2013) depicts a total of seven steps in the standard application of the NK model. The following research methodology is a synthesis of the existing literature and adopted for the purposes of this research work. Table 5 denotes the single components of the NK model at first.

No.	Component	Description
1	N	Elements in a system
2	A	Possible element states ("alleles")
3	S	System as string of elements' states
4	K	Degree of interrelationship between elements in a system
5	$N_P$	Performance measure of single element
6	$S_P$	Performance measure of system
7	L	Fitness landscape ("search area")

**Table 5:** Overview of NK model components (own table based on Kauffman, 1993; Frenken, 2001 and Giannoccaro, 2013)

The standard application of the NK model primarily aims at the calculation of system performance ( $S_P$ ). Thus, the overall performance of a system such as a technological artefact is examined. The following steps illustrate the application of the NK model to derive system performance ( $S_P$ ) and indicate the optimal overall solution for a complex decision-making problem:

#### Step 1: Define N and A

The initial step in the standard application of the NK model involves the decomposition of the examined system in its single elements. The number of elements (N) is derived. It is important to define elements on a similar level from the perspective of the underlying system. This

ensures the comparability among the elements and their direct influence on the overall system performance ( $S_P$ ). Furthermore, it is important to define the elements in a way that they are distinct and non-overlapping. Once the elements are defined according to the above stated premises, the possible states of the elements ( $A$ ) are derived. In reality, this search space for solutions of single elements is not given but has to be developed. The standard application of the NK model almost exclusively depicts binary element states, thus an element may adopt two different solutions  $[0; 1]$ . A larger number of element states is possible.

#### Step 2: Derive S

In the next step, all possible systems ( $S$ ) that result from the defined number of elements ( $N$ ) and their different solutions or states ( $A$ ) are derived. A system ( $S$ ) is a binary string of the elements ( $N$ ) as illustrated in (3.1).

$$(3.1) \quad S = (N_1, N_2, N_3, \dots, N_i) \text{ with } N_A [0;1]$$

where  $N_A$  are the single elements in binary states

The overall number of possible system configurations ( $C$ ) depends on the number of elements ( $N$ ) and their possible states ( $A$ ). On the basis of the number of elements ( $N$ ) and the possible element states ( $A$ ), the overall number of possible system configurations ( $C$ ) can be derived according to (3.2).

$$(3.2) \quad C = A^N$$

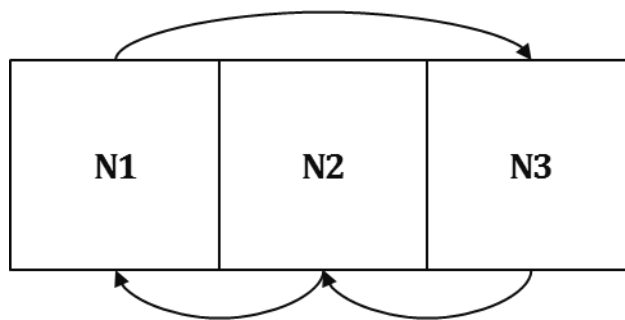
where  $A^N$  is the possible element states ( $A$ ) to the power of the number of elements ( $N$ ) in a system

The increase in the number of possible system configurations ( $C$ ) is exponential. This leads to the assumption that the overall landscape of possible systems ( $S$ ) as strings of binary element states becomes increasingly complex with rising numbers of elements ( $N$ ) and their respective possible solutions ( $A$ ).



### Step 3: Describe K and establish interaction matrix

After the system (S) as well as its number of elements (N) and their respective possible solutions (A) are identified, the interactions between the single elements (K) are described and visualized. Aside from N, K is the second main parameter in the NK model and influences the overall complexity of the system (S). The interaction between the single elements (K) creates premises for the overall system performance as changes to one element of a system may have an effect on its own performance ( $N_{Pi}$ ) as well as on the performance of all dependent elements ( $N_{Pj}$ ) and finally on the performance of the overall system ( $S_P$ ). After describing the interactions between the single elements (K), they can be visualized as shown in Figures 16 and 17. Figures 16 and 17 illustrate typical visualization approaches as seen in the existing literature. Whereas Figure 16 is particularly suitable for systems (S) with smaller numbers of elements (N), Figure 17 qualifies to visualize also larger systems (S).



**Figure 16:** Interaction matrix B – Interaction of single elements (K) with  $N=3$  and  $K=1$  (own figure based on Kauffman, 1993)

	N1	N2	N3
N1	X	X	-
N2	-	X	X
N3	X	-	X

**Figure 17:** Interaction matrix A – Interaction of single elements (K) with  $N=3$  and  $K=1$  (own figure based on Frenken, 2001)

The main difference between the two interaction matrices is that Figure 16 illustrates that  $K=1$  means that the element  $N_i$  is not solely dependent on the state of one other element in the system but also on the state of the element  $N_i$  itself regarding its element performance ( $N_{Pi}$ ). In Figure 17, the elements of the columns influence the elements of the rows.

### Step 4: Calculate $N_P$ and $S_P$

A crucial step in the standard application of the NK model is illustrated by the calculation of the performance of the single elements ( $N_P$ ) as well as the calculation the performance of the overall

system ( $S_P$ ). Each element contributes to the overall system performance ( $S_P$ ). The performances for the single elements ( $N_P$ ) are randomly derived from a uniform distribution over the possible states of an element ( $A$ ), namely over  $[0; 1]$  in the case of binary states, each time it or an interrelated element changes. Then, the overall system performance ( $S_P$ ) is calculated. The overall system performance ( $S_P$ ) is also referred to as “fitness value” and posts the overall quality of the system solution. It is calculated by averaging the performances for the single elements ( $N_P$ ) as illustrated in (3.3).

$$(3.3) \quad S_P = \frac{1}{N} \sum_{i=1}^N N_P$$

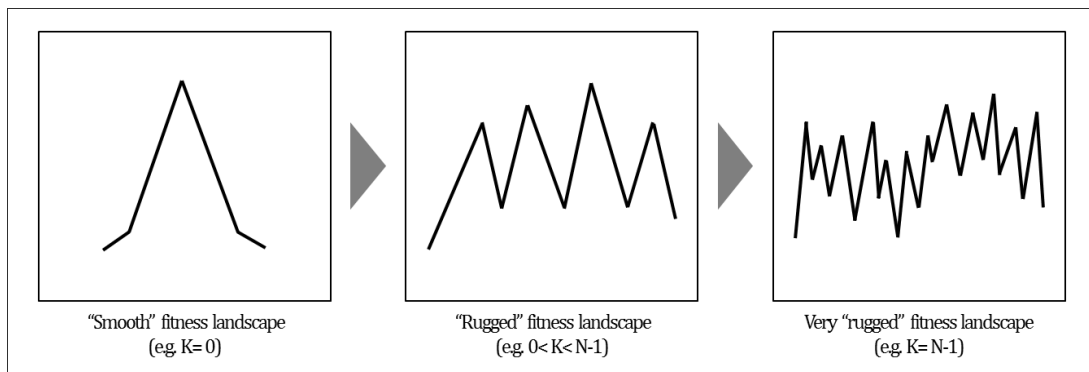
where  $N$  is the number of elements in a system  
and  $N_P$  are the performances for the single elements

The fitness value finally depends on the single contributions from the elements of the system. Furthermore, the time that is needed in order to reach a certain fitness value is also of importance. This time factor is derived as the average performance improvement during the stages of search.

#### Step 5: Perform search on $L$

Various solutions for a complex decision-making problem exist. Each of the configurations that results from (2) states such a possible solution. The mapping of each of these configurations into a common search area results in a fitness landscape ( $L$ ). The visual form of the fitness landscape ( $L$ ) depends particularly on the interactions between the single elements ( $K$ ) as a main driver of complexity as stated in step 3. In the case of  $K=0$ , no interactions between the single elements are existent.

This is the least complex case where the fitness landscape is “smooth” with only one optimum and the solution is respectively trivial to be located. As  $K$  increases until the extreme form of  $K=N-1$ , more local optima appear and the fitness landscape becomes increasingly “rugged” as illustrated in Figure 18.



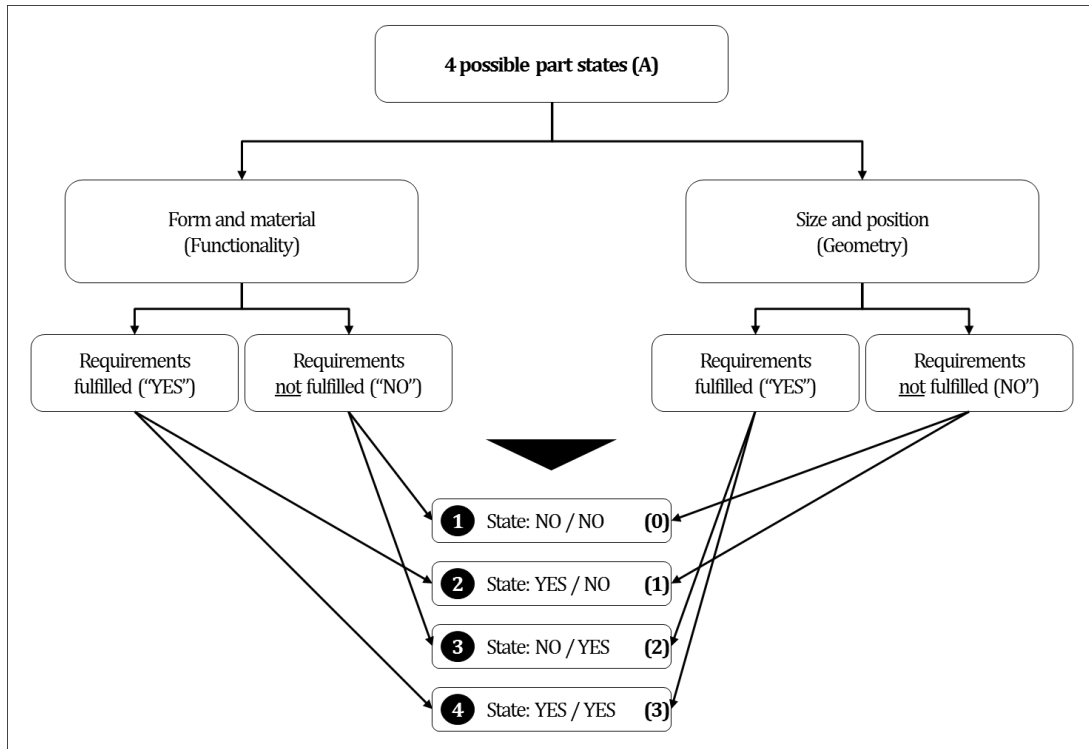
**Figure 18:** Exemplary overview of fitness landscapes (own figure based on Frenken, 2001)

A “rugged” fitness landscape complicates the search for the optimal solution. As the interactions increase between the single elements, more and more solutions for a system (S) emerge. The “rugged” fitness landscape has to be searched for an optimal solution. This search proves to be difficult and reached solutions must not necessarily be held onto. In search of better overall solutions or higher peaks, it is necessary to apply a general search strategy that guides the search towards such an optimal solution across a given fitness landscape. Two general search strategies are existent. First of all, the adaptive walk strategy where a fitness landscape is searched with incremental steps to move towards higher peaks. Second of all, the long jump strategy where search is performed in larger steps with more dramatic and rapid changes. The search strategy particularly depends on the concept of path dependence. For instance, if an existing solution is characterized by low quality and insufficient maturity, a long jump strategy is performed as existing results may be neglected at the benefit of large gains. In the opposite case where an existing solution is characterized by a higher level of quality and therefore more maturity, incremental steps in line with an adaptive walk strategy may be chosen to ensure that existent benefits are not lost. Regardless of the chosen search strategy, simulations should be applied for the calculations of the search algorithms as the underlying calculation capacity may be large. All simulation tools are stand-alone solutions and have different functionality ranges. The simulation tools can be applied with the use of a standard personal computer.

### *3.3.4 NK Model Sample and Application*

#### **Step 1: Define N and A**

The first physical engine prototype (“A sample”) in the considered example comprises of 35 parts (N). Each of the 35 parts takes one of four possible states (A) as illustrated in Figure 19.



**Figure 19:** Overview of possible part states (A) (own figure based on OEM, 2015)

The engine prototype performance or fitness value ( $S_P$ ) relies on the construction quality of the parts. In turn, the parts construction quality depends on the individual choices of the involved design engineers. And the choices of the design engineers also have a direct impact on the engine prototype performance or fitness value ( $S_P$ ). In terms of requirements fulfillment, the design engineers primarily have to make construction choices regarding the form and material (functionality) as well as the size and position (geometry) of their parts. The combination of these choices results in four general outcomes or states [ $A=0, 1, 2$  or  $3$ ] for each part. First of all, both, requirements for functionality and geometry are not fulfilled. Second and third of all, either functionality requirements or geometry requirements are fulfilled. And fourth of all, all requirements for functionality and geometry are fulfilled. For simplification, this research work limits the view on the states of the parts (A) to the fulfillment of requirements in the dimensions of functionality and geometry. Depending on the specific set of states of the parts (A), the outcome for the engine prototype varies.

## Step 2: Derive S

The engine prototype (S) is reflected by a string of 35 parts (N), with each part being in one of the mentioned four part states (A). Figure 20 exemplifies three possible engine prototypes (S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>).

Engine prototype (exemplary)	String of 35 parts (N) (exemplary)
S <sub>1</sub> =	[0, 0]
S <sub>2</sub> =	[3, 3]
S <sub>3</sub> =	[0, 3, 2, 3, 3, 2, 2, 0, 1, 2, 1, 3, 0, 0, 2, 1, 3, 0, 1, 3, 2, 3, 2, 2, 1, 0, 3, 3, 1, 2, 3, 0, 0, 3, 1]

**Figure 20:** Overview of exemplary engine prototypes (S<sub>1</sub>, S<sub>2</sub>, S<sub>3</sub>) (own figure, 2015)

The first engine prototype (S<sub>1</sub>) exemplarily depicts an engine prototype that fulfills all requirements regarding the single parts, thus equals a perfect overall parts construction result. The second engine prototype (S<sub>2</sub>) exemplarily illustrates the opposite case where all parts of the engine prototype fulfill none of the stated requirements. With regard to the third engine prototype (S<sub>3</sub>), a component with parts in various different states is exemplified. The third engine prototype (S<sub>3</sub>) is located between the two previous examples (S<sub>1</sub> and S<sub>2</sub>) regarding the construction results of the single parts. Figure 20 illustrates only three of a total of 4<sup>35</sup> (four to the power of thirty-five) possible configurations (C) for the engine prototype (S). This large total amount of possible configurations (C) for the engine prototype (S) results on the basis of the high numbers of parts (N=35) and their respective possible states (A=4). Although, the engine prototype illustrates a large system, its complexity is not derived from the pure scope of the parts but rather from the interactions between them.

## Step 3: Describe K and establish interaction matrix

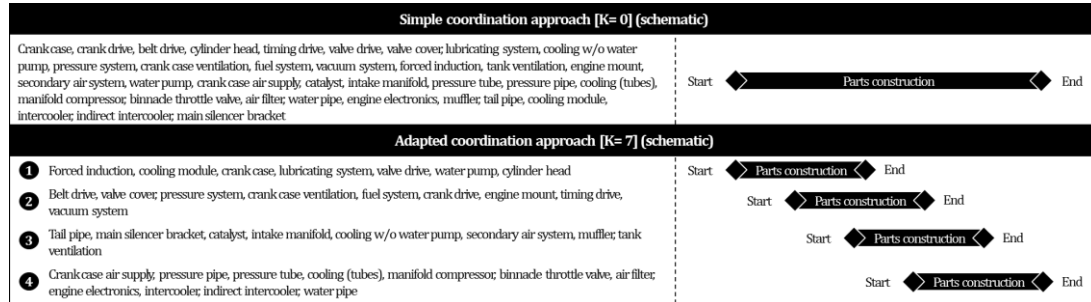
The 35 parts of the engine prototype may interact in two ways, namely through a direct interface between the respective parts and through a shared construction space. The construction of the parts and the engine prototype respectively is led by the question of how to achieve an optimal result in the context of this interaction and specified NPD targets. This

research work considers three coordination approaches – simple (no interaction), adapted (realistic interaction) and complex (high interaction) – to examine different possibilities. Initially, the extreme case of no interaction between the single parts is assumed. Thus, design engineers work independently and in parallel on the construction of their parts. They also define the construction sequence of the single parts in an individual manner. The “big picture” may be neglected either due to a lack of knowledge over interfaces or a low prioritization based on diverging design engineer targets. The performance of each part solely depends on its own part state (A). The overall engine prototype performance does not receive much attention as the interaction between single parts (K) is not accounted for.

In order to shift focus, this research work assumes a change to the extremely independent and parallel work focus by increasing the interaction between the single parts (K) in accordance to the realistic interaction need [K=7 on average] (OEM, 2015). Appendix 3.2 illustrates the respective interaction matrix. The interaction matrix shows that numerous parts of the engine prototype interact with each other. It is created based on evidence from the design engineers that are involved in the specific NPD of the automotive manufacturer. This evidence yields realistic and meaningful interactions between the parts of the engine prototype. The result is a total number of 238 interactions between the parts. Whereas some parts as for instance forced induction, cylinder head and crank case are highly “interactive”, other parts have only low or even no interaction. In this regard, requirements are always stated in both directions to define the specific interaction between two parts in a successful way from the overall performance perspective of the engine prototype.

Figure 21 shows four lead clusters according to the realistic interaction need [K=7 on average] as basis for the parts construction sequence as a result of Appendix 3.2. These lead clusters guide the overall parts construction. For instance, the design engineers that are responsible for the seven parts of the first lead cluster have to be aligned with all interacting parts according to the interaction matrix prior to creating a product design. The adapted coordination approach takes interactions realistically into account and puts the engine prototype performance at the core of decision-making. Though, this leads to a higher dependency between the single parts as well as increasing specifications that have to be taken into account in parts construction. These additional requirements finally lead to a reduction of the overall search space in parts

construction as well as decreasing parallelization of parts construction. Additionally, the definition of lead groups allows for the optimization of the parts construction sequence with regard to the upcoming parts procurement process as for instance parts with high procurement duration are subject to earlier construction.



**Figure 21:** Parts construction with simple and adapted coordination approach (own figure based on OEM, 2015)

For illustration purposes, this research work further considers a third case where the highest possible interaction between the single parts [ $K=N-1$  or  $K=34$ ] is assumed. Three different coordination approaches are in the focus. These coordination approaches are judged based on the resulting engine prototype performance or fitness value ( $S_P$ ). In turn, this requires the calculation of the performance of the single parts ( $N_P$ ) in a prior step.

Steps 4 and 5: Calculate  $N_P$  and  $S_P$  and perform search on  $L$

As the engine prototype can be considered a fairly large component [ $N=35$ ] and as this research work is considering complex interactions [up to  $K=34$ ], a simulation tool (Sendero) is applied. The simulation tool is an application on Repast basis to reproduce the NK model. It is recommended to apply a simulation tool to handle the large amount of raw data (Vidgen and Padget, 2009). An overview of simulation tools is referred to in Appendix 3.3. Also, the simulation parameters and values can be extracted from Appendices 3.4 and 3.5.

Firstly, this research work focuses on the calculation of the performance of the single parts ( $N_P$ ) to derive the engine prototype performance or fitness value ( $S_P$ ) for the three coordination approaches. A long jump strategy is applied. The statistical significance is achieved over a high number of simulation runs. Secondly, this research work considers the time to performance saturation for the three coordination approaches. In this regard, performance saturation states the point in time when the final or maximum fitness value ( $S_P$ ) is reached. Thirdly, this research

work explores the role of communication for the three coordination approaches. The engine prototype performance or fitness value ( $S_p$ ) as well as the time to performance saturation is analyzed with regard to the communication effect.

### *3.3.5 Using Sendero Application as Decision Aid*

This research work applies Sendero as decision aid, a simulation tool built in Repast (open source simulation platform), that allows agent-based simulation as presented with the NK model by Kauffman (1993). Sendero is generally freely accessible for research use and can be flexibly adopted to different research purposes as the source code is open. Thus, in addition to Kauffman's standard NK model, Sendero allows for extended research possibilities as for instance the consideration of communication networks and different search strategies. The simulation tool can be considered a well-structured and objective-oriented solution that may be applied reasonably efficient on standard personal computers (base code is standard Java embedded in Repast).

Given the obvious advantages of Sendero, the reasonable use of computer-based models nevertheless has to answer two distinct questions. First of all, if it runs as intended (verification). In the means of this research work, this especially means if Sendero adequately represents the NK model. And second of all, if it stands a comparison to the real world system that is supposed to be modeled (validation). Or in other words, does Sendero fulfill practitioners' expectations with regard to coordination in NPD. In terms of verification, in contrast to previous research that is based on the application of the NK model and that works with no publically accessible simulation tool (for instance Lazer and Friedman, 2007), the access to Sendero is open to the research public and has been verified by illustrating consistency to the earlier research of Kauffman's NK model (Vidgen and Padget, 2009). By comparing (also fairly large) combinations of  $N$  (8, 16, 24, 48 and 96) and  $K$  (0, 2, 4, 8, 16, 24, 48 and 96) (with  $A=2$ ), it can be shown that (with 100 runs and averaged fitness value results) the simulation results from Kauffman's NK model and from Sendero simulation are clearly similar with regard to means and standard deviations. Figure 22 illustrates the comparison accordingly and points out that Sendero is capable of reproducing the NK model in an adequate way.



N																				
K	8				16				24				48				96			
	Kauffman		Sendero		Kauffman		Sendero		Kauffman		Sendero		Kauffman		Sendero		Kauffman		Sendero	
0	0.65	0.08	0.67	0.08	0.65	0.06	0.66	0.06	0.66	0.04	0.67	0.05	0.66	0.03	0.67	0.03	0.66	0.02	0.67	0.02
2	0.70	0.07	0.71	0.07	0.70	0.04	0.71	0.05	0.70	0.08	0.70	0.04	0.70	0.02	0.71	0.03	0.71	0.02	0.71	0.02
4	0.70	0.06	0.70	0.07	0.71	0.04	0.71	0.05	0.70	0.04	0.70	0.04	0.70	0.03	0.71	0.02	0.70	0.02	0.71	0.02
8	0.66	0.06	0.67	0.06	0.68	0.04	0.68	0.05	0.68	0.03	0.69	0.04	0.69	0.02	0.69	0.02	0.68	0.02	0.69	0.02
16					0.64	0.04	0.65	0.04	0.66	0.03	0.65	0.03	0.66	0.02	0.66	0.02	0.66	0.02	0.67	0.02
24									0.63	0.03	0.63	0.03	0.64	0.02	0.64	0.02	0.64	0.01	0.64	0.02
48													0.60	0.02	0.60	0.02	0.61	0.01	0.61	0.02
96																	0.58	0.01	0.58	0.01

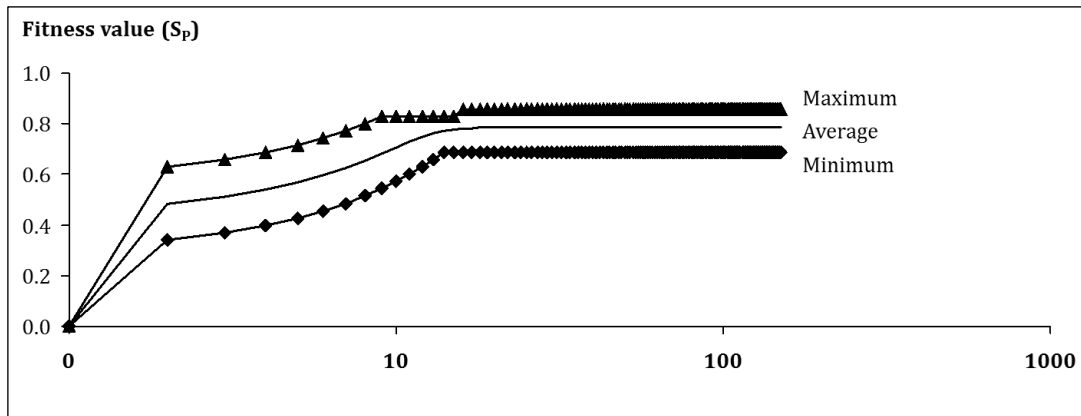
**Figure 22:** Comparison between NK model (Kauffman) and Sendero simulation results for different set-ups (own figure based on Kauffman, 1993 as well as Vidget and Padget, 2009)

The NK model can be reproduced and even complemented by the functionality of Sendero. Though, the question remains if Sendero, or the NK model respectively, is the right setting to deal with complex coordination decisions in NPD (validation). According to Gass (1983), Sendero as computer-based model can gain credibility by considering for instance a face validity test that judges if the model results are reasonable from the practitioners' point of view. In this regard, the following research results increase the confidence degree in decision-making on the basis of Sendero. The following chapter (especially under "3.4.2 Engine Prototype Performance Development") comments on the comparison between real world expectations and the reproduction of the NK model by Sendero.

### 3.4 Research Results

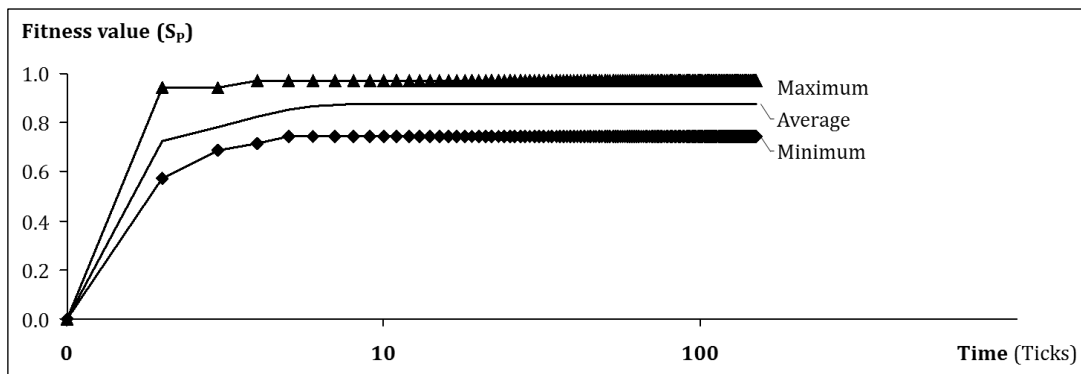
#### 3.4.1 Coordination Approaches and Engine Prototype Performances

The initial situation of the construction of the first physical engine prototype ("A sample") in a specific NPD of an automotive manufacturer is characterized by distributed incremental search as well as concurrent engineering. This leads to an independent and parallel coordination approach. The design engineers decide upon the parts construction sequence and the way to transfer specified requirements into a product design in the context of their parts responsibility. Figure 23 illustrates that the engine prototype performance or fitness value ( $S_P$ ) averages here to about 0.79.



**Figure 23:** Fitness values ( $S_P$ ) – simple coordination ( $K=0$ ) (own figure, 2018)

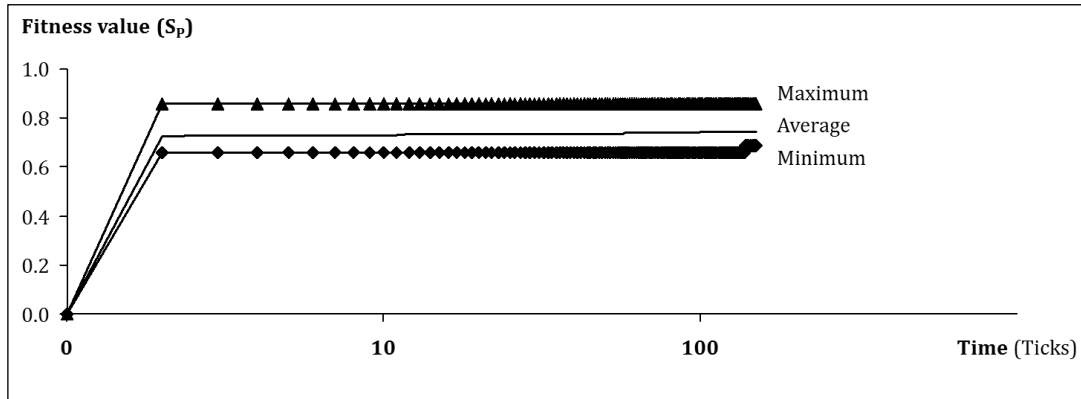
The introduction of lead clusters and thus parts prioritization according to part interfaces and necessary part procurement duration results in a change of the coordination approach. Instead of independent and parallel parts construction, design engineers now follow a given parts construction sequence. They rely on the clarification of interfaces before they are allowed to proceed with parts construction. In turn, this coordination approach leads to higher overall fitness values. Figure 24 shows that the engine prototype performance or fitness value ( $S_P$ ) averages in this case to about 0.88.



**Figure 24:** Fitness values ( $S_P$ ) – adapted coordination with lead clusters ( $K=7$ ) (own figure, 2018)

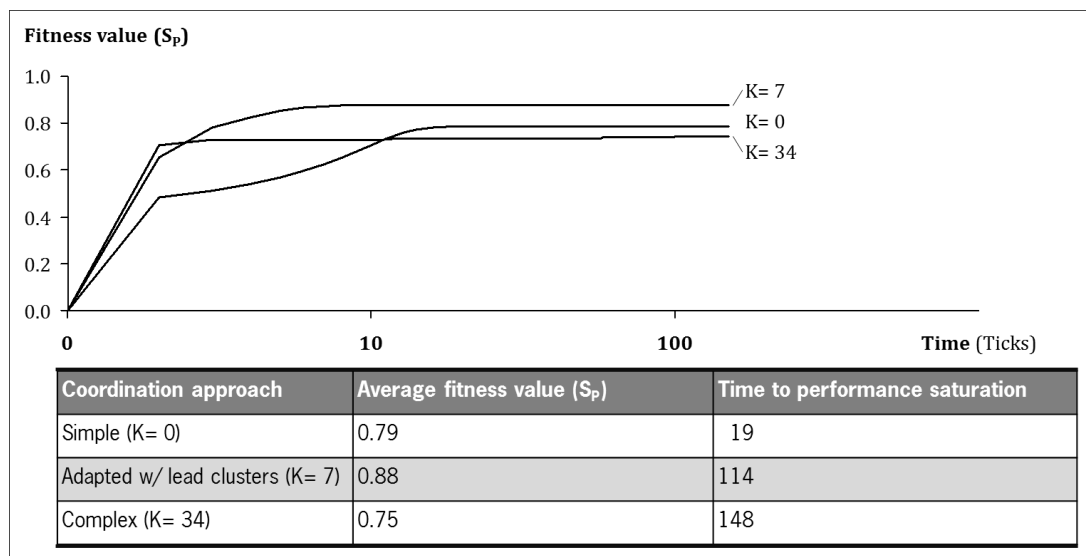
The final coordination approach builds on the premise that there is a complete interaction between all the parts of the engine prototype. Here, a complex situation arises where conflicts between the single parts become increasingly probable. In this extreme case, the resulting engine prototype performance or fitness value ( $S_P$ ) averages to about 0.75 as illustrated in Figure 25. This fitness value depicts a low fitness value compared to the previous coordination approaches. It becomes obvious that a minimum of interactions results in an initially minimal

conflict potential but yields only a mediocre engine prototype performance or fitness value ( $S_P$ ). On the other hand, an extremely high consideration of interactions leads to a suboptimal engine prototype performance or fitness value ( $S_P$ ). An intermediate or realistic number of interactions results in a relatively high engine prototype performance or fitness value ( $S_P$ ).



**Figure 25:** Fitness values ( $S_P$ ) – complex coordination ( $K=34$ ) (own figure, 2018)

The overall engine prototype performance represents one target dimension for parts construction. In addition, the time dimension plays an important role. NPD are generally relying on a precise time schedule and optimal results have to be accordingly delivered. Figure 26 consolidates the average fitness values ( $S_P$ ) of the three coordination approaches (Figures 23, 24 and 25) and considers these results with regard to the time dimension. In addition, the key figures for average fitness values ( $S_P$ ) and time to performance saturation are summarized.



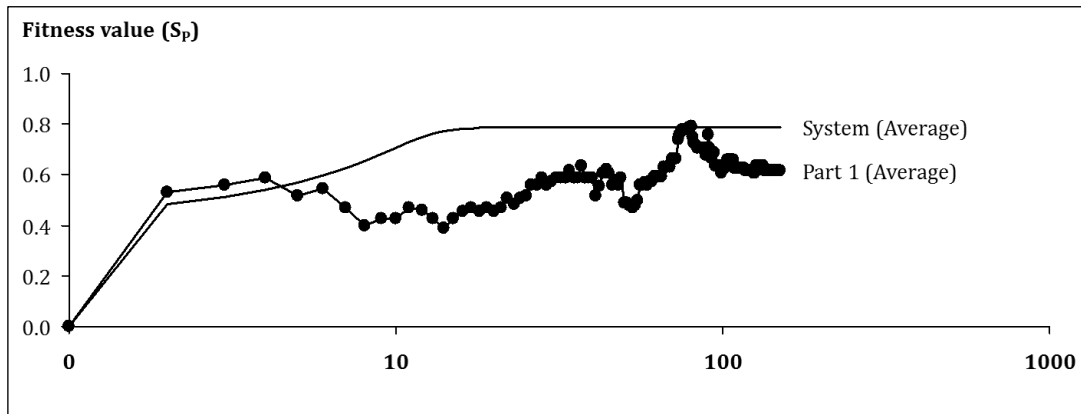
**Figure 26:** Average fitness values ( $S_P$ ) ( $K=0, 7$  and  $34$ ) and saturation points (own figure, 2018)

Figure 26 illustrates that both, all three coordination approaches climb fairly rapid and steep at the beginning of the simulation. Their fitness value ( $S_P$ ) continuously further improves, especially with regard to adapted and complex coordination approach that also take longer until saturation levels are reached. Thus, interaction leads to more required time to reach the final maximum fitness value ( $S_P$ ). In comparison, the simple coordination approach climbs less rapidly and steeply over the length of the simulation. But this approach saturates a lot earlier than the adapted and complex coordination approaches. The early performance saturation at a comparatively high level clearly provides justification for selecting the simple coordination approach over one of the other two illustrated coordination approaches. As NPD generally suffer from increasing time pressure, the positive time effect from this coordination approach brings benefits despite the fact that higher fitness values ( $S_P$ ) can be reached.

#### *3.4.2 Engine Prototype Performance Development*

The above fitness values ( $S_P$ ) reflect the engine prototype performance on the system level. The performance of the single parts ( $N_P$ ) is implicitly linked but not explicitly graphically illustrated on the system level performance related figures above. It is noticeable that the system level performance is increasing, although to a different magnitude, in all three regarded coordination approaches over time. This does not mean that “chaotic behavior” in a way that performances not just increase but also decrease over time as seen in previous research (as for instance Loch et al., 2003) is not present. Such “chaotic behavior” can certainly be expected on the system level and the level of single parts that may oscillate up and down in performance over time. Though, the focus here lies on the overall system performance level and the applied search strategy (long jumps, in step 5 under “3.3.3 NK model procedure”) that only allows for changes in part configurations if system performance increases. Thus, there is a choice between available alternatives and no general need to change unless higher systems performance levels can be reached. Following the applied search strategy, a reached system performance level is only left in the presence of a new parts configuration that allows for higher system performance (“global optimum” vs. “local optimum”). In terms of the mentioned face validity test (Gass, 1983) (under “3.3.5 Using Sendero Application as Decision Aid”), this fulfills the practitioner’s perspective on how development on different levels is realized. Though, despite fluctuating performance values for single engine prototype parts (“local optimum”), the premise of continuously

increasing system performance (“global optimum”) remains (partly at the expense of the “local optimum” in terms of reduced single prototype parts performance levels as exemplarily shown in Figure 27). Figure 27 exemplarily and schematically illustrates how system and (random) part performance are developing over time.

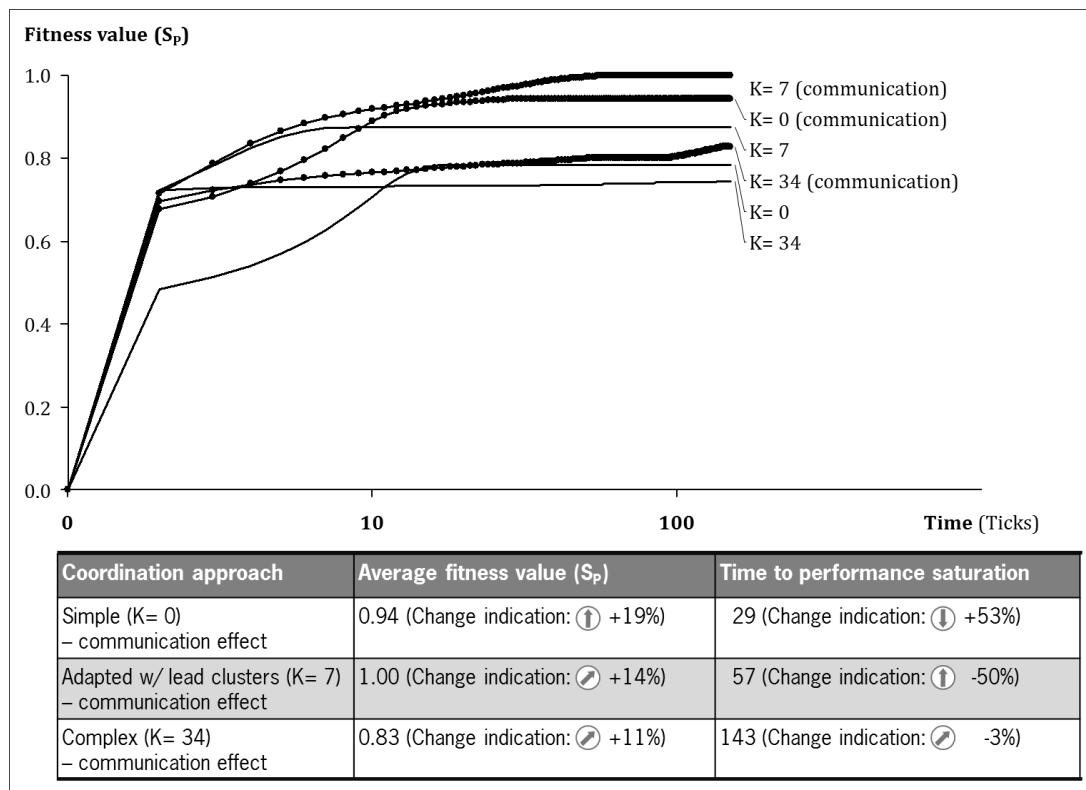


**Figure 27:** Exemplary comparison between system and part performance (based on Figure 23 “Fitness values (SP) – simple coordination ( $K=0$ )”) (own figure, 2018)

The target in NPD is clearly to increase system performance over time and select part configurations that allow for such gradual performance increase in the scope of the NPD timeframe. This premise is reflected in the search strategy and further in the fitness value simulations (Sendero calculations). The search space for the product or more specifically engine prototype in this case is still large but not “open” in NPD. This is a special case that differentiates the perspective of this research work from other research work where the search space is much larger as for instance in the case of (product unrelated) fundamental research projects. Here, the search space is open due to the fact that the target product or process is not yet clearly defined and performances may also be much more volatile which can lead to performance oscillations on all levels over time. Furthermore, such projects may not be time-bound (as a target product or process is not yet defined) which reduces the threat of a possibly low maturity degree for follow-up processes that expect a certain defined maturity degree. The premise of increasing system level performances ( $S_P$ ) therefore reflects the special nature of NPD as well as the real world model where product maturity is time-bound and steadily to be increased (even at the expense of single part performances).

### 3.4.3 Communication Effect

The investigation of communication is important to achieve a realistic overall picture. Communication is particularly applied in the context of the simple coordination approach in order to reduce possible negative side effects from working individually and parallelized. This includes but is not limited to rework based on not communicated technical changes to a product design or ignoring of defined parts construction premises for instance. Figure 28 illustrates the results for the average fitness values ( $S_P$ ) of the three coordination approaches under the effect of communication. It further summarizes the key figures for average fitness values ( $S_P$ ) and time to performance saturation. A communication network has a large effect on the average fitness values ( $S_P$ ).



**Figure 28:** Average fitness values ( $S_P$ ) (K=0, 7 and 34) and saturation points, with communication effect (own figure, 2018)

All coordination approaches benefit from communication. Though, the largest benefit results for the simple coordination approach. In general, the higher the number of interactions between the parts of the engine prototype, the lower is the benefit of communication. Although, the simple coordination approach benefits the most from communication, the adapted coordination approach still leads the field in terms of average fitness value ( $S_P$ ). The

development of the time to performance saturation is interesting. Whereas the simple coordination approach reaches performance saturation later, both, the adapted and the complex coordination approach show positive time effects. The adapted coordination approach improves by -50%.

### **3.5 Managerial Implications**

The presented example illustrates a typical managerial issue in new product development, namely solving a complex issue with multiple involved target dimensions. Here, the construction of an engine prototype may follow one of six different coordination approaches to get to an output: 1) simple, 2) adapted w/ lead clusters, 3) complex, 4) simple with communication, 5) adapted w/ lead clusters with communication and 6) complex with communication. The coordination approaches lead to fairly different outputs regarding the target dimensions of performance and time. From the managerial point of view, it has to be decided which target dimension is prevailing from the perspective of the NPD. In the underlying example, the performance dimension is the leading factor as the NPD is in a fairly early stage and the performance of prototypes is important for the overall cost development in subsequent NPD stages. Thus, quality or maturity issues relating to the prototype engine have to be prevented at this early stage. With this premise at hand, a managerial decision falls onto the fifth coordination approach (adapted w/ lead clusters with communication). The performance or fitness value ( $S_F$ ) is the highest among all coordination approaches (1.00).

In general, the results from the NK model application indicate that the adapted coordination approach w/ lead clusters poses the most balanced solution in the presented example. This coordination approach results in the highest relative engine prototype performance or fitness value ( $S_F$ ) as well as a medium performance with regard to the time to performance saturation. The latter performance level is increased by the installation of a communication network among the involved design engineers. The consideration of a realistic interaction level between the parts is a premise that increases parts specifications in the course of the construction process. In turn, this leads to a stronger sequencing in parts construction. Although, the overall parts construction duration increases compared to the more parallelized initial coordination approach, this change in coordination is necessary to improve the engine prototype performance or fitness value ( $S_F$ ) in the specific example. Additionally, the stress level in parts

construction may be reduced through the adapted coordination approach, particularly in the case of completely new product designs and higher levels of uncertainty. As the technical change frequency regarding the product design is considered high in such cases, a more sequential coordination approach poses an option to prevent failure from concurrent parts construction progression. On the other hand, the consideration of the interaction between the parts implies a reduction of the overall search space from the parts perspective of the design engineers. This eventually reduces the chances to achieve optimal construction results from the parts perspective ( $N_P$ ).

Though, this perspective shift can generally be considered at the core of the coordination issue. In order to shift from a parts construction focus towards an engine prototype construction focus, it is recommended to also align incentive systems and key performance indicators for the design engineers. The shift towards an engine prototype construction focus must be accompanied with a motivation for an optimal engine prototype performance or fitness value ( $S_P$ ) instead of a motivation for the highest performance of the single parts ( $N_P$ ). This is a search-related issue that particularly exists in inter-organizational and inter-departmental search problems where conflicting interests may be prevailing. Though, the presented example illustrates that this search-related issue also applies for search problems within a single engine development main department that comprises of comparable specialists with equal know-how and qualification as well as an aligned strategy.

### **3.6 Conclusion**

This research work deals with coordination as a main issue in NPD. Despite the fact, that this topic has attracted much attention in the literature over the past decades, there is still no overall consensus on the question of how coordination is achieved. From the perspective of this research work, this question must be answered in relation to a specific example. Coordination depends on both, the specific initial organizational situation as well as the general possible courses of action including relevant premises and target dimensions. Thus, coordination needs a clear context. This context was given in this research work by considering the example of the engine prototype construction at an automotive manufacturer.



Three main findings with regard to coordination in NPD are at the core of this consideration. First of all, coordination in NPD is difficult. Coordination in NPD has to balance the numerous perspectives in NPD, namely the achievement of different target dimensions on the various levels of any given technical artefact (e.g. product, components and parts). In the presented example, the question for the optimal coordination approach can only be answered based on the prior decision towards focusing on the component level and the performance or fitness value ( $S_P$ ) as prevailing target dimension. Second of all, coordination in NPD is complex. A realistic estimation of the interaction levels between the single parts of the prototype engine leads to an increase of the performance or fitness value ( $S_P$ ). It is important to realistically estimate the interactions within any given technological artefact. Being aware of the interactions supports the understanding of dependencies and further the definition of sequences or lead clusters as illustrated in the underlying example. And finally, third of all, coordination in NPD requires communication. The performance or fitness value ( $S_P$ ) as a main target dimension in NPD increases in all coordination approaches through the establishment of communication networks. Thus, the role of communication must be implicit when dealing with coordination in NPD.

Based on the fact that the presented example is case-sensitive, it is recommended to conduct further research in two preferable ways. Firstly, apply other available simulation tools to verify the presented results and make use of additional simulation possibilities as for instance in the specific case of communication networks. Some simulation tools allow for a more differentiated simulation of variables as for instance communication by including different communication intensity levels. These simulation tools may bring additional insights for the role of communication and other variables to the table. Secondly, it is highly recommended to further consider other technological artefacts, either completely different components as for instance chassis, body and electrics/electronics or shift the focus towards different observation levels as for instance by considering the whole vehicle.

On the basis of defined processes and methods, the general question of how to organize and coordinate a workforce to efficiently conduct these processes and methods poses a core managerial challenge. Chapter 3 addresses the managerial activity of organization and coordination in complex NPD where many different perspectives come into play and have to

be integrated. In this regard, organizations seek to optimize their processes and methods on a constant basis and adapt their organizational structures and coordination approaches accordingly. This effort aims at increased efficiency in the line and project organization. In turn, line and project activities are performed increasingly well in an upward spiral of continuous improvement. It is important to understand that there is an underlying premise that must hold in order to increase efficiency in this gradual manner. The external conditions have to be stable in order to not interfere the actual effectiveness of established processes and methods. If established processes and methods are undermined, the organization has to shift from efficiency to effectiveness. An adaptation of the process and method landscape as well as a respective redefinition of the organization and coordination approach becomes necessary. Thus, it is not enough to perform established processes and methods efficiently in line with optimal organization and coordination of the workforce if the processes and methods themselves are not effective due to a change in the externalities of the organization. Chapter 4 regards this issue of external changes and points out that it is crucial for organizations to question established processes and methods even if they are currently efficient. Thus, the focus of the organization must be on both, the efficiency of established processes and methods as well as on their effectiveness.

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## **4 IMPLICATIONS OF EMERGING NEW PRODUCT DEVELOPMENT PROJECT (NPD) TYPES ON RISK FRAMING – THE COMPLEX ADAPTIVE SYSTEMS PERSPECTIVE<sup>1</sup>**

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### **4.1 Introduction**

The success of firms relies on the ability to evaluate and react to their business environment and satisfy customers and markets through product offerings. This intention becomes increasingly difficult for firms if the needs of customers and markets change progressively in a way that the business environment is less stable and predictive. The automotive industry is an example as it finds itself in such a phase of transition. The shift in customer and market demand from traditional drive concepts towards the electrification of automobiles leads to a change in the dominant technological design. The change in customer and market mobility requirements that is generally seen as a natural industry development has the potential to transform this mature industry fundamentally (Christensen, 1992). The automotive industry moves from a phase of consolidation, stability and continuous efficiency improvement towards fundamental strategic changes in the product portfolio. As a result of this strategic shift, new types of NPD emerge. The market pull for new products and technologies increases complexity for the automotive industry and leads to a stage of limited stability that is referred to as the “edge of chaos” (Kauffman, 1993 and Anderson, 1999). Leaving a stable comfort zone and dealing with emerging NPD types further leads to the exposure to new risks. A commitment to established risk management practices may result in a misinterpretation of the risk landscape in emerging NPD types. Ultimately, a lack of systematical risk framing in NPD may even harm the overall project success (Tah and Carr, 2000; Lakemond et al, 2013; Sharma, 2013 as well as Marle and Vidal, 2014).

This research work illustrates how risk framing, that is the combined activities to sort identified risks in a firm-specific risk framework for further risk analysis, in NPD is affected through emerging NPD types. It shows that established risk framing has to be adjusted in order to facilitate risk management in emerging NPD types. These evolving NPD types challenge

<sup>1</sup> Vu, M. and Spinler, S. (2016). Implications of Emerging New Product Development Project (NPD) Types on Risk Framing – The Complex Adaptive Systems Perspective. Unpublished working paper.

established processes and methods (here: risk framing) and shift the focus from “efficient execution of existing processes and methods” to “search for new and effective processes and methods”. At first, the characteristics of regular NPD types are used to explain why established risk framing in NPD is such an efficient and suitable approach under given circumstances. In order to evaluate the implications of emerging NPD types on this given set-up, this research work then considers complexity theory and views NPD, or more specifically the newly evolving NPD types, through the lens of complex adaptive systems (CAS). The integration of complexity theory is reasonable under the assumption that the development of new products is a complex string of activities that involves a complex set of stakeholders and their complex cross-functional requirements. Comparing traditional NPD with newly evolving NPD types, it becomes obvious that processes and methods in the example of risk framing activities have to be adopted to the new circumstances in order to still add value in the overall risk management process. As a result, this research work results in the formulation of an effective risk framework for emerging NPD types. The outcome indicates that standardly applied risk framing approaches do not sufficiently depict the complexity of emerging NPD types as for instance the risk landscapes differ to a large extent. The benefits of this research work are twofold. From the academic perspective, this research work contributes to the developing literature base that links complexity theory and risk management in the NPD area (Akgün et al., 2014). From the industry perspective, this research work provides managerial implications on risk management as a basis for risk framing in emerging NPD typed. The need for effective risk framing in emerging NPD types is particularly existent for firms that find themselves in a phase of transition as for instance the case of the automotive industry. The aim of this research work is to derive a NPD risk framework that enables effective risk management for emerging new types of NPD and that points out the challenges in risk management with newly evolving NPD types. Based on the recent developments in the automotive industry with regard to changes in the requirements of customers and markets, this research work combines theory and evidence from practice. This research work builds on two sources. First of all, it is based on an extensive literature review with a research focus on NPD characteristics, resulting NPD risk management with emphasis on risk framing and the principles as well as characteristics of CAS. Second of all, this research work is based on semi-structured interviews with 12 experts from three different original equipment manufacturers (OEMs) in the automotive industry (note: interviewee

overview is referred to in Appendix 4.1). The focus of the expert interviews lies on established NPD risk frameworks as well as on the characteristics and resulting risks of emerging NPD types.

This research work is structured as follows. The subsequent chapter 4.2 focuses on the consolidation of NPD characteristics. Furthermore, prevalent risk framing is derived as a result of the consolidated understanding of NPD. Chapter 4.3 addresses the idea of CAS and provides a synthesis of CAS characteristics. In addition, emerging NPD types are defined and considered in more detail. Chapter 4.4 is central for deriving the implications of emerging NPD types on risk framing. The characteristics of NPD are compared to the characteristics of emerging NPD types under the CAS lens. With the support of the CAS perspective, NPD risk framing is extended and a new NPD risk framework for emerging NPD types is developed. Chapter 4.5 summarizes the key findings and develops the main implications from the management viewpoint. Finally, chapter 4.6 concludes this research work with a recommendation for future supportive research paths.

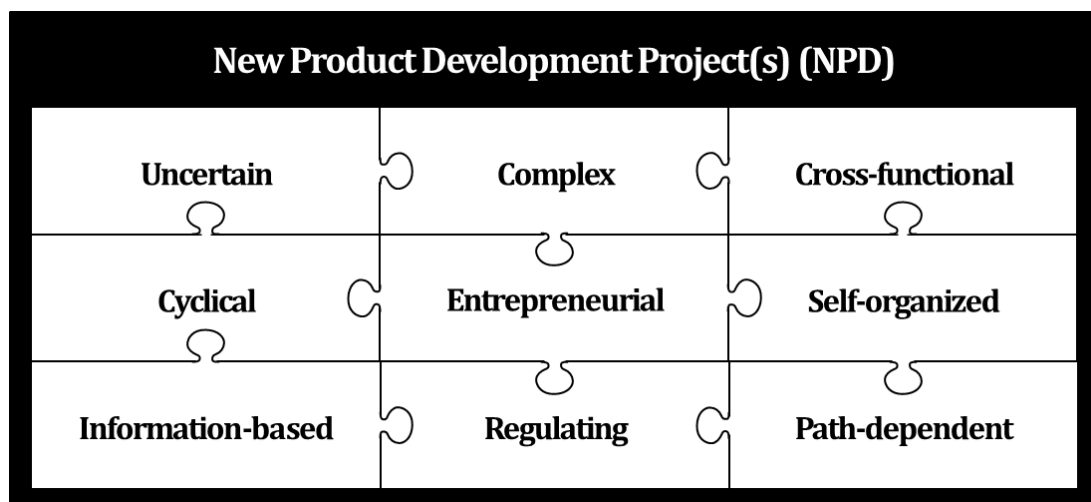
## **4.2 Literature Review**

### *4.2.1 New Product Development Projects (NPD)*

NPD are relevant for the long-term success of firms (Ulrich and Eppinger, 2012). The development of new products is a core process within firms. Although, various definitions for NPD exist in the literature, there is a wide common understanding about the nature of NPD. Krishnan and Ulrich (2001) define NPD as transforming a market opportunity into a sellable product. Unger and Eppinger (2011) understand NPD as the sum of procedures and methods that are applied to result in a new product that can be introduced to the market. And according to Tabatabai et al. (2014), NPD are seen as formal framework to increase product maturity in a systematical way until market release. Previous definitions in terms of NPD targets show a similar understanding (Cannon, 1978 and Cooper, 1990). All in all, the definitions of NPD rather support than contradict each other. Accordingly, NPD enable the release of new products into the market. It is important to understand the characteristics of the core process that allows this in order to grasp the established risk framing approaches.

#### 4.2.2 New Product Development (NPD) Project Characteristics

Although, NPD follow a formal framework that fits the needs and peculiarities of a specific firm, a wide common understanding about NPD indicates the existence of NPD characteristics that are shared across different firms (Tabatabai et al., 2014). The literature offers a broad spectrum of general NPD characteristics that also differentiate the underlying core process from other core processes within a firm (Krishnan and Ulrich, 2001; Rozenfeld et al., 2006; Ahmad et al., 2013 as well as Ulrich and Eppinger, 2015). McCarthy et al. (2006) define high degrees of uncertainty and complexity as the key characteristics of NPD and present an in-depth literature review with focus on corresponding research reaching back as far as 1968. Further characteristics of NPD are summarized in Figure 29.



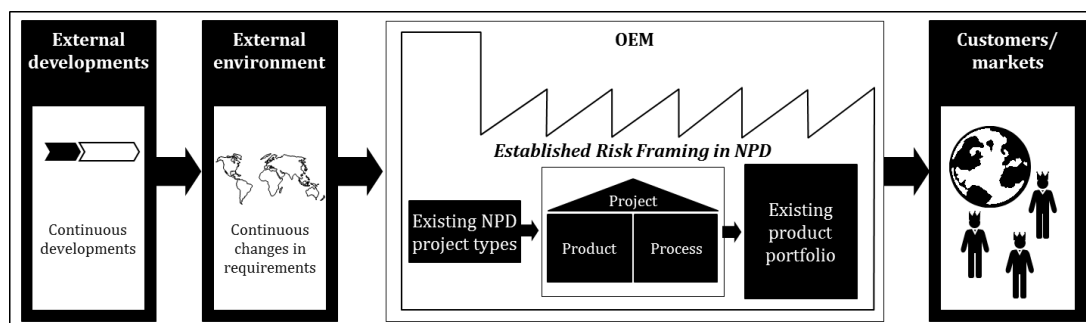
**Figure 29:** Overview of NPD characteristics (own figure based on Krishnan and Ulrich, 2001; Rozenfeld et al., 2006; Ahmad et al., 2013 as well as Ulrich and Eppinger, 2015)

According to McCarthy et al. (2006), the definitions and derived characteristics of NPD illustrate that the development of new products is primarily perceived as a linear process. Although, NPD may regulate and steer activities to a certain degree as they are self-organized and entrepreneurial entities in way that they are also responsible for the final project outcome, NPD generally follow a cyclical path and depend on previously taken decisions. An early example of the linearity of NPD is provided by Cooper (1990) who emphasized a stage gate model for an efficient and consistent increase of new products' development maturity. This linear process that follows a defined sequence with fixed stage gates focuses particularly on the efficiency in NPD with regard to process lead time and project cost adherence. The NPD focus on linearity and efficiency is reflected in the established risk framing approach.

#### 4.2.3 Established Risk Framing Approach in New Product Development Projects (NPD)

Risk management is a critical part in the conduction of NPD (Kim and Wilemon, 2013 as well as Thamain, 2013). The activities that lead to effective risk management in NPD can be summarized under the phases risk identification, risk analysis, risk mitigation and risk control (Schawel and Billing, 2011; Holzmann, 2012 as well as Lakemond et al., 2013). Priority is given to the initial phases in effective risk management. Following the identification of relevant risks, the risk management focus then shifts to the analysis phase where risks are sorted and summarized into risk categories (also known as risk framing) as basis for a subsequent detailed analysis according to defined criteria. The elaboration of the single risk management phases is specific and may differ from industry to industry and from firm to firm.

This research work has the focus on risk framing as integral component of the analysis phase within risk management. Framing risks aims at scrutinizing and structuring all identified risks to support the risk consolidation and make a risk landscape manageable within the scope of a NPD. According to Lakemond et al. (2013), successful risk mitigation primarily builds on effective risk framing. Risk framing is particularly important under the assumption that firms stick to established risk frameworks for the longer term and also reapply already existing risk landscapes from previous NPD for the intended benefit of future NPD (expert interviews A, C, G and H). This approach is mainly caused through time and cost pressure in NPD. It is legitimate to follow this approach in line with an efficiency increase in the case of the development of known or standard products. In contrast, if this assumption does not hold, there is a risk that the reapplication of previous risk landscapes and established risk framing approaches does not reflect the risk situation in future NPD. A synthesized risk framework builds the basis for the further research approach of this research work (Figure 30).



**Figure 30:** Established risk framing in NPD (own figure based on Vu and Spinler, 2016 as well as expert interviews A, C, D, G and H)

The established risk framework in Figure 30 states the initial situation and consists of the three risk categories project, product and process (Vu and Spinler, 2016). This risk framework is simple and reflects the NPD definitions and derived characteristics as mentioned in 4.2.2. As firms do not invest in multiple risk frameworks for time and cost reasons, balancing between known or standard products and emerging NPD types becomes a challenge in terms of effective risk management (expert interviews A, C, D, G and H).

## **4.3 Research Methodology**

### *4.3.1 Complex Adaptive Systems (CAS)*

The focus of NPD on efficiency states a disadvantage to the NPD perspective on effectiveness. And focusing on management practices in NPD that are suitable for the development of products with a limited innovation character does not cope with the needs of NPD that deal with emerging NPD types (Carlisle and McMillan, 2006). Carlisle and McMillan (2006) outline that firms are sometimes very effective in developing products with no or incremental innovation degrees but then fail at developing highly innovative products. The idea of CAS provides some indication at this point. CAS originate from the natural sciences where the concept is initially used to illustrate how organisms adapt and evolve in non-linear ways in the course of time (Kauffman, 1993; Kauffman, 1995 and Simon, 1996). The concept of CAS rapidly finds fertile ground in the social sciences as well. As a key concept of complexity theory, CAS become increasingly popular in business management. Here, the attention lies particularly on the fields of strategy application (Levinthal, 1997 as well as Gevatti and Levinthal, 2000), production technology (Auerswald et al., 2000 as well as Kauffman et al., 2000), operations management (Giannoccaro, 2013) and innovation management (Chiva-Gomez, 2004). CAS are used in these fields according to their definition as systems that are composed of interacting agents or decision-making sub-systems as McCarthy (2002) entitles them. These sub-systems undergo constant change, both autonomously and as a result of their environmental interaction. This leads to the ability of CAS to configure and evolve new systems (McCarthy et al., 2006). Based on the various fields of CAS application, these systems may assume a variety of forms such as new corporate strategies, innovative technological artefacts, agile development methods or as in the case of this research work NPD.



The literature that combines the concept of CAS with the topic of NPD is considered rather limited (Chiva-Gomez, 2004; McCarthy et al, 2006 as well as Akgün et al, 2014). This research work aims to extend this literature base by applying the CAS lens to NPD with regard to the challenge of risk framing in the light of emerging NPD types. As firms seek to proactively manage risk, shortcomings in the early risk management phase as in the case of risk framing will lead to ineffective risk management. The established risk frameworks in NPD ignore the specific CAS characteristics as they widely assume NPD to be naturally linear as illustrated in 4.2.2. If characteristics of CAS are considered in the context of NPD, they are only considered to a limited extent. For instance, McCarthy et al. (2006) include a limited sample of three CAS characteristics in the comparison between NPD and CAS, namely non-linearity, emergence and self-organization. A shortcoming in the reflection of CAS characteristics in processes and methods for project environments that are CAS-like may lead to failure in a way that these project environments cannot be adequately handled through established processes and methods. Therefore, this research work seeks to illustrate the full scope of CAS characteristics in the first place in order to entirely understand the idea of CAS and contrast it to the subject of emerging NPD types. This will lead not just to an understanding of the two concepts but further help to practically understand what is the impact of emerging NPD types on established processes and methods as for instance risk framing.

#### *4.3.2 Complex Adaptive System (CAS) Characteristics*

Viewing NPD as CAS requires a prior identification of the CAS characteristics. The concept of CAS has been characterized in multiple ways. The literature provides both, CAS characteristics and CAS principles. As the lists are similar more than contradictory, it can be assumed that both terms, CAS characteristics and CAS principles, are used interchangeably. This research work provides a synthesis of the latest findings regarding CAS characteristics as presented in Figure 31. This synthesis includes the literature reviews of McCarthy (2002) (8 CAS characteristics), Hammer et al. (2012) (16 CAS characteristics), Alaa and Fitzgerald (2013) (13 CAS characteristics) as well as Akgün et al. (2014) (6 CAS characteristics) that each consolidated the characteristics of CAS in their frameworks. As Figure 31 illustrates, overlaps as well as differences between the various frameworks exist, not just concerning the sheer number of CAS characteristics. The synthesis provided in Figure 31 seeks to group all CAS characteristics

within 5 groups based on their respective descriptions to result in a complete overview of CAS characteristics that is free of overlaps. The characteristics of CAS reflect emerging NPD types that are considered in the following.

McCarthy (2002)	Hammer et al. (2012)	Alaa and Fitzgerald (2013)	Akgün et al. (2014)	
Existence of paradoxes	Local and remote	Unpredictability	Complex and non-linear	
	Non-linearity	Non-linearity		
Instability	Positive or negative feedback	Variation and diversity	Interaction of parts	
	Large numbers of elements			
Uncomputability	Continuous interaction	Interactions		
	Connected open systems	Edge of chaos		
Connectivity	Rich interactions	Adaptations	Emergent character	
	Coevolving relationship	Connectivity and interdependence		
Emergence	Emerging patterns	Feedback	Untraceable evolvement	
	Far from equilibrium			
Creativity	Origins of patterns	Pattern recognition		
	Patterns	Path dependence		
Memory	Whole system ignorance	Self-organization and selection	Existing structure	
	Histories	Coevolution		
Adaptability	Space possibilities	Simple rules	Learning from experience	
	Self-organization			
Proposed synthesis of CAS characteristics and main contents				
Non-linear	Instable	Emergent	Connected	Learning
▪ Untraceable evolvement ▪ Uncomputability ▪ Unpredictability ▪ Complex ▪ ...	▪ Far from equilibrium ▪ Existing structure ▪ Edge of chaos ▪ Simple rules ▪ ...	▪ Whole system ignorance ▪ Self-organization ▪ Coevolution ▪ Creativity ▪ ...	▪ Connected open systems ▪ Large no. of elements ▪ Continuous interaction ▪ Local and remote ▪ ...	▪ Pattern recognition ▪ Adaptability ▪ Memory ▪ Histories ▪ ...

**Figure 31:** Synthesis of CAS characteristics (own figure based on McCarthy, 2002; Hammer et al., 2012; Alaa and Fitzgerald, 2013 as well as Akgün et al., 2014)

#### 4.3.3 Emerging New Product Development Project (NPD) Types as Complex Adaptive Systems (CAS)

The emergence of NPD types is a natural phenomenon that is linked to strategic shifts as well as regular developments in product management or more specifically in the product roadmap of a firm (expert interviews D, E and F). Whereas regular developments include the further development of existing products in the course of existing NPD types (the automotive industry speaks for instance of “facelifts” or “product renewals”), strategic shifts incorporate entirely new products. Here, “new” can adopt different peculiarities such as new to the firm, new to the industry or even new to the world (expert interviews D, E, F and H). This research work considers emerging NPD types that result from strategic shifts and consider new products. This

means that the underlying subject of an emerging NPD is characterized by its standalone technical specifications, partly not just within the specific industry but within all industries. Thus, the focus of emerging NPD types is not limited on efficiency but first and foremost on effectiveness. The automotive industry presents several examples of emerging NPD types that are primarily a result of radical developments with implications on the requirements of customers and markets (expert interviews D and E). Concretely, the transition from a classic understanding of the automobile as means of transportation with a combustion engine towards the increasing electrification and connectivity of the automobile (also for instance driven by increasing CO<sub>2</sub> fleet emission restrictions) gives rise to NPD types such as the electric automobile (including for instance electric drive, battery and recuperation systems), charging infrastructure, connected services and energy management systems.

The emerging NPD types are short-cycled and highly innovation-focused. Clift and Vandebosch (1999) characterize such projects for instance as fast-moving with adapted decision and review stages. These projects seek for frontloading of project activities and a maximization of activity overlap. The focus in such projects lies on a participative management style and customers are further involved as early as possible in the process. Wherever possible, external suppliers are used in order to benefit from their specialization and experience. McCarthy et al. (2006) add that highly innovative projects are recursive in their conduction, thus non-linear in a way. This “chaotic” appearance of highly innovative projects is also confirmed by automotive industry experts (expert interviews A, B, C, G and H). According to them, information flows are unforeseeable and “chaotic” project conditions are particularly to be found in the early project stages where the project team is still small in size, project team members still have to form and project targets are not yet firm. These conditions at the “edge of chaos” support innovation and new ways of thinking and working that lead to effective project conduction (Kauffman, 1993 and Anderson, 1999). From the viewpoint of emerging NPD types, the mentioned CAS characteristics can be confirmed. Based on the findings from Figure 31, Figure 32 exemplarily illustrates emerging NPD types as CAS and contrasts them against selected characteristics of highly innovation-focused projects.

Complex adaptive systems	Highly innovation-focused projects	Emerging NPD types
Non-linear	Recursive project conduction	Frequent changes of technical concepts Fixed process frameworks not existent/ unstructured project conduction Unclear product architecture
Instable	Adapted decision and review stages	Non-approved venture capital Lack of suitable IT systems Arbitrary information flows New, unknown processes Changing project targets Flexible review stages
Emergent	Maximal activity frontloading Maximal activity overlap Fast-moving	Spin off establishment (new firm) New "development culture" New business model
Connected	High degree of external value creation Participative management style Early customer involvement Changing team structure	New organizational roles and responsibilities Involvement of unknown new stakeholders New legal framework/setting of operation Supplier base is undefined/unknown Larger supplier base than usually
Learning	-	Adaptation of established methods/tools Combination of know-how across firm Missing employees/know how Transfer of quality standards Use of known processes

**Figure 32:** New product development projects (NPD) as complex adaptive systems (CAS) (own figure based on Clift and Vandenbosch, 1999; McCarthy et al, 2006 and expert interviews A, B, C, G and H)

## 4.4 Research Results and Practical Transfer

### 4.4.1 Research Results

Emerging NPD types can be considered highly innovation-focused and observed through the CAS lens. This puts the focus in emerging NPD types primarily on effectiveness instead of efficiency as compared to existing NPD types. The latter are defined by linearity in the conduction of the project. According to this, the development of known or standard products follows simple risk framing approaches that highlight risks that endanger efficiency targets with regard to project time and costs in the categories of project, product and process. This risk framing approach cannot be supported for emerging NPD types in the light of the focus on effectiveness under the CAS lens. Thus, existing processes and methods have to be re-thought when considering new project challenges. The underlying support has to come from the line organization, although the project organization identifies these shortcomings in terms of processes and projects because only this will lead to a firm-wide harmonized and equal approach. Besides the fact that there exist differences in the focus of both NPD types (efficiency

vs. effectiveness), emerging NPD types can be differentiated from existing NPD types in terms of their characteristics.

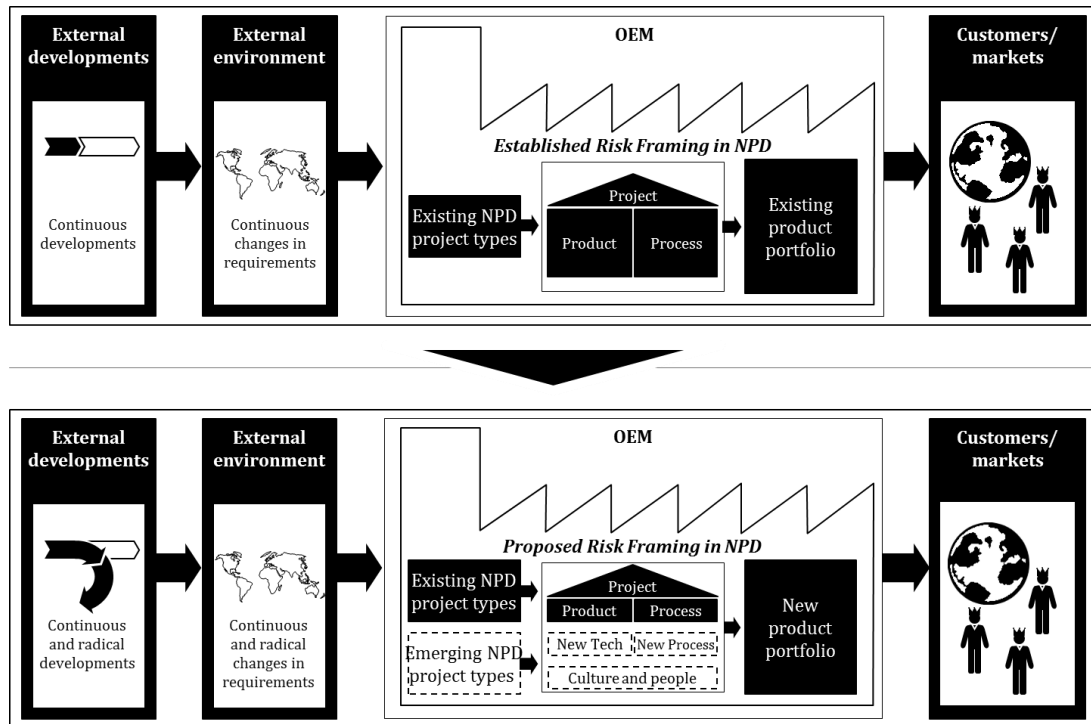
As illustrated in Figure 29, existing NPD types are characterized in a framework that leads to a linear consideration of the development of new products. In comparison, emerging NPD types stand for an intensification of this framework for developing new products. Uncertainty and complexity levels are increased based on the non-linear character of emerging NPD types. A gradual and systematical increase of the maturity of the underlying product is non-existent. Neither is stability with regard to the project environment (e.g. project organization, processes, IT-systems or project targets). Emerging NPD types rather benefit from an evolving project result than from narrowly defined expectations that have to be reached over a given formal framework. In turn, this requires a different approach to developing new products, both in terms of organization, processes and tools as well as regarding culture and people. Comparing existing and emerging NPD types, it becomes obvious that differences in the focus, the characteristics and even the approach to development exist. This leads to the assumption that existing and emerging NPD types also differentiate in terms of risk framing.

Established risk framing		Exemplary risks in emerging NPD types (efficiency focus)
1	Project	<ul style="list-style-type: none"> <li>▪ Incomplete project team in critical project phase/non-fulfillment of project responsibilities</li> <li>▪ Necessary involvement of other Group entities (for networking purposes)</li> <li>▪ Unclear project time schedule (incl. critical path)</li> </ul>
2	Product	<ul style="list-style-type: none"> <li>▪ Undecided supplier base with few commitment and experience</li> <li>▪ Larger development scope than in previous project</li> <li>▪ Unknown requirements regarding product quality</li> </ul>
3	Process	<ul style="list-style-type: none"> <li>▪ Unclear involvement of government agencies regarding norms and legal requirements</li> <li>▪ Non-transparency over total project activities (process map)</li> <li>▪ Need for definition of long-term product testing approach</li> </ul>
Unestablished risk framing		Exemplary risks in emerging NPD types (effectiveness focus)
4	Non-assignable	<ul style="list-style-type: none"> <li>▪ Dealing with non-automotive processes (certification) and partners (possibility of "C suppliers")</li> <li>▪ Unknown product architecture and undefined level of recommended internal value creation</li> <li>▪ Missing supportive organizational structure and team expertise</li> </ul>

**Figure 33:** Risks in emerging new product development (NPD) types (own figure based on expert interviews A and H)

Figure 33 illustrates an extract of a possible risk landscape in emerging NPD types as encountered in the automotive industry (expert interviews A and H). Whereas a majority of the listed risks can be framed with risk categories that are established in existing NPD types (categories 1-3), some risks cannot (category 4). As these risks are considered strongly important in the scope of the effectiveness focus in emerging NPD types, they have to be

included in the risk framing activities in a way that they are separated and highlighted (for instance in contrast to “efficiency risks” instead of mixed up with them). The listed risks under category 4 reflect the nature of CAS. They deal with effectiveness in NPD and address fundamental topics rather than usual project topics. These topics require different attention levels and have to follow specific risk management processes.



**Figure 34:** Proposed risk framing in new product development (NPD) projects (own figure based on Vu and Spinler, 2016 as well as expert interviews A, C, D, G and H)

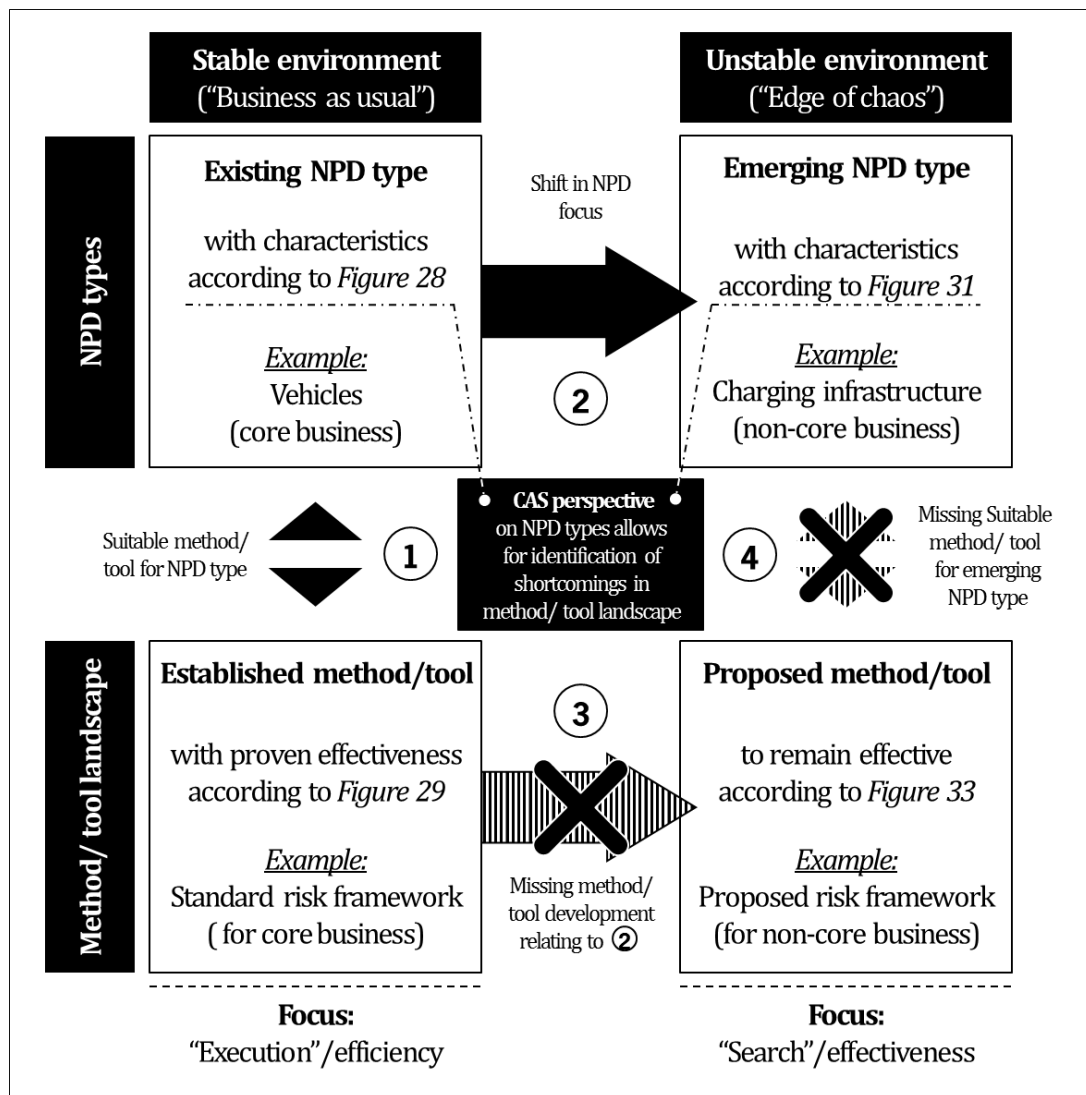
Therefore, this research work suggests an extended approach to risk framing for emerging NPD types as illustrated in Figure 34. This risk framing approach supports the categorization of a risk landscape that is specific to the characteristics of emerging NPD types. In contrast to Figure 30, this extended risk framework meets the requirements of NPD with focus on existing NPD types (efficiency) as well as emerging NPD types (effectiveness). Thus, it can be applied for risk framing in either NPD type. The risk framework is extended by three risk categories, namely new technology, new process as well as culture and people. Whereas the risk category new technology incorporates all risks related to fundamental technological hurdles, the risk category new process incorporates all risks related to non-existent processes, methods/tools and (IT-) infrastructures and the risk category culture and people incorporates all risks related to lacking organizational capabilities and fundamental change processes. All three risk

categories deal with corporate risks on the level of the NPD. With regard to Figure 33, the three exemplary unassigned risks of category 4 can be transferred to the proposed risk framing approach as illustrated in Figure 34. The first risk is part of the risk categories new process (non-automotive processes) and culture and people (non-automotive partners). The second risk (unknown product architecture/internal value creation level) can be included in the risk category new technology. Finally, the third risk (organizational structure/team expertise) can be included in the risk category culture and people.

Though, the objective of analyzing risks in the scope of the risk management activities in NPD is not limited to structuring NPD-specific risks based on a formal risk framework but lies first and foremost in the creation of risk transparency over the entire NPD duration. Although, this objective is fairly difficult to reach in emerging NPD types due to their very nature, risk transparency can be ensured over an adaptation of the risk management activities. More specifically, there are implications for risk framing activities in emerging NPD types that result from the deployment of the CAS lens.

#### *4.4.2 Exemplary Practical Transfer of Research Results*

As described earlier, the automotive industry currently finds itself in a phase of transition. Established business models are challenged by new products and services that are supported by economic incentives and restrictions as well as increasing consumer interest; specifically, when it comes to E-Mobility. Automotive manufacturers react to this complex situation by adapting their business models and opening up for new topics. The example of E-Mobility shows that holistic business models with electric vehicles, charging infrastructure and charging services are targeted. Charging infrastructure is widely seen as an important prerequisite for the success of electric vehicles and therefore sales-relevant with regard to vehicles. This means for automotive manufacturers to engage in new product and service offerings in order to protect their core business in the future, namely (electric) vehicle sales. The challenges that arise from this development are reflected by the CAS lens that is applied on NPD in this research work. Figure 35 generically illustrates how the CAS perspective on NPD types allows to identify the shortcomings of established standard methods/tools (here: standard risk framework) based on changing NPD type characteristics that lead to different framework conditions (here: changing risk landscapes).



**Figure 35:** CAS perspective on NPD types (own figure, 2018)

As the example of charging infrastructure depicts an industrial good that underlies different requirements in the development process compared to vehicles (such as for instance a structured industry good certification process with specific quality/ release criteria), there is a threat that the existing organizational, processual and methodological/tool baseline that automotive manufacturers have built and invested in for a long period of time is not applicable. Using this baseline will result in difficulties and risks that will not be identified in such new NPD types (for instance missing ability to certify the product). This is a new paradigm. This research work seeks to create awareness for this shortcoming and the lacking risk transparency in new NPD types that are treated like existing NPD types. Based on the research results and their practical relevance, five propositions are put forward in the following for further discussion.



## 4.5 Managerial Implications

### *Proposition 1: Implement higher frequency of risk framing activities in emerging NPD types*

Based on the non-linearity and instability of emerging NPD types under the CAS lens, it is difficult to foresee or even “freeze” project results; especially in the earlier project phases. The conventional conduction of risk framing activities focuses on using the risk landscape of similar prior NPD. Thus, risk analysis activities may be carried out as a one-time exercise at the beginning of a NPD before the focus shifts towards risk assessment, risk evaluation and particularly risk mitigation to process risk by risk. The result is that there may only be one to a few risk management cycles that is/are fairly long and extent over an entire NPD. In contrast, the risk management cycle under the CAS lens is supposed to be much shorter as risks change in line with the further development of the project. This asks for a higher frequency of risk management activities. With regard to risk analysis and particularly short-cycled risk framing exercises, the defined risk framework provides stability in emerging NPD types where risks may frequently change. This helps to set priorities as the focus lies primarily on the categories of the risk framework instead of single risks. This is important as the project management function not necessarily has more resources for risk management activities in emerging NPD types in comparison to conventional NPD. Shorter and thus more risk management cycles are not supposed to lead to an increase in risk management resources.

### *Proposition 2: Set risk analysis focus (“80-20 rule”) in risk framing activities in emerging NPD types*

Emerging NPD types are characterized as instable under the CAS lens. Risk analysis activities such as framing risks becomes more complex as a result. Although, risk management becomes more demanding in general, emerging NPD types do not benefit from additional resources with regard to the project management function. In turn, resources for risk management activities are on a comparable level as in conventional NPD. In order to guarantee focus and prevent higher levels of frustration based on a changing risk landscape through project dynamics, it is proposed to be efficient in the naming and description of risks in the scope of risk analysis or risk framing respectively. The focus has to lie on low-maintenance risk framing. It is more important to focus on creating risk transparency through risk framing of all relevant risks instead of deep dive descriptions of single risks. On the opposite, this does not mean that risks

should be left out from the risk framing exercise. This may lead to a distorted picture of the risk landscape and thus does not grasp the complexity of emerging NPD types. The value of overall risk management would be endangered.

*Proposition 3: Enable cross-functional involvement in risk framing activities in emerging NPD types*

Agents (or more specifically stakeholders) are considered to be more interconnected in emerging NPD types than in conventional NPD as a result of the consideration of CAS. A cross-functional involvement in the risk analysis activities is an important prerequisite for successful risk management in emerging NPD types. This is particularly important for “receiving” functions as for instance Production, Logistics, Sales and After Sales. These areas receive NPD results after the start of production (phase of series production) and are thus highly effected by the project outcome but may be neglected in the development of a NPD. Furthermore, external stakeholders such as suppliers have to be involved. Here, the interconnection of suppliers is not limited to automobile manufacturers but also exists between single suppliers. These complex interconnections also have to be reflected in the risk framing activities that are finally steered and controlled by the project management function of the automobile manufacturer. This function builds the functional link between all involved stakeholders. Bringing all cross-functional areas together is a first step, the interaction level is another factor.

*Proposition 4: Foster higher interaction rates between functional areas in risk framing activities in emerging NPD types*

In order to understand the multiple and heterogeneous risk causes and effects in the scope of the risk analysis activities, it is important to foster higher interaction rates between the agents (or stakeholders respectively). The involvement of all relevant stakeholders has to be guaranteed at first. Whereas in conventional NPD, decentralized risk analysis with loose ties between neighboring stakeholders may be sufficient based on a high degree of experience and lower project dynamics, emerging NPD types may benefit from centralized risk analysis activities. This allows a consolidated overall picture of the risk landscape. An increase in the possible interaction touchpoints as well as intensified interaction levels are considered advantageous in the light of emerging NPD types and a higher dependency between

stakeholders (interconnection). The exchange of information on numerous occasions supports the understanding of the risk landscape and its acceptance from the various stakeholder sides.

*Proposition 5: Draw lessons learned from risk framing activities in emerging NPD types for the overall organization*

Emerging NPD types push the organization forward as fundamental risks appear that reveal possible shortcomings of an organization with regard to the successful conduction of certain product ventures. This may be in the risk categories of new technology (e.g. lacking innovation or pre-development results that can be transferred into an NPD environment), new processes (e.g. missing needed process standards and IT solutions) or culture and people (e.g. insufficient capabilities). And although, the shortcoming of certain resources is specific to the NPD (as the NPD is in a leading position at this very moment), it becomes an overall organizational issue when the line organization is not capable of serving the requirements of a NPD from a resource-based viewpoint. In order to prevent the organization (and upcoming product ventures) from failing to develop a new product, it is necessary that NPD-specific risks as a result of risk analysis activities are transferred to the overall organization. The ability to do so will be critical to push the organization, then from a new baseline, forward on a continuous basis. Thus emerging NPD types under the CAS lens have a learning effect not just regarding emerging NPD types but also with regard to the overall organization.

#### **4.6 Conclusion**

This research work has its focus on how risk framing in NPD is affected through the emergence of new NPD types. The concept of CAS as part of complexity theory is brought together with the ideas of NPD. The perspective of CAS supports the understanding of the unique nature of emerging NPD types. With their special focus, characteristics and approach to developing products, emerging NPD types also require a special approach to risk framing in order to provide effective risk management in the scope of a NPD. This research work is based on the experiences and inputs from automobile manufacturers. Although, this may be considered a limitation with regard to the industry focus, the automotive industry is widely considered a pioneer in many aspects of operations management. And the industry provides a prime example as it finds itself in a phase of transition where new types of NPD emerge. Nevertheless, it is proposed to underpin the findings of this research work also in other mature and

transitional or even young and developing industries. This should also include a different starting point in terms of risk framework. This research work assumes a synthesized risk framework for emerging NPD types but others are conceivable as well. It would be interesting to learn how this different starting point could result in a different risk framework for emerging NPD (or even hybrid risk frameworks). Furthermore, it is proposed to learn about the effectiveness of the extended risk framework in the field, either within the automotive industry or other relevant industries. It is particularly of interest how this framework performs against established frameworks. Though, it is important to outline that the formal structuring activities of risks only states the basis for reaching continuous risk transparency in the course of emerging NPD types. It is important to understand that risk analysis activities (or risk framing activities respectively) have to be supported as indicated in the five propositions above. These propositions are a result of the CAS consideration and are up for further discussion and confirmation by future research. All in all, the propositions illustrate that due to their specific nature, emerging NPD require a different approach to risk framing. Whereas risk framing is relatively straight forward and linear in existing NPD types, risk framing in emerging NPD types is more complex and non-linear. This also means that risk management in emerging NPD types has to be generally understood in a fragile and non-linear way, thus has to be flexible, adaptive and recursive more than a sheer execution of defined risk management activities.

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## **5 CONCLUSION**

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The focus of this dissertation lies on managing risk in complex NPD. The findings of this research work contribute to a still developing research stream that combines the areas of risk management and complexity theory. This research work integrates the perspective of the automotive industry and aims to extend the existing literature base by providing new insights on the relationship between risk and complexity in the scope of a specific industry. NPD in the automotive industry are complex per se. This is primarily referable to two factors that are highlighted in this research work. On the one hand, complexity is defined by the product architecture in terms of structural complexity and the underlying novelty of parts, components

and systems (product perspective). On the other hand, complexity is also defined by the cross-functional nature of NPD and the various different organizational levels that are involved (organizational perspective). The perspective of the automotive industry is particularly interesting as the industry faces an enduring complexity increase with regard to new product developments. NPD have increased in complexity over the past few years and the underlying industry trends indicate a further intensification of the complexity levels in NPD. This carries implications for risk management in NPD. This dissertation provides a comprehensive access to risk management in complex NPD with consideration of the industry developments and addresses aspects of risk management in complex NPD that are perceived as underdeveloped in the existing literature base.

With regard to chapter 2, risk management in new product development does not suffer from a shortage of methods and tools. The issue of risk management in complex NPD as illustrated in the specific case of the automotive industry is rather related to focusing on preventive risk management from the NPD viewpoint instead reactive risk management from the viewpoint of single functional areas. The identification and assessment of risk in NPD as the initial steps in risk management are also regarded as the most critical steps. Chapter 2 illustrates the application of the AHP method for a selected complex NPD in the automotive industry. It outlines that teamwork is necessary to identify and assess risks in complex NPD. The use of a workshop format allows an integrated view on NPD risks and a shared approach among the different NPD stakeholders. The AHP method is a simple and structured method that additionally includes the experience and knowledge of the single workshop participants. As there are already multiple and mostly decentralized risk management methods and tools established (for instance risk management databases, critical path observation, value stream analysis and so on), the benefit from the AHP method results from integrating the viewpoints of NPD stakeholders and including their experience and knowledge to come to a shared solution. The AHP method builds on the individual perspectives and drives a shared understanding of the risk position in complex NPD. This leads to a large acceptance of the AHP method in the field. In turn, this allows for stronger preventive management of risk in complex NPD. The findings of chapter 2 indicate that the selected complex NPD results in a high risk position with an underlying probability of almost 70%, thus confirming the positive

relationship between risk and complexity for a specific case. The shared viewpoint on the risk landscape of the selected complex NPD provides the basis to deal with root causes rather than effects and equally supports the definition of preventive actions in the course of the overall risk management process. The AHP method is positively tested in the scope of chapter 2 and proves to be an effective and efficient risk management tool.

Chapter 2 indicates the important role of the organization in managing risk in complex NPD. In chapter 3, the topic of organization and coordination in complex NPD is addressed. A topic that is strongly discussed in the existing literature base but has not yet provided sufficient answers on how effective and efficient coordination in NPD is reached. Chapter 3 approaches this question by considering an NPD example from the automotive industry. The complexity in this example results from the challenge of balancing the NPD targets on different levels of the organization. It is illustrated that the success of complex NPD strongly relies on two factors. First of all, the level of interaction between the NPD stakeholders has to be realistically assessed in a way that efficient work is possible in the light of concurrent processes. Here, intermediate levels of interaction between the NPD stakeholders lead to superior NPD performance in comparison to extremely high or even no interaction. And second of all, the role of communication is considered as important factor for success in complex NPD as it enhances the NPD outcome as well as the time-to-market in all coordination setups. In terms of risk management in complex NPD, chapter 3 provides insights and general guidance to designing coordination in new product developments in order to increase the chances of successful project conduction. The findings of chapter 2 and 3 are highly relevant for complex NPD in the automotive industry.

Chapter 4 extends the view on complex NPD from chapters 2 and 3 and assesses newly emerging NPD types as a result of industry trends. Whereas chapters 2 and 3 consider highly complex NPD, chapter 4 regards emerging NPD types that focus on completely new products instead of an existing product portfolio. These new types of NPD drive complexity levels further up and pose new challenges to risk management in NPD. Chapter 4 illustrates how risk framing activities have to adapt to emerging NPD types. NPD are considered as CAS and existing risk management frameworks are not able to sufficiently cope with the changes in the NPD risk landscape. Chapter 4 offers insights to the unique situation that the automotive industry finds itself in. The transition of the automotive industry towards establishing a new product portfolio

in line with the changing demands of customers and markets offers a new perspective on risk management in complex NPD. Managing risk is to become an increasingly important project management task to secure the achievement of NPD targets, especially in emerging NPD types. The automotive industry has to adapt its risk frameworks as well as its risk framing activities per se (suggested propositions) in a way that more strategic and cultural viewpoints with an overall organization focus can be included. This allows to capture the full scope of risks that the automotive industry is facing in the conduction of emerging NPD types.

This research work provides selected cases and examples from the automotive industry perspective. The resulting field evidence supports the understanding of the point of departure for risk management in complex NPD. The relation to the most relevant topics in a literature stream that combines risk management and complexity theory are established. Though, the findings of this research work lead to further advancements of this literature stream as certain relationships are tested. In general, it seems important to consider more cases and examples from the field. In the case of the automotive industry, particularly automotive suppliers have to be increasingly included. They account for the vast majority of the NPD value chain and are therefore a potential source of risk. Furthermore, other industries that are in a phase of transition as for instance the machinery industry may be regarded to confirm the findings of this research work. In fact, it is also considered valuable to include potential findings from industries that traditionally focus on extremely short lifecycles and introduce innovations on a consistent basis such as the information technology and software industry. Considering risk management, the general research interest moves more and more from processes and methods towards organization and coordination as well as strategic and cultural aspects of the topic. These sub research areas promise a lot of potential, especially in combination with complexity theory.

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## APPENDIX

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Value	Definition	Explanation
9	Extreme importance	Highest possible domination of one influence factor over the other
8	Very strong importance	Intermediate value
7	Strong importance	Judgment and experience strongly favor one influence factor over the other
6	Absolute importance	Intermediate value
5	Solid importance	Judgment and experience favor one influence factor over the other
4	Essential importance	Intermediate value
3	Moderate importance	Only minor domination of one influence factor over the other
2	Weak importance	Intermediate value
1	Equal importance	No existing domination between compared influence factors
Reciprocal values are used in comparison: if influence factor i is assigned a value then influence factor j is assigned the reciprocal value, thus the pairwise comparison is limited to the area in the matrix above the diagonal		

**Appendix 2.1:** Saaty scale (own table based on Saaty, 1980)

**Appendix 2.1** exemplifies the Saaty scale that is used for the pairwise comparison of risks in the process of the AHP method application. The Saaty scale reaches from 1 to 9, where the uneven numbers state the primary scale that is used for the pairwise comparisons and the even numbers state intermediary stages of the scale that are especially used to find consensus in case experts find it difficult to conduct a pairwise comparison based on the primary scale only. The scale supports the structured assessment of risks and a certain comparability between different pairwise comparisons. Whereas some decision problems may need a larger or adapted scale, the Saaty scale proved to be very efficient in the course of this research work.

n	1	2	3	4	5	6	7	8	9	10
CI <sub>R</sub>	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

**Appendix 2.2:** Random consistency index (CI<sub>R</sub>) (own table based on Saaty, 1980)

**Appendix 2.2** illustrates the random consistency index (CI<sub>R</sub>) as defined by Saaty. Based on the calculated consistency index (CI) and the random consistency index (CI<sub>R</sub>), it is possible to calculate the consistency ratio (CR) that brings both indices in relation. This allows a validation of the subjective expert assessments (with regard to the numerous pairwise comparisons) in terms of overall consistency. A consistent result is indicated by a value  $\leq 10\%$ . In the case of this research work, all expert assessments are consistent. It is further possible to repeat single pairwise comparisons if the consistency is not sufficient.

No.	Risk category	Risk	Risk description
1	Product	Product development scope	Large product development scope with high amount of unknown suppliers (e.g. high amount of engine and body derivatives)
2	Product	Product innovation degree	High product innovation degree (e.g. completely new infotainment systems)
3	Product	Product definition	Insufficient description of product performance and customer requirements (i.e. missing requirements translation into technical product target values)
4	Product	Product geometry	Large difficulty with the derivation of the product structure, package and product space distribution
5	Process	Resource availability	Low consideration of parallel internal projects as well as current resource workload in the functional areas (i.e. multiple occupancy of employees and thus missing final definition of complete NPD organization)
6	Process	Employee competences	Strong challenge for employees in functional areas due to lacking new process and new product knowhow

No.	Risk category	Risk	Risk description
7	Process	Physical validation	Missing consideration of physical validation measures and optimization loops due to single focus on digital validation results
8	Process	Concept competitions	Insufficient process description, standards and rules regarding transparent concept competitions
9	Process	Production orientation	Large difficulty with the consideration of production-oriented product development (e.g. assembly group definition)
10	Process	Group affiliation	Mandatory styling release through parent company (notice: increased probability of late styling release)
11	Process	Systems responsibility	Missing knowhow in systems engineering and integration (e.g. necessary internal product development due to loss of systems supplier)
12	Process	Supplier focus	High amount of single sourcing activity
13	Process	Supplier contract contents	Large difficulty with the statement and cross-functional synchronization of supplier contract contents
14	Process	Ongoing internal changes	Requested piloting of new standards within the NPD (e.g. new bill of materials/product architecture)
15	Project	NPD planning	Existing time gap between forward and backward termination and lacking acceptance of the NPD schedule in the functional areas
16	Project	NPD steering	Non-transparent releases of quality gates without content review and high amount of risk releases
17	Project	Internal decision delay	Missing responsibility for open decisions (e.g. carry-over-part vs. new product development) and obvious internal decision delay in case of escalation
18	Project	Task re-prioritization	High amount of task re-prioritizations and missing task parallelization

No.	Risk category	Risk	Risk description
19	Project	Communication	Non-transparent information flow in the direction of the functional areas after taken decisions
20	Project	Pre-development results	Necessary compensation of missing pre-development results is caught up in new product development
21	Project	"Frontloading" contents	Enormous danger of late order placement for "frontloading" contents
22	Project	Technical change management	Severe technical changes after supplier nomination and existence of "moving targets"
23	Project	Engineering service providers	Large reliability on continuous availability and solution development of external engineering service providers

**Appendix 2.3:** Risk overview and description (own table based on OEM, 2015)

**Appendix 2.3** shows 23 risks that are identified within the workshop team. The identification of risks brings three main difficulties where a workshop format has clear benefits. First of all, it is important to specify if the risk is per se a risk (=probability of occurrence < 100%). Some of the identified "risks" proved to be actual problems where immediate measures in the form of a task force have to be defined in order to foster attention. Second of all, it is important to differentiate between root cause and effect. The risk has to be formulated in a way that it describes the root cause rather than the effect as counter measures in the next stages of the risk management process cycle have to be defined for the root cause. Third of all, the scoping and definition of risks has to be consistent and precise in order to guarantee a risk landscape that is free of overlaps. This is particularly difficult as some risks have boundaries to a certain degree. This lies in the nature of NPD where the maturity degree of the product is increases over interconnected processes with a cross-functional workforce.

Engine parts overview		
No.	German term (original)	English term (translation)
1	Kurbelgehäuse	Crank case
2	Kurbeltrieb	Crank drive
3	Riementrieb	Belt drive
4	Zylinderkopf	Cylinder head
5	Steuertrieb	Timing drive
6	Ventiltrieb	Valve drive
7	Ventilhaube	Valve cover
8	Schmierung	Lubricating system
9	Kühlung, ohne Wasserpumpe	Cooling w/o water pump
10	Druckanlage	Pressure system
11	Kurbelgehäuseentlüftung	Crank case ventilation
12	Kraftstoffsystem	Fuel system
13	Unterdrucksystem	Vacuum system
14	Aufladung	Forced induction
15	Tankentlüftung	Tank ventilation
16	Motorenlagerung	Engine mount
17	Sekundärluftsystem	Secondary air system
18	Wasserpumpe	Water pump
19	Kurbelgehäusebelüftung	Crank case air supply
20	Katalysator	Catalyst
21	Ansaugkrümmer	Intake manifold
22	Druckschlauch	Pressure tube
23	Druckrohr	Pressure pipe
24	Kühlung (Schläuche)	Cooling (tubes)
25	Saugrohr-Verdichter	Manifold compressor
26	Hutze Drosselklappe	Binnacle throttle valve
27	Luftfilter	Air filter
28	Wasserleitung	Water pipe
29	Motorelektronik	Engine electronics
30	Schalldämpfer	Muffler

Engine parts overview		
No.	German term (original)	English term (translation)
31	Endrohr	Tail pipe
32	Kühlermodule	Cooling module
33	Ladeluftkühler	Intercooler
34	Indirekter Ladeluftkühler	Indirect intercooler
35	Hauptschalldämpfer-Halterung	Main silencer bracket

**Appendix 3.1:** Engine parts overview (own table based on OEM, 2015)

**Appendix 3.1** illustrates the 35 engine parts that build up the first prototype of the engine. The engine architecture is specific to the automotive manufacturer and may be different from manufacturer to manufacturer. Each engine part has a responsible design engineer that represents a “small project manager” in charge of the quality, cost and time targets for the specific engine part. All 35 engine parts combined result in an engine that fulfills the desired engine functionality. In order to guarantee this engine functionality, it is necessary that each engine parts fulfills its function and is compatible with the adjacent engine parts as defined.

No.	Interaction matrix (for 35 parts of engine prototype, source: OEM, 2015)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	

**Appendix 3.2:** Interaction matrix – Interaction of single parts (K) with N=35 and K=7 on average (own figure based on OEM, 2015)

have no or few interfaces to other engine parts (e.g. cooling module, tail pipe and muffler), other parts have numerous interfaces that have to be regarded in the course of the development process. Especially

technical contents that are relatively large or spread throughout the engine system such as engine electronics have numerous interfaces to other engine parts. Based on the interaction with other engine parts, the single design engineers mark the interfaces for the part(s) that they are responsible for. This also means that the design engineers are responsible for managing these specific interfaces in a way that they have to ensure the functionality of their part(s) with respect to possible interface premises. Some design engineers are responsible for more than one part which may lead to less interface issues. In general, the single design engineers are in a conflict to ensure the functionality of their engine part(s) and the functionality of the entire engine system that does not necessarily result from local optima but an overall optimum.

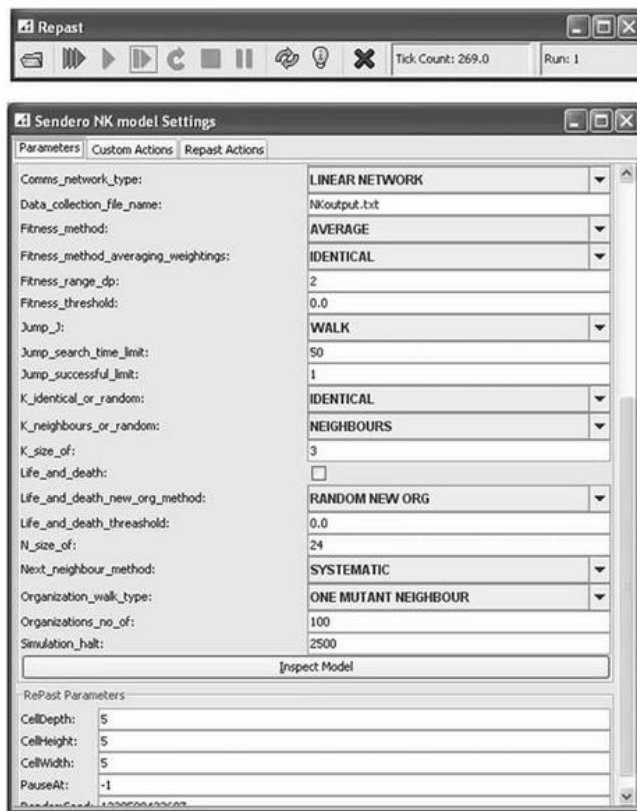
No.	Simulation tool	Short description
1	Agent Analyst	Introductory and open source application to agent-based modeling based on the ArcGIS software
2	AnyLogic	Only application to support all common simulation methodologies: System dynamics, process-centric (discrete event) and agent-based modeling
3	D-MASON	Parallel freeware application of MASON library for writing and running simulations of agent-based simulation models
4	NetLogo	Freeware application with multi-agent programmable modeling environment to simulate social phenomena
5	Repast	Open source application to collect, create, run and display data from agent-based simulations
6	Sendero	Freeware application on Repast basis to reproduce the NK model with extensions, including population dynamics and communication networks  (simulation tool applied in this research work)

**Appendix 3.3:** Selection of suitable simulation tools (own table, 2015)

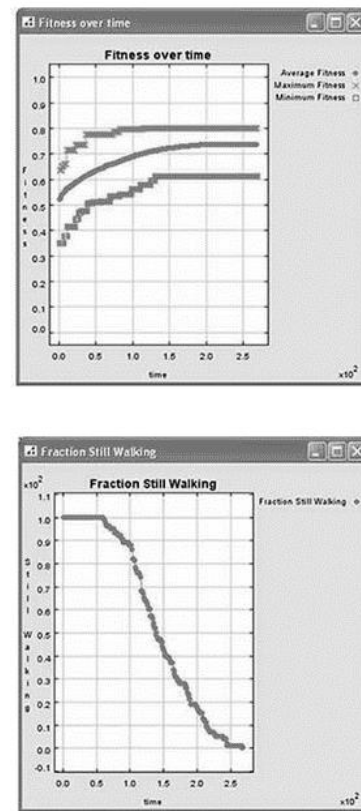
**Appendix 3.3** lists a number of simulation tools that can be used for running agent-based simulations. In the course of this research work, the choice is made in favor for the Sendero simulation tool. The Sendero simulation tool is based on an open source application (Repast) and allows to reproduce Kauffman's NK model. The simulation tool is a result of a project at the University of Bath (UK). A full project documentation and a guideline for the Sendero simulation tool can both be downloaded online at: <https://wiki.bath.ac.uk/display/sendero/download>. The Sendero simulation tool including the source code can also be directly downloaded from this website without charge. It can be installed on all



conventional computers running MS Windows. Central to the usage of the simulation tool is the input screen as shown below. Here, all the simulation parameters and values are entered (also refer to Appendices 3.4 and 3.5).



*Exemplary input screen*



*Exemplary outputs (graphs)*

As shown above, the Sendero simulation tool provides graphical results with regard to fitness values over time. All results are also provided in a text document that can be transferred to MS Excel for further analysis. Depending on the complexity of the simulation (e.g. number of runs) and the available computational power, a simulation run may take up to a few minutes.

No.	Simulation parameter	Value
1	A_identical_or_random:	0
2	A_size_of:	4
3	Collect_data:	2
4	Comms_network:	false
5	Comms_network_change:	false
6	Comms_network_change_chance:	0
7	Comms_network_change_frequency:	0
8	Comms_network_connection_probability_percentage:	0
9	Comms_network_rewire_probability_percentage:	0
10	Comms_network_small_world_connect_radius:	0

11	Comms_network_type:	0
12	Data_collection_file_name:	Output.txt
13	Fitness_method:	0
14	Fitness_method_averaging_weightings:	0
15	Fitness_range_dp:	0
16	Fitness_threshold:	0.0
17	Jump_J:	1
18	Jump_search_time_limit:	0
19	Jump_successful_limit:	0
20	K_identical_or_random:	0
21	K_neighbours_or_random:	1
22	K_size_of:	0 or 7 or 34
23	Life_and_death:	false
24	Life_and_death_new_org_method:	0
25	Life_and_death_threashold:	0.0
26	N_size_of:	35
27	Next_neighbour_method:	1
28	Organization_walk_type:	1
29	Organizations_no_of:	100
30	Simulation_halt:	150

**Appendix 3.4:** Simulation parameters and values (100 runs, w/o communication) (own table, 2015)

**Appendix 3.5:** Simulation parameters and values (100 runs, with communication) (own table, 2015)

No.	Simulation parameter	Value
1	A_identical_or_random:	0
2	A_size_of:	4
3	Collect_data:	2
4	Comms_network:	true
5	Comms_network_change:	false
6	Comms_network_change_chance:	0
7	Comms_network_change_frequency:	0
8	Comms_network_connection_probability_percentage:	0
9	Comms_network_rewire_probability_percentage:	0
10	Comms_network_small_world_connect_radius:	0
11	Comms_network_type:	0
12	Data_collection_file_name:	Output.txt
13	Fitness_method:	0
14	Fitness_method_averaging_weightings:	0
15	Fitness_range_dp:	0
16	Fitness_threshold:	0.0
17	Jump_J:	1
18	Jump_search_time_limit:	0
19	Jump_successful_limit:	0
20	K_identical_or_random:	0
21	K_neighbours_or_random:	1
22	K_size_of:	0 or 7 or 34
23	Life_and_death:	false
24	Life_and_death_new_org_method:	0
25	Life_and_death_threshold:	0.0
26	N_size_of:	35
27	Next_neighbour_method:	1
28	Organization_walk_type:	1
29	Organizations_no_of:	100
30	Simulation_halt:	150

**Appendices 3.4 and 3.5** illustrate simulation parameters and values that are used in this research work to model the NPD environment. A detailed description of the single positions can be drawn online from the website: <http://jasss.soc.surrey.ac.uk/12/4/8.html>. A clear benefit of the Sendero simulation tool are the numerous simulation possibilities as for instance with regard to communication topologies. The

simulation tool allows to test the development of the overall fitness value (system performance) over time under the influence of different communication strategies as for instance none, fully connected, randomly connected or connected within defined groups/networks.

No.	Group	Role	Level of practical NPD experience
1	A	NPD leader	> 10 years
2	A	NPD sub-project leader	7 years
3	B	NPD sub-project leader	5 years
4	B	NPD sub-project leader	5 years
5	C	NPD sub-project leader	> 10 years
6	D	Manager eMobility	> 10 years
7	D	Manager eMobility	n/a
8	E	Manager process	> 10 years
9	F	Manager connected car	n/a
10	G	Principal (consulting)	5 years
11	H	Project manager (consulting)	2 years
12	H	Senior consultant (consulting)	2 years

**Appendix 4.1:** Overview of expert interviews within automotive industry (own table, 2016)

**Appendix 4.1** refers to the interviewees that are involved in semi-structured interviews on risk management under the lens of emerging new NPD types. The interviewees are asked to state their level of practical NPD experience within as well as outside the current company. The voluntary request results in ten out of twelve responses. The majority of interviewees has extensive relevant experience, meaning that several NPD have been served in the past.