TOWARDS A HOLISTIC LEAN PRODUCT DEVELOPMENT FRAMEWORK

by

JOACHIM FREUDENBERG

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Department of Marketing
Birmingham Business School
College of Social Sciences
University of Birmingham

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Abstract

Companies consider product development (PD) their competitive lever to survive in a technology-fuelled and fast-paced environment. Lean Product Development (LPD) is a promising concept currently being adopted by companies focusing on maximising customer value, shortening lead times, and reducing costs in PD.

This research initially concentrates on developing a comprehensive LPD framework which subsumes existing concepts and supersedes them by including findings from the wider PD research area. The investigation then leads into understanding the highly-interwoven, yet under-investigated, character of LPD to pave the way for its implementation into the complex knowledge-based PD environment. The deduced systematic implementation plan, which both provides an appropriate level of detail and accounts for the inherent complexities of LPD, supports companies in their struggle to embrace Lean practices in PD.

The LPD framework is developed by employing a content analysis of existing concepts and integrating insights from the wider PD environment. The relationships between the framework's elements are investigated using the results of a self-administered questionnaire embedded in a cross-sectional research design and complemented by the fruitful discussions found in literature. The insights into the inner workings of the framework are subsequently appropriated to formulate general recommendations and an effective implementation plan.

Dedication

To my beloved wife Anika.

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Abbreviations

APQC	American Productivity and Quality Center
CAD	Computer-Aided Design
CAE	Computer-Aided Engineering
IMVP	International Motor Vehicle Program
IT	Information Technology
LAI	Lean Aircraft Initiative
LPD	Lean Product Development
MIT	Massachusetts Institute of Technology
OEM	Original Equipment Manufacturer
PD	Product Development
PDMA	Product Development and Management Association
PLM	Product Lifecycle Management
SBCE	Set-Based Concurrent Engineering
TPS	Toyota Production System

LPD Element Abbreviations

CE	Concurrent Engineering
CI	Continuous Improvement
CKT	Communication and Knowledge Transfer
PM	Process Management
PVM	Product Variety Management
SBD	Set-based Design
SPM	Strong Project Manager
SRI	Supplier Relationship and Integration
T	Teams

1 Introduction

This first chapter initially contextualises the inquiry at hand by summarising the research background and rationalises its direction of investigation through identifying current gaps in contemporary LPD literature. Embedded in literature, the following section formulates the general directions of this study in form of objectives which are subsequently refined into three research questions this research seeks to thoroughly address. The remaining two sections in this chapter outline the focus and scope of this investigation and lay out the remainder of the work at hand.

1.1 Research Background and Motivation

Driven by changes in the internal and external business environment, academics and practitioners have developed a number of concepts to support organisations concentrating on PD as their lever to maintain competitiveness in a fast-paced and complex environment (Ahmadi et al., 2001). The LPD approach is currently increasingly focused and adopted by companies concentrating on maximising customer value, shortening lead times, and reducing costs in PD processes (León and Farris, 2011). The fundament for this approach to managing and structuring innovation projects has been by Clark et al.'s (1987) study of Japanese PD practices (Hoppmann, 2009). The concept, however, is largely implicit at the pioneering Japanese automobile manufacturer Toyota thus required a great level of understanding, abstraction, and interpretation (Morgan and Liker, 2006). The development of LPD greatly reflects the gradually increasing understanding of Japanese development practices and the adaption to the changes in the business environment as it progressively adjusted its focus and widened its scope. The initial rather rudimentary understanding for the Japanese high productivity level in PD (cf. Clark and Fujimoto, 1989b; cf. Clark et al., 1987; cf. Cusumano and Nobeoka, 1992; cf. Karlsson and Åhlström, 1996; cf. Womack et al., 1990) slowly began to be translated in increasingly holistic concepts (cf. Brown, 2007; cf. Fiore, 2005; cf. Hoppmann, 2009; cf. Krumm and Schittny, 2013; cf. Mascitelli, 2011; Morgan and Liker, 2006; cf. Ward et al., 2007). These Western interpretations of Toyota's and, to a smaller degree, other Japanese companies' development practices have been moulded over the years into increasingly comprehensive development systems which the remainder of this work will refer to as LPD frameworks. The most established LPD frameworks which are based on a sound empirical basis and offer a distinct degree of originality[1] are summarised in Figure 1. The frameworks and the individual components they comprise of, are listed according to their publication chronologically from left to right.

[1] There are a number of LPD frameworks which do not meet these criteria. Kennedy (2003), for example, is largely based on Allen Ward's ideas about LPD who mentored Michael Kennedy. In addition to Kennedy's (2003) lacking originality, his publication is exclusively based on his experiences at his workplace, Texas Instruments, and to a lesser degree based on his consultancy work. Other examples include, but are not limited to, Mascitelli (2011), Radeka (2013), and Reinertsen (2009). Their exclusion, however, should not be understood as a judgement of their quality but merely as decision based on the criteria set for this work.

LPD elements	Clark et al., 1987	Womack et al., 1990	Karlsson and Åhlström, 1996	Morgan and Liker, 2006	Brown, 2007	Ward, 2007	Hoppmann et al., 2011	Schuh, 2013
1	Strong Project Manager	Leadership	Supplier Involvement	Customer Value Definition	Use of Design Sets	Entrepreneurial System Designer	Strong Project Manager	Strategic Positioning
2	Supplier Integration	Teamwork	Simultaneous Engineering	Front-loading	Information and Process Flow	Teams of Responsible Experts	Specialist Career Path	Clear Prioritisation
3	Cross-functional Teams	Communication	Cross-functional Teams	Leveled Process Flow	Continuous Improvement	Set-based Concurrent Engineering	Workload Leveling	Roadmapping
4	Overlapping Phases	Simultaneous Development	Functional Integration	Standardisation	Process Monitoring	Cadence, Pull, Flow	Responsibility-based Planning and Control	Product Architecture Design
5			Heavyweight Team Structure	Chief Engineer System	Value Stream Mapping		Cross-project Knowledge Transfer	Product Range Optimisation
6			Strategic Management	Balance Functional Expertise and Cross-functional Integration	Standardisation		Simultaneous Engineering	Design Space Management
7				Technical Expertise	Concurrent Design		Supplier Integration	Value Stream Optimisation
8				Supplier Integration			Product Variety Management	Data Consistency
9				Continuous Learning and Improvement			Rapid Prototyping, Simulation and Testing	Multi Project Management
10				Build a Culture of Excellence			Process Standardisation	Innovation Controlling
11				Adapt suitable Technology			Set-based Engineering	Release Engineering
12				Communication				Continuous Improvement
13				Integrate Tools				

Figure 1: LPD frameworks

The early frameworks of Clark et al. (1987), Womack et al. (1990), Karlsson and Åhlström (1996), as well as Ward (2007)[2] only consist of a number of LPD elements which, as the discussion in section 2.3.1 will highlight, are at best loosely connected. While Brown (2007) offered rich insights into LPD in their benchmark study, it was Morgan and Liker's (2006) publication which marked a new era of comprehensive LPD frameworks consisting of closely connected and interdependent elements. But even the more developed and inclusive frameworks of LPD differ significantly in their focus and scope (León and Farris, 2011).

[2] Ward's (2007) publication is based on a manuscript from 2001 and was posthumously published by his son and work colleagues.

Hoppmann et al. (2011) as well as Schuh et al. (2008a), who have made significant contributions to the LPD research community, report a lack of a generally accepted LPD framework which might be attributed to the number of different frameworks, their changing focus and scope, and generally to their constantly evolving nature. This lack creates ambiguity among academics and practitioners and represents a major impediment to advancing this nascent research area (Hoppmann et al., 2011; Schuh et al., 2008a) and thwarts the implementation efforts of companies striving to introduce LPD principles in their product development (Hoppmann, 2009). In an attempt to tackle this issue, Hoppmann et al. (2011) summarised and merged the most established LPD frameworks into one concept. Their work, however, bears two major limitations. The results presented by Hoppmann et al. (2011) are entirely based on Hoppmann's (2009) Diploma thesis which is usually prepared over the course of six months and therefore naturally constraint in its resources. The second major limitation, most likely a consequence of the limited time available, is the exclusive focus on LPD literature. The LPD research area only sprang into existence with the discovery of superior Japanese development practices in the late 1980's (cf. Clark et al., 1987) and can therefore still be considered to be in its infancy. Hence, the sole focus on LPD literature means concentrating on a fairly narrowly defined population while excluding the fruitful discussions and insights of the larger PD community (Hoppmann et al., 2011). In conclusion, the lack of a widely-accepted LPD framework which not only consolidates the most established and recent existing LPD frameworks but also integrates the findings of the wider PD research area constitutes a major opportunity for advancing the LPD research to overcome the current ambiguity among practitioners.

Next to a lacking consensual framework, LPD literature suggests that many companies encounter great difficulties when introducing LPD (Hoppmann, 2009; León and Farris, 2011;

Schuh et al., 2008b). Although an increasing number of companies is focusing on implementing LPD since they have identified PD as a key to defining customer value and recognised the large potential for improving their performance in terms of time, cost, and quality, many still struggle to find a systematic approach to introducing Lean principles in their PD environment (Hoppmann et al., 2011; Karlsson and Åhlström, 1996; León and Farris, 2011; Schuh et al., 2008b). The transfer of Lean Thinking, the driving logic behind Lean, into the tightly-interwoven and complex knowledge-based product development environment has proven far more difficult than altering the easier to grasp material-based production processes (Morgan and Liker, 2006). Aside from the inherent difficulties of such implementation efforts, LPD literature suggests three main reasons why businesses struggle to implement LPD. Firstly, as previously mentioned, there are a number of LPD frameworks which greatly vary in the number of elements and the concepts they represent. This greatly varying focus and scope of current frameworks creates uncertainty among companies about the individual model's suitability for their business requirements (León and Farris, 2011). In addition to the strongly varying LPD frameworks, the interrelationships between the single components which make up a LPD framework remain under-investigated (León and Farris, 2011; Hoppmann et al., 2011). As a consequence, Hoppmann et al. (2011) urge the research community to conduct empirical research into the relationships of the individual LPD components at a system level which would allow the formulation of an effective implementation order. Lastly, there is currently no quantitative empirical study on LPD implementation with the notable exception of Hoppmann (2009). Existing implementation recommendations are mostly limited to non-specific aspects of change management, which neither take the inherent complexity of a LPD framework into account nor provide sufficient detail to enable practitioners in their efforts (Kennedy, 2003). Furthermore, these recommendations are all tailored towards the individual LPD frameworks and therefore cannot be understood as general guidelines to introducing LPD. In addition, all but Hoppmann (2009), lack a quantitative base for their implementation recommendations as they are mostly based on mere intuition since they were often treated as an accessory to the formulation of an LPD framework or were simply built around best practices identified in small case studies thus lack generalisability (Hoppmann, 2009). Since Hoppmann's (2009) first study in this area is strongly tailored towards his framework bearing the previously discussed major limitations, his quantitative exploratory investigation into defining implementation recommendations provides a good starting point in terms of providing measurement items and constructs. The need, expressed by León and Farris (2011) as well as Hoppmann et al. (2011) in a later publication, to develop an implementation plan which is appropriate in its level of detail, considers the intricate interrelationships of an LPD framework, and is aligned with the urgently needed comprehensive and coherent framework which goes beyond the narrow LPD research area and incorporates aspects from the wider PD field, remains an important opportunity to advance LPD research.

To summarise the aforementioned discussion, LPD has been recognised to yield great potential for PD performance and is therefore increasingly attracting attention from academia and industry alike. The lack of an inclusive and consensual framework, the missing understanding of its inner workings, as well as the poor availability of well-founded implementation recommendations pose major obstacles to the advancement of the LPD research frontier and businesses eager to drive effectiveness and effectivity in PD.

1.2 Research Objectives

The proposed research follows Hoppmann et al. (2011) and León and Farris' (2011) call and addresses the previously briefly outlined and in the literature review more detailed described gaps.

(1) Development of a comprehensive LPD framework which not only subsumes existing concepts but supersedes them by including approaches from the wider product development research community.

The inclusion of other research areas concerned with the study of PD would help this nascent but rapidly evolving research area to establish itself and find its position in the wider product development research area. Having defined an integrative framework and described their components in detail, the research then focuses on its second objective.

(2) The investigation of the relationships between the single components within the proposed LPD framework through the analysis of empirical data collected in a questionnaire and enriched by findings in LPD literature.

The second objective allows gaining insights into the interplay within the LPD framework, the different understandings of LPD the companies have developed over the years as well as the experiences with the introduction of LPD. The knowledge gained throughout this process forms an essential stepping stone to address the third and last objective.

(3) The development of an empirically as well as theoretically grounded systematic implementation plan which not only provides an appropriate level of detail but also takes the inherent complexity and nature of a LPD system into account.

1.3 Research Questions

After having previously rationalised and contextualised the topic and provided some direction through formulating objectives, the research process now asks for research questions. The research questions translate gaps identified in Hoppmann et al. (2011) and León and Farris (2011) into a clearly defined and specific set of interrogative statements that will direct the investigation at hand (White, 2009). The questions directly correspond to the previous sections as they restate each of the three aims and objectives but take them to a more specific level (Punch, 2005; White, 2009).

1. What constitutes a coherent and comprehensive LPD framework?

Following de Vaus' (2001) typology, this first question can be characterised as descriptive. By comparing existing LPD frameworks and including best practices and other insights from the wider PD research area, answering this question will make 'sure about the fact and dimensions of the phenomenon' (de Vaus, 2001, p.2) under investigation. The answer to the first research question is crucial to the following second one as it, among other things, determines and describes which elements a LPD framework constitutes of.

2. How do the single LPD components affect each other?

The second research question serves a descriptive as well as explanatory purpose and directs the inquiry to the interaction of the single elements. The findings of this second research question will form the basis and strongly contribute to addressing the last research question.

3. How can organisations effectively implement the LPD framework?

The third question seeks to describe and prescribe an effective implementation order. This last research question will be addressed together with the previous one by analysing the data collected using a questionnaire and by combining the findings of the second research question with further insights gained from literature.

Each of the previously formulated questions divides the inquiry in individual, distinguishable elements which will be answered or, as the case may be, appropriately addressed in a sequential order. This consecution is vital as each subsequent question is based on the findings of the previous. In few words, the research at hand seeks to paint a clear picture of an all-encompassing LPD framework, explain how its single components interact, and derive an effective implementation plan.

1.4 Scope

The focus of the investigation, as expressed in the research objectives and research questions, has been defined in direct response to the research needs identified in contemporary LPD literature. This section narrows down the scope of the inquiry by establishing a border between the central object of this research and the methods, concepts, and other research areas it has contact points with.

The sole focus of this inquiry is LPD. The forthcoming discussions will therefore refrain from considering competing approaches to organising and managing PD such as quality function deployment, agile product development, etc. A comparison with these strategies, a discourse on their advantages and disadvantages, an investigation into their driving logic, as well as any other conceivable discussion surrounding LPD and another competing approach lies outside the scope of this inquiry.

The framework proposed in this study is independent of a company's innovation strategy whether it is a product-market-focussed strategy, an opportunity-risk-focussed strategy, a time-based (industry- and competitor-focussed) strategy, a proactive strategy, or any other type of strategy which does not fall into Ahmed and Shepherd's (2010) generic typology. Their discussion will therefore not be part of this work.

The investigation into LPD is predominantly conducted on a strategy-level which focuses on structure and organisational characteristics and not on operational aspects which would include methods and tools a company might want to employ to enable and facilitate LPD on the 'shop floor'. References to insightful publications, however, will be provided throughout the work.

Further, the investigation at hand seeks to detach itself from the organisational structure the proposed LPD framework might be embedded in. Although LPD has largely been developed at Toyota which uses a complex form of matrix structure, sometimes referred to as multinational design (cf. Robbins and Judge, 2013), the Lean way of structuring, organising, and coordinating the functions involved in PD has proven in the field to be compatible with other organisational structures as well. Thus the forthcoming discussion frees itself from the complexities of organisational structures in an attempt to maintain general applicability and a high degree of compatibility with other organisational forms.

The dataset analysed and interpreted by this research is collected in the automobile industry in which LPD has its origins. The automobile industry has been selected for the survey not only because LPD has been developed at an automobile manufacturer but also because the originally Japanese development practices have been quickly adopted by Western car companies which sought to close the wide development performance gap. Therefore the automobile industry is expected to yield good empirical results as well as deep insights into LPD. In addition, the author’s personal background provides a firm understanding of the industry which further added to choosing the automobile industry over other potentially insightful industries such as consumer electronics, aerospace, defence, or software development which have been excluded from this investigation.

In the course of this inquiry, especially when discussing the elements of the proposed LPD framework in chapter 3, there will be numerous contact points with other research areas such as project management, supply chain management, organisational learning and knowledge transfer, and countless more, which would justify conducting research projects in their own rights. Due to the predominantly theoretical approach to answering the first research question and the large amount of research areas LPD overlaps with, the discussions about the LPD elements need to be conducted with great discipline not only to maintain the original LPD character of these elements but also to keep the investigation focused on its research object.

The forthcoming LPD framework is informed by a number of existing frameworks which outline the LPD elements by describing their key characteristics. These frameworks are chosen according to a number of criteria which are explained in detail in section 3.1.2. LPD frameworks not meeting these criteria are excluded from this inquiry and will not be discussed in any detail.

As previously outlined, the LPD framework developed in the course of this investigation is based on existing frameworks and subsequently enriched by tapping into recent findings in the corresponding research areas. This investigation does not seek to transfer the guiding principles underpinning the Lean philosophy into product development anew – a process which has taken the pioneers of LPD decades.

1.5 Thesis Outline

In the course of this first chapter, the research background has been outlined to contextualise the work at hand and several gaps have been identified which currently form the research frontier in the nascent LPD research area. The research opportunities have been translated into objectives to provide general guidance and a firm direction. These objectives were subsequently restated into three concise research questions which give this study a clear purpose and aim to work towards to. In an effort to paint a clear picture of this inquiry, the remaining sections of the first chapter have delineated the study from other research areas, concepts, and methods and lastly laid out the remainder of the thesis.

The second chapter forms the theoretical foundation by mapping and assessing relevant areas of Lean, product development, and Lean Product Development. Accordingly, the chapter is divided into three parts to provide a clear structure. The first section in the literature review chapter discusses in detail the roots of Lean to establish a firm understanding of the internal and external environment in which Lean has been developed and how this management approach has evolved over time to adapt to an increasingly dynamic landscape. This first section further seeks to eliminate any confusion about the Lean approach by outlining the most contemporary interpretation of Lean thus illustrating the current research frontier. After this historical approach to discussing Lean, the focus shifts to its target dimensions and the Lean principles which provide guidance for companies striving towards Lean goals. These first three sections are followed by a discussion about the key concepts of value and waste to further strengthen the understanding of Lean while providing a contrasting picture to their interpretation in the knowledge-based PD environment. The second part of the literature review summarises the most important changes in the business environment and how companies have altered their development practices to cope with these external changes. The following section investigates PD through a process lens by discussing the most established development process models. The last section in this second part of the literature review presents the findings of contemporary best practice studies to, in summary, paint a brief but comprehensive picture of how companies have developed over time and arrived at their current way of organising and structuring their PD efforts. The last part in the chapter fully concentrates on the topic at hand – LPD. The central object of research is introduced with a detailed discussion of its evolution and how this development has impacted on LPD frameworks which can be understood as the manifestation of the understanding of LPD. In the course of this discussion, the research gaps, which the work at hand has been built around, are assessed in more detail to establish a firm basis for the remainder of the study. The remaining two sections focus on the LPD key concepts value and waste to further the understanding of the driving logic behind this approach and pave the way for a comparison with the interpretation of these concepts with the ones from the material-based Lean environment.

After the study and its most relevant areas have been firmly embedded in literature, the third chapter seeks to comprehensively address the first research question – what constitutes a coherent and comprehensive LPD framework? In an effort to systematically approach this question, the chapter starts off by introducing and discussing the existing LPD frameworks which will inform the framework proposed in this work. The subsequent section lays out the methodology which has been employed to develop the LPD framework presented and discussed in much detail in the second part of this chapter. This second part is subdivided into nine sections which each presents a detailed discussion of the key features and characteristics making up the elements which form the LPD framework. These nine LPD elements are not only informed by the previously discussed existing frameworks but also by contemporary research in the corresponding fields as well as the best practice studies introduced in the literature review to extend this nascent research area beyond its current boundaries. The resulting LPD framework subsumes existing frameworks and extends them by including the findings and fruitful discussions from the numerous research areas it overlaps with. The last section in this tripartite chapter shifts the focus from the individual LPD elements to their relationships and interdependencies to explore the inner workings of the proposed framework.

Once the theoretical foundation has been laid and the first research question addressed by establishing a coherent and comprehensive LPD framework, the fourth chapter controversially discusses the methodology underlying this research. The chapter initially elucidates the research design providing the logical structure of the investigation which most appropriately addresses the research gap within the constraints of this study. The following chapter discourses on research philosophy and concludes by making a personal stand in this debate to control for potential influences from this metaphysical direction, contextualise the employed research methods, and make the work generally easier accessible for the reader. After questions about ontology, epistemology, axiology, and rhetoric have been put to rest, the subsequent section discusses both quantitative and qualitative methods before transitioning to the main research method – the questionnaire survey. Within this last part of the methodology chapter, the reader is acquainted with the sample, the sampling strategy, and the design of the questionnaire itself.

At the outset of chapter five, the insights of the descriptive analysis are organised in three sections which initially account for the demographic aspects of the sample, then present the implementation status of LPD, and conclude with a more detailed portray of the usage of LPD elements. Following the disclosure of the collected data, the subsequent section delves into the dataset to investigate the current usage of LPD elements, also referred to as ‘Leanness’, to shade light on influencing factors which promote or impede the introduction of LPD practices in product development. The next section scrutinises the inner workings of the proposed framework through investigating correlating elements, conducting an exploratory factor analysis to identify clusters of correlation, and finally adding causality to the previously undirected relationships by including the responses to the influence matrix of the survey. The understanding of the interrelationships informs the implementation recommendations detailed in the last section. This last section brings together the understanding of the inner workings of the LPD framework with the survey items which inquired into the introduction of LPD development and potential problems associated with it. Throughout the chapter, the findings are synthesised with theory so that the empirical results directly lead into a fruitful discussion on the current status of LPD, the inner workings of the proposed framework, and lastly the implementation recommendations. Discussing the latter two effectively answers research questions two and three which inquired about the relationships between the individual LPD elements and asked for effective, empirically-grounded implementation recommendations.

The work at hand concludes by initially providing a research summary which revisits the most important aspects of this inquiry. The chapter then translates the research findings into contributions to both academia and industry before highlighting the limitations of this study and expressing opportunities for future inquiries into LPD.

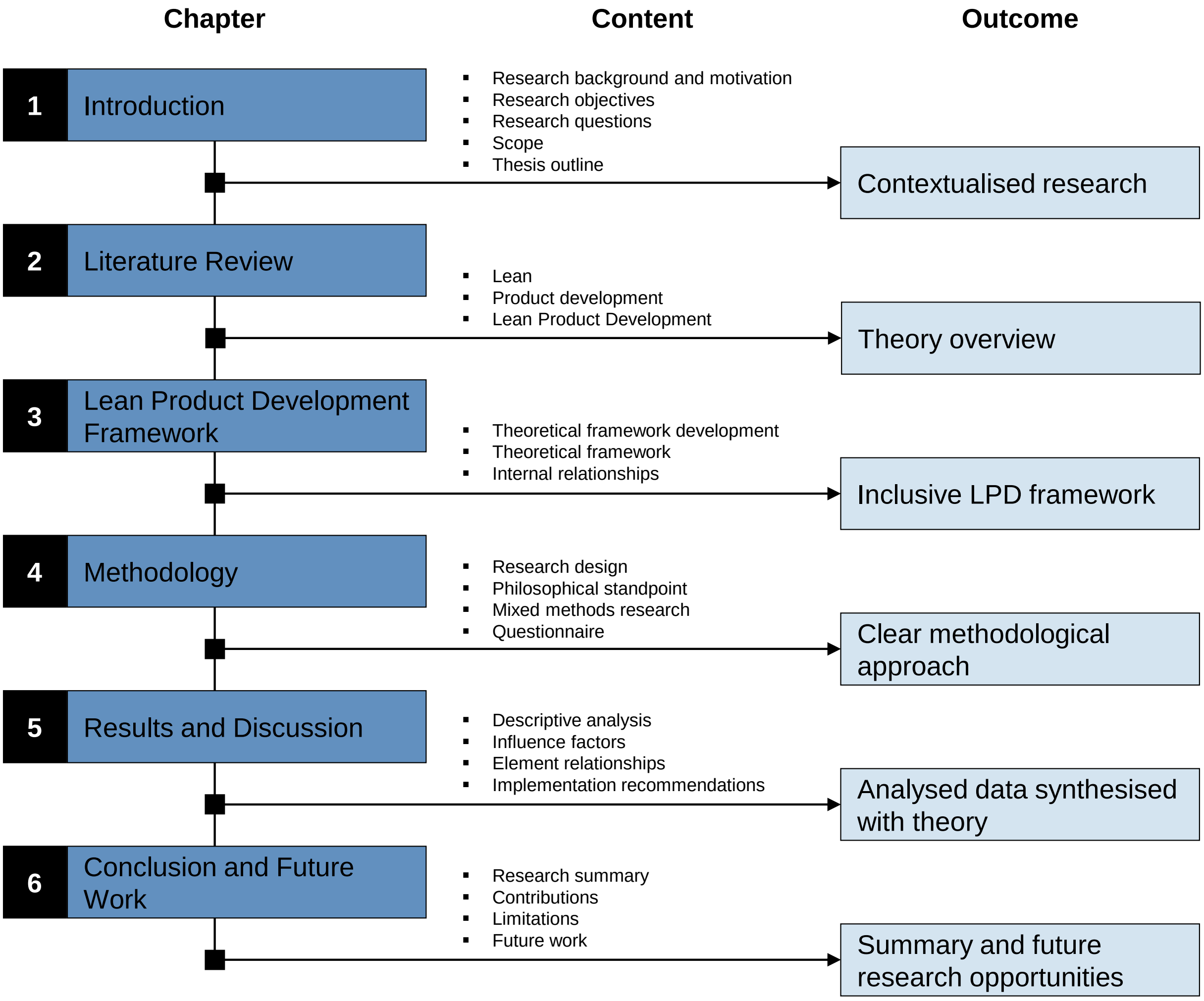


Figure 2: Thesis outline

2 Literature Review

The following chapter maps and assesses the topics Lean, product development, and LPD to contextualise the research and identify existing gaps in the literature. It is organised in three parts to provide a more thorough and clearly arranged literature review. The first part takes a historical approach and summarises past and recent developments to firstly eliminate the confusion related to Lean and secondly illustrate the current research frontline. It will also discuss the targets of Lean, its principles and how they have changed over time as well as the concepts value and waste which are essential to a sound understanding of Lean and its driving forces.

The second part on PD summarises the most significant changes in the business environment and their influence on development practices. Subsequently, it will detail the most established PD process models and complement the previous two sections by presenting the most recently identified best practices to paint a comprehensive picture of how companies have arrived at their current way of structuring and organising their PD efforts.

The last part begins with the introduction of LPD and a detailed description of its evolution and then focuses on the most relevant gaps to this research. The remaining two sections will discuss LPD's core concepts value and waste which allows for a comparison with the corresponding concepts in the material-based Lean production environment and further strengthen the understanding of LPD's driving logic.

2.1 Lean

The first section of the tripartite literature review details the Lean approach as it can be found in many manufacturing companies around the world. Initially, the first section maps the evolution of Lean starting with its origins, the Toyota Production System (TPS), its abstraction and translation into what was later coined Lean or Lean Production, and finishing with more contemporary but less discussed interpretations of this management philosophy. After describing Lean in its historical context, the subsequent section addresses the targets or objectives of Lean. Once it has been established where Lean comes from, what it is, and what it is trying to achieve, section 2.1.3 deals with the philosophical guidelines, often referred to as Lean principles, which provide guidance in Lean efforts and facilitate the communication of this approach. The section on Lean as employed in a predominantly material-based environment finishes by describing the concepts value and waste which are considered key concepts in this management approach.

2.1.1 Evolution of Lean

The adverse economic conditions in post-war Japan in the 40s which demanded the profitable production of a great variety of new models in small volumes sparked the development of what will be later known as the TPS (Cusumano, 1985; Fujimoto, 1999; Ohno, 1988). Constrained by financial capabilities (Fujimoto, 1999), limited by material shortages and subjected to intense domestic rivalry (Hines et al., 2004), Toyota introduced its production system to gain international competitiveness in the automobile industry. Toyota's production system was no sudden creation but the result of decades of largely trial and error development between the late 40s and 70s (Ohno, 1988; Holweg, 2007). Although some elements of the TPS have been introduced earlier (Cusumano, 1985; Toyota Motor Corporation, 1988), most aspects were pioneered and implemented by Taiichi Ohno who is widely recognised as the original founder of Toyota's system of production management (Cusumano, 1985; Fujimoto, 1999; Monden, 1983; Ohno and Kumagai, 1980; Pegels, 1984; Shingo, 1988, 1989; Sugimori et al., 1977).

Pushed by basic material shortages and rising commodity prices in the aftermath of the oil crises in the 1970s (Schonberger, 1982a), Western automobile manufacturers largely renewed their product mix and entered direct competition with small Japanese automobiles (Fujimoto, 1999). In these conditions, when Toyota was earning exceptionally large profits while its competition was struggling in a weak economic situation, TPS started gaining the attention of Western researchers and practitioners (Fujimoto, 1999; Lander and Liker, 2007; Ohno, 1988; Shingo, 1989). Consequently, Sugimori et al. (1977) and Ohno and Kumagai (1980), all Toyota employees, authored the first academic papers on TPS in English. In subsequent years, a small study group published a number of books (cf. Hall, 1983a; cf. Monden, 1983; cf. Schonberger, 1982a) and articles in academic (cf. Hall, 1983b; cf. Schonberger, 1982b, c, 1983a, b; cf. Schonberger and Gilbert, 1983) and practitioner journals (cf. Monden 1981a, b, c, d; cf. Nakane and Hall, 1983) to explain the superior quality level and productivity rates. These quite narrowly inventory-focused contributions were complemented in subsequent years by copious publications which explored the wider organisational aspects (cf. Cusumano, 1985; cf. Imai, 1986; cf. Japan Management Association and Lu, 1989; cf. Ohno, 1988; cf. Shingo, 1983, 1988, 1989). For a more detailed review of the early TPS body of knowledge see Holweg (2007), Sohal et al. (1989) and Waters-Fuller (1995). These early works have been vital first step as they codified the basic components of TPS, which have been deliberately left implicit to secure Toyota's competitive advantage (Bozdogan, 2010).

‘Lean Production’, the more generic term describing the Western interpretation of Toyota’s productions practices, was coined by Massachusetts Institute of Technology (MIT) researcher Krafcik in 1988 and found widespread acceptance through the landmark publication ‘The machine that changed the world’ by Womack et al. (1990). In Holweg’s (2007) view, the success of the book can be largely credited to its non-technical language, its system view bringing together previously loosely connected but in far more detail described techniques and practices, the contrast it was able to provide to Western performance and practices and maybe most importantly its timing. Despite being awarded ‘Business Book of the Year’ by the Financial Times, sales were slow in the beginning and only started picking up after a feature story in the practitioners’ journal Automotive News in 1991 coinciding with a growing crisis in Detroit’s automobile industry. The book condensed the findings of MIT’s global automotive industry study ‘International Motor Vehicle Program’ (IMVP) which set out to measure the performance differences between the West and Japan. The insights gained in this comprehensive study delivered the indisputable message that the Lean approach to managing and organising production yields better performance. Based on their insights, the authors further claim that the practices and techniques that make up TPS are not limited to Toyota’s organisation context or the Japanese culture but are applicable to Western countries and companies (Womack and Jones, 1996a; Holweg, 2007). Although previous publication already detailed the core elements of Lean, it was to a large extent Womack et al.’s (1990) non-technical and easily readable publication which triggered a paradigm shift in Western manufacturing companies away from mass production towards Lean practices (Parry and Graves, 2008). In an effort to overcome the limitations, such as insufficient compatibility with Western managerial practices or a limited applicability to only a very specific range of activities, and support implementation efforts, a group of researchers, companies, and industries made substantial efforts to develop Lean further. Consequently, the scope of the Lean approach progressively widened (Womack and Jones, 1996b). Particularly notable in this context is Womack and Jones' (1996b) work. Having gained the industries' interest, they started their own consulting business to disseminate the Lean idea and support practitioners who provided valuable input and constantly tested the concepts' boundaries, especially in terms of implementability. Womack and Jones (1996b) reacted on practitioner requests by summarising the Lean philosophy in five guiding principles (see section 2.1.3). This newly found understanding restated the TPS framework to improve the compatibility of Lean with established Western management styles (MIT, 2000).

In addition, the value stream[3] concept, which represents a core method in Lean, evolved beyond its origins in the production environment (cf. Hines and Rich, 1997; Rother and Shook, 2003). This advancement was largely made possible through Rother and Shook's work on a tool to map the value stream and afforded the link between Lean and the supply chain, helping to integrate upstream suppliers and customer-focused downstream activities (Hines et al., 2004). The idea of a value stream provided a way of thinking which allowed shifting the focus from an inner departmental optimisation, typical to the so called 'over the wall' approach where a department was only concerned for what happened within its limited sphere of responsibility without much consideration for other involved up and downstream activities, to a more holistic thinking which concentrates on optimising the value creation process as a whole. This important

[3] The value stream concept should not be confused with Porter's value chain concept. The idea of the value stream concept includes all activities from start to end product and seeks to improve and optimise the entire set of activities from the stakeholder's point of view. In contrast, Porter's value chain concept tends to aggregate a certain set of activities such as marketing, sales, or production and seeks for opportunities to maximise profits and how the rest of the company can be orchestrated to support this endeavour (Womack and Jones, 1996b).

concept helped Lean to grow beyond its initial main area of focus, manufacturing, into a more company-wide approach to restructuring and refocusing a firm's primary activities. Value Stream Mapping (VSM), a tool to meaningfully visualise a value stream for optimisation, also marks an important stepping stone as it helped the Lean approach to develop beyond the automobile industry (Freudenberg, 2012). Meanwhile, extensive studies were carried out on transferring Lean principles to other industrial sectors, including aerospace (e.g. Murman et al., 2002), automobile distribution (e.g. Reichhart and Holweg, 2007), health care (e.g. Bridges, 2006; e.g. de Koning et al., 2006) and grocery retailing (Holweg, 2007; e.g. Womack and Jones, 2005).

In the US aircraft and aerospace industry, the increasing globalisation, end of the Cold War, as well as maturity of various core products created a completely new market environment and challenged established business models in the 90s (Bozdogan, 2010; Murman et al., 2002). This development led to a paradigm shift away from performance towards affordability on which the industry reacted with a prolonged period of streamlining operations, consolidation and realignment. But since these measures have proven insufficient, the industry began to focus on process management to improve effectiveness and efficiency (Bozdogan, 2010). MIT's Lean Aircraft Initiative[4] (LAI) responded to these developments and adapted Lean for the aircraft and, in subsequent years, aerospace industry (Murman et al., 2002). Although the newly defined

[4] The name of the 1993 founded Lean Aircraft Initiative evolved corresponding to its focus to Lean Aerospace Initiative in 1996 and was renamed again in 2007 to Lean Advancement Initiative to reflect the interest from a wide range of industries.

principles were developed in the aerospace and aircraft industry, the authors claimed their transferability to other industries (Murman et al., 2002).

Building on the LAI's research and including the insights of a large set of case studies, Nightingale and Srinivasan (2011) took the Lean approach to the next level. LAI's extensive studies not only concentrated on Murman et al.'s (2002) customer-focused strategic level but also on the techniques, methods, and tools to operationalise this contemporary comprehension of Lean. Nightingale and Srinivasan (2011) followed the LAI's vision to empower 'enterprises to effectively, efficiently, and reliably create value in complex and rapidly changing environments' (Lean Advancement Initiative, 2012, p.2) and refined Murman et al.'s (2002) work[5] and developed seven principles of Lean enterprise transformation. This newly gained understanding of Lean should help companies in their entirety to constantly transform to keep the internal structures aligned with the external business environment (Nightingale, 2009). Nightingale and Srinivasan (2011) thereby seek to overcome a major limitation of traditional Lean, the strong emphasis on the shop-floor level, and fully elevate it to a company level (Nightingale and Srinivasan, 2011). Their newly defined principles have been firstly presented in 2009 (cf. Nightingale, 2009) and were later made available to a wider audience in the comprehensive publication 'Beyond the Lean Revolution' (cf. Nightingale and Srinivasan, 2011). The authors assert to have developed a domain independent framework comprising of principles, methods, and tools which support companies in the continuous alignment of their processes in order to meet strategic targets most effectively and efficiently (Nightingale, 2009).

[5] Nightingale took over after LAI co-director Murman retired in 2002 and from then on drove this long-term research project.

As the foregoing discussion illustrates, the Lean concept has undergone major developments since Western researchers began abstracting Toyota's production system in 1977. Since then, the Lean approach was ceaselessly developed further to enhance its applicability to contemporary Western managerial practices and operational techniques. Lean began to grow beyond production and gradually extended its focus by integrating functions such as accounting, supply chain management, and administration. Simultaneously, Lean gained hold in other industrial sectors, such as health care, service, and electronics, nurturing its continuing evolution. Figure 3 builds on Holweg's (2007) Lean research and dissemination time line and summarises the Lean evolution by contrasting major publications and key events.

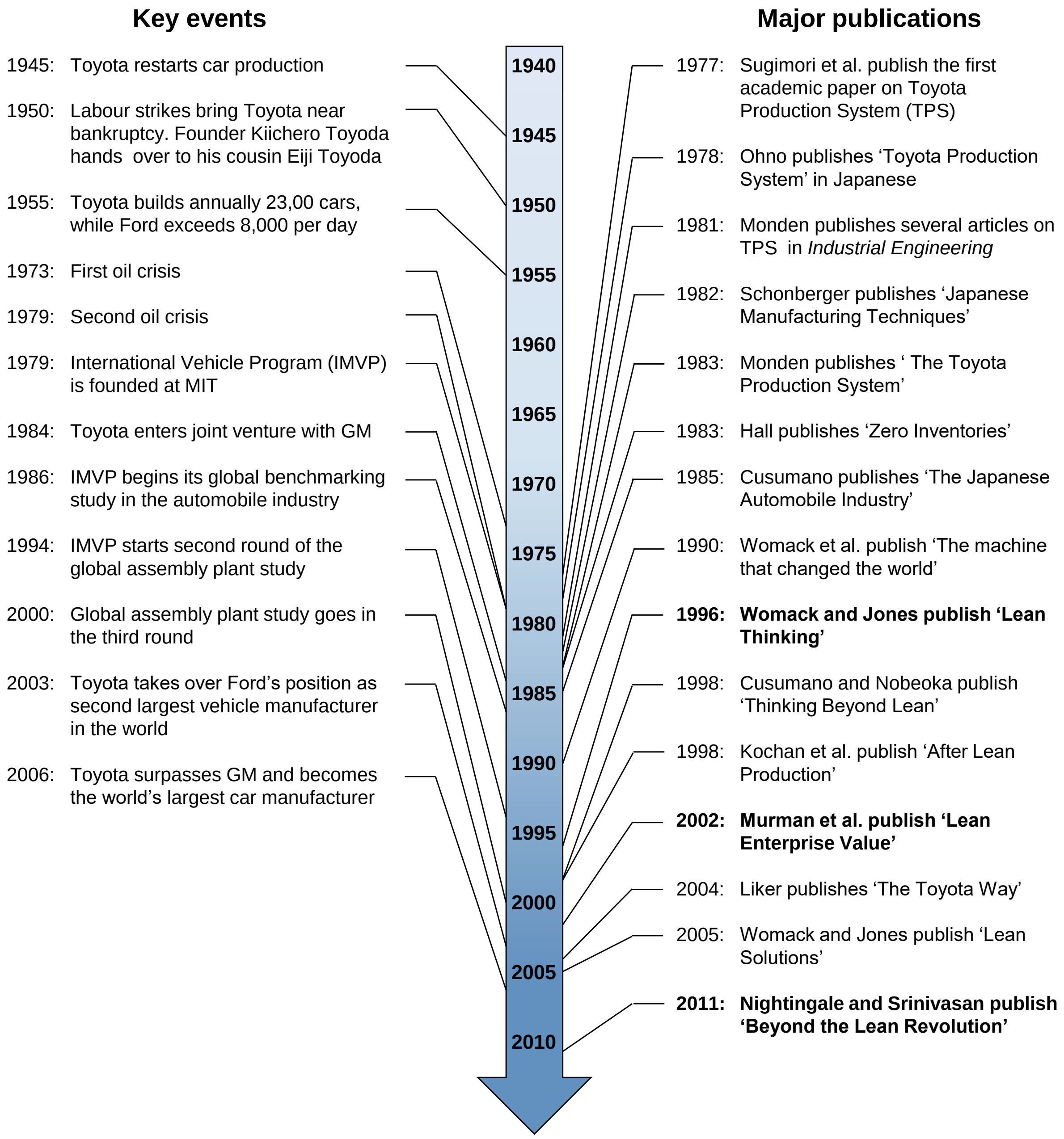


Figure 3: Lean timeline (adapted from Holweg, 2007)

The Lean approach has been continuously developed over time and is still being refined today (Bozdogan, 2010; Hines et al., 2004; Monden, 1983). Consequently, researchers and practitioners alike often struggle with recognising Lean in its contemporary form (Hines et al., 2004; Hoppmann, 2009; Shah and Ward, 2007). Since Lean originates in a production-based environment and was initially labelled 'Lean Production', it is typically associated with and mentally confined to production (Bicheno, 2004). According to an interview with the Lean pioneers Womack, Jones and Krafcik in 2013 the term Lean Production was meant to contrast this new approach with General Motor's established mass production system which included elements of product development, purchasing, customer relations, etc. and not confine it to one department of a company. The world, however, took the authors literally and perceived it to be restricted to production processes and started building on and developing this concept by largely focusing on manufacturing. In addition, nurtured by the initial crude understanding of TPS, Lean is frequently reduced to a mere set of tools rather than perceived as a holistic approach to transform the company (Lean Enterprise Academy, 2013). A firm understanding of Lean, its core elements, and the involvement of all employees, however, is vital when applying the Lean idea to new industrial sectors and other domains.

2.1.2 Lean Targets

Under occupation after World War II, Toyota was restricted in the prices for automobiles by the Price Control Ordinance and later Price Control Order and was facing a raging inflation (Cusumano, 1985; Sumiya, 2004; Toyota Motor Corporation, 1988). Although demand slowly began to increase, the devaluation of the money and Toyota's struggle to be paid by their customers was so severe that the company was only able to survive through plunging into enormous debts (Toyota Motor Corporation, 1988). Reingold (1999) reports, that the company's cash flow was so horrendous that at one point in 1948 Toyota's debt exceeded its total capital value by eight times. The financial situation brought the company to the verge of bankruptcy (Toyoda, 1987). To make matters worse, Toyota was afflicted by severe problems to achieve an acceptable productivity level. Seeking a way out, the company initiated a number of measures which, amongst others, triggered the development of the TPS (Ohno and Kumagai, 1980; Toyota Motor Corporation, 1988). Meanwhile, Toyota restructured its product portfolio to make the transition from the low variety high volume truck production in wartime economy to wide variety small volume post-war passenger car production (Cusumano, 1985; Fujimoto, 1999; Ohno and Kumagai, 1980; Toyota Motor Corporation, 1988). Ohno (1988) summarised the situation objectively stating the 'problem was how to cut costs while producing small numbers of many types of cars' (Ohno, 1988, p.1). This notion partially translates into the TPS' core objective to cut costs through constant and thorough waste elimination (Monden, 1983; Ohno, 1988). Elaborating on this objective, Ohno (1988) equates the cost reduction aspect with production efficiency which will be later picked up by Womack and Jones (1994, 1996a, 1996b). Toyota's strong focus on cost reduction, corresponding in this context to waste elimination, not only allowed offering their products at competitive prices thus successfully challenged the Western mass production paradigm but also helped to drastically reduce lead-times and increase production flexibility. This in turn has a number of positive side effects including higher quality, better customer responsiveness, and resource utilisation (Bicheno, 2004; Fiore, 2005; Liker, 2004). Monden (1983), for instance, partly picks up these side effects and defines them as sub-goals which are strongly interrelated with the primary objective of cost reduction.

As Western researchers and practitioners start codifying Toyota's production system, MIT researcher Krafcik (1988) aptly expressed the core objective naming the Western interpretation of TPS 'Lean Production'. Lean since the production system continuously cuts away excessive thus wasteful activities leaving the company on a higher productivity level with the same or lower resource input; therefore the notion 'more with less'. Womack et al. (1990) and Womack and Jones (1994, 1996a, 1996b) adopted the main goal of the original TPS and made waste elimination the primary target of Lean.

Adding to this core objective, academics and researchers typically refer to the logic through which a company may achieve this target: pushing efficiency and effectiveness in the company's value stream by reducing waste and rearranging all value-creating activities in a steady flow to the customer (cf. Womack and Jones, 1994, 1996a, 1996b). In other words, Lean Thinking[6] provides a systematic concept to identify value, line-up the value-creating activities most efficiently, uninterruptedly execute these activities when they are requested, and constantly improve them. In short, Lean strives to promote customer value while increasing efficiency and effectiveness in the company's value stream by eliminating waste (Womack and Jones, 1996b). This driving logic, however, should not be considered as targets of the traditional Lean approach. Accordingly, other benefits a company might expect to realise, if leaving the mass production mentality for the Lean approach behind, typically include, in addition to the previously mentioned, increased workforce productivity, more transparent processes, lower inventory levels, shorter time-to-market, reduced scrap, closer supplier relationships, and improved responsiveness to changes in the business environment (MIT, 2000). These beneficial side-effects, however, should not be viewed as targets of Lean but as logical consequences of the underlying logic that leads to the elimination of waste. For a more comprehensive list of potential benefits refer to Bhasin and Burcher (2006). The wide array of benefits covering all

[6] Womack and Jones (1994, 1996b) define Lean Thinking as the business logic driving the Lean approach.

three, time, cost, and quality, constitutes the main reason for companies to embrace Lean (Hoppmann, 2009).

The initial exclusive focus on waste elimination, to be equated with TPS' original target of cost reduction, nurtured a misinterpretation of Lean with alarming consequences; the IMVP's third automobile study identifies a notable number of companies employing Lean exclusively to reduce costs, even if cutting into quality. This narrow-minded employment prompted in a number of cases negative associations of Lean with flattening organisational hierarchies and cutting costs at the expense of employees (Hoppmann, 2009; Murman et al., 2002). Particularly the latter is considerably problematic since it causes resistance among the employees whose contribution is vital to successful Lean efforts (Murman et al., 2002; Womack and Jones, 1996b). Albeit being true to the core objective of cost reduction, presumably through putative waste elimination, this narrow interpretation of Lean does not apply the driving logic of maximising value through increasing efficiency and effectiveness in the entire value stream to arrive at this goal. This clearly demonstrates how the whole Lean concept is often insufficiently understood.

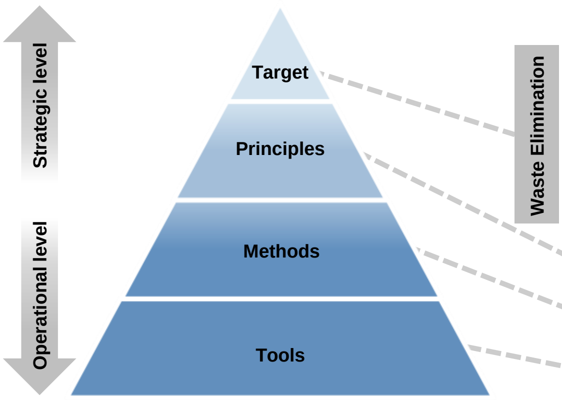
Murman et al. (2002) who adopted and redefined the Lean principles for the aerospace and aircraft industry tackled this detrimental development by emphasising the significance of value creation. This step was perceived necessary to address constraints of the original concept which set a systematic focus on eliminating waste without equally concentrating on creating value (Murman et al., 2002).

Marking the most recent major development of the Lean approach, Nightingale and Srinivasan (2011) kept this increased focus on creating value but refined the main objective of Lean. The MIT researchers complemented Lean by integrating the systematic elimination of organisational misalignments and including the achievement of strategic objectives as a main priority to help leveraging Lean to a strategic, company-wide concept (Nightingale and Srinivasan, 2011).

Having undergone much change over time, Lean is prone to be misunderstood. In fact, the large majority of literature from both academia and industry still focuses on Lean as it was initially interpreted by Womack and Jones in 1996. Consequently, there is a danger of misinterpreting the ideas and objectives of Lean and therefore of choosing a concept for the wrong purpose or at least reducing it to its very basics.

2.1.3 Lean Principles

Lean is promoted by a large array of practitioners and researchers as a total approach (cf. Browning, 2003; cf. Convis, 2001; cf. Elliott, 2001; cf. Liker, 2004; cf. Meier, 2001; cf. Nightingale, 2011; cf. Sánchez and Pérez, 2001; cf. Shingo, 1989; cf. Womack and Jones, 1996a, b). This more recent understanding of Lean stands in stark contrast to its early interpretations as a set of tools and practices which has often been attempted to be only partially implemented and typically from the bottom up in a method-driven approach (Hines et al, 2004). However, it soon became apparent that the full benefits can only be reaped if Lean is implemented on more than just the shop-floor level (Convis, 2001) and not just driven from the bottom up by implementing a number of tools and practices (Nightingale, 2011). In an attempt to better understand and communicate Lean, the system has been broken down in a varying number of layers (cf. Baines et al., 2006; cf. Convis, 2001; cf. Liker, 2004; cf. Pullin, 2002). Albeit Lean varies in the number of layers it consists of, all constructs include philosophical guidelines and a class for tools or processes. Although it has been debated that Lean constitutes for a business philosophy (Lewis, 2001), as proposed by Ohno (1988) and Womack and Jones (1994, 1996a, 1996b), the vast majority of researchers promote to view Lean as a philosophy which includes a number of concepts (Bhasin and Burcher, 2006; Convis, 2001; James, 2005; Liker, 2004; Nightingale, 2011; Pullin, 2002). Despite this well-established differentiated view on Lean, there are still many discussions of academics and practitioners which fail to recognise the different levels of Lean and often reduce it to a set of tools which only reflects the crude early understanding of this approach. The philosophical guidelines, usually referred to as ‘principles’, serve to provide direction in the daily ‘chaos’ (Bicheno, 2004; Karlsson and Åhlström, 1996; Liker, 2004; Murman et al., 2002; Olexa, 2002a, b); they guide into a direction rather than an end state (Karlsson and Åhlström, 1996) and are made actionable by the methods and tools provided.



Term	Definition
Customer Value	Achievement of customer satisfaction by identifying and delivering customer value.
Effectiveness	Procurement of objectives corresponding with customer needs and the strategic targets of the company.
Efficiency	Optimal use of all resources directly or indirectly invested in value creation.
Principles	Statements which provide guidance in the pursuit of the target dimensions.
Method	A systematic technique or procedure for conducting specific tasks, typically involving various steps.
Tool	A facilitator or enabler for the use of a method such as an design evaluation form or piece pf software.

Figure 4: Layers of Lean

The generic depiction of Lean in Figure 4, representing the various layers of Lean, shows on the first level of the pyramid common goals defining the target dimensions which are pursued by the items on the levels below. Previously described as the logic behind Lean, i.e. Lean Thinking, the common goals are all aligned to the one overarching main target of waste elimination. Beneath the target layer are the guiding principles which seek to provide guidance when striving towards these goals. On the third level follow methods and techniques which provide actionable procedures for the pursuit of tasks and activities. The bottom layer is made up of tools which facilitate and enable the use of methods. Within the scope of the work at hand, the operational level of Lean with all its well-known methods and tools such as just-in-time, value stream mapping, just-in-time, zero inventories, 5S, visual management and many more[7], will not be discussed since, as pointed out in section 1.4, they all fall into the operational level thus are strongly inherently limited with regards to their transferability into the knowledge-based environment of product development.

After MIT's five-year IMVP landmark study and several confirmatory benchmarking studies (Andersen Consulting Group, 1993; Boston Consulting Group, 1993; IBM Consulting Group, 1993), the message that Lean yields superior performance quickly spread in industry. Unequivocally, researchers hereby attach great importance to the book 'The machine that changed the world' published by the three MIT researchs Womack et al. (1990) which reached a wide audience with its non-technical and easily readable character (Holweg, 2007). Subsequently, two of the book's authors went into consultancy to aid companies seeking to embrace Lean. During their consultancy workshops, Womack and Jones were facing practitioners who took their work to a pragmatic and user-oriented next level (Womack and Jones, 1996b).

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[7] For a good overview of existing Lean methods and tools refer to Bicheno (2004).

Womack and Jones (1996b) acted upon their input by summarising the Lean philosophy in five guiding principles (see Figure 5). According to the authors, this was no easy task since most Lean techniques have been developed from the bottom up and in most cases tailored towards activities specific to the individual departments. Although by time of publication many Lean techniques have already been explained in detail (cf. Cusumano, 1985; cf. Hall, 1983a, b; cf. Imai, 1986; cf. Japan Management Association and Lu, 1989; cf. Monden 1981a, b, c, d, 1983; cf. Nakane and Hall, 1983; cf. Ohno, 1988; cf. Ohno and Kumagai, 1980; cf. Schonberger, 1982a, b, c, 1983a, b; cf. Schonberger and Gilbert, 1983; cf. Shingo, 1983, 1988, 1989; cf. Sugimori et al., 1977), the system which ties them all together was largely implicit (Womack and Jones, 1996a, b). This lacking understanding of Lean as an integrative and holistic system led in many instances to the formation of isolated islands of efficiency and effectiveness. Without implementing Lean as a whole, these companies often struggled to sustain their Lean efforts and never came close to reaping the full array of benefits this approach offers (Womack and Jones, 1996b). Womack and Jones (1996b) expressed their framework in five principles to redefine Toyota's practices and increase their compatibility with established Western managerial approaches (MIT, 2000).

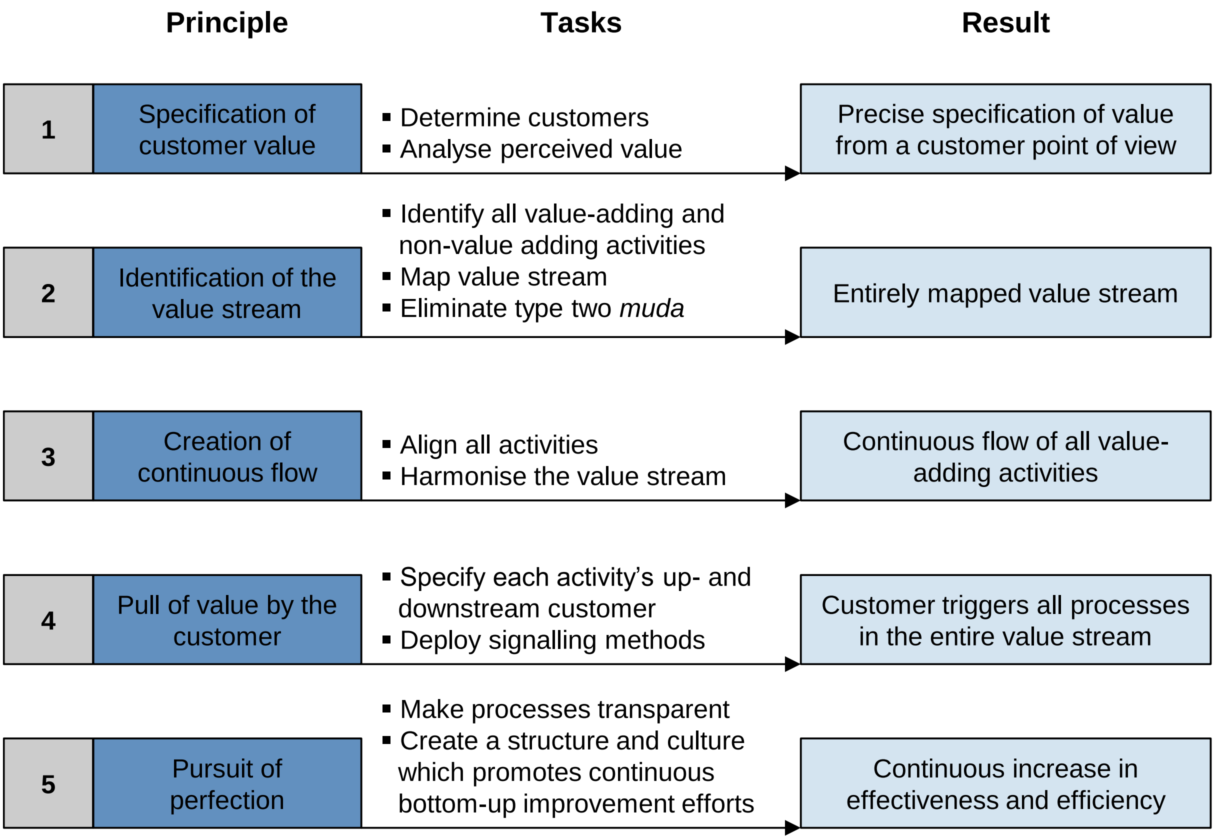

Figure 5: Summary of Womack and Jones' (1996b) Lean principles (Freudenberg, 2012)

Challenged by economic and political developments described in section 2.1.1, Murman et al. (2002) redefined the original Lean principles for the aerospace and aircraft industry (see Figure 6). On this endeavour, the authors emphasised the core theme of 'Lean Enterprise Value' to extent the focus and scope of Womack and Jones' (1996b) principles. Murman et al. (2002) shift the initial focus on waste elimination towards creating value for not just the customers in- and outside the company but all relevant stakeholders. Moreover, the scope is widened through redefining the Lean principles to improve their applicability at a company level. Despite the claim of full applicability to the entire company, Womack and Jones' (1996b) initial understanding of Lean predominantly concentrated on methods and tools specifically designed for the manufacturing environment. Murman et al.'s (2002) promoted enterprise perspective lifts Lean out of its traditional production environment to a company level to enable exerting influence on the complete value stream and systematically addressing not only the interdependencies of internal structures but also the interconnections with the external environment. This newly found understanding of Lean was not simply created by the array of MIT researchers who have contributed to the publication of Murman et al. (2002) but was developed over many years of research in the unique environment provided by the LAI. In the LAI, universities, companies, and government agencies collaborated on an international level to continuously develop Lean further and disseminate this managerial approach to all industrial sectors (Murman et al., 2002).

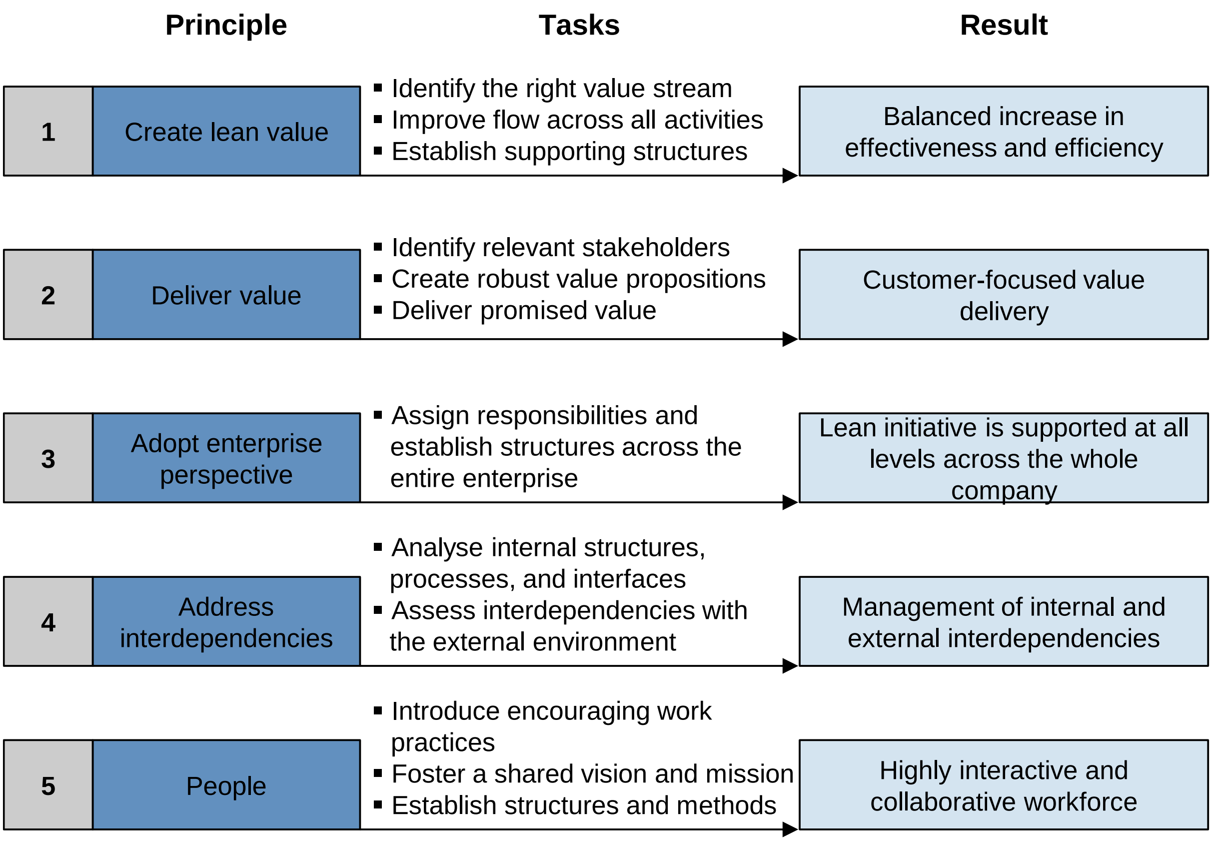

Figure 6: Summary of Murman et al.'s (2002) Lean principles (Freudenberg, 2012)

Driven by LAI's mission to assist large and complex companies in their organisational restructuring efforts (Lean Advancement Initiative, 2012), Nightingale and Srinivasan (2011) refined on Murman et al.'s (2002) work and developed their seven principles of Lean Enterprise Transformation (see Figure 7). The idea behind Lean Enterprise Transformation is to combine Lean with established models for organisational change thus take Lean's flexibility and responsiveness to an organisational level and support businesses in their restructuring efforts in an increasingly dynamic environment (Nightingale and Srinivasan, 2011). While Murman et al.'s (2002) redefined understanding of Lean sought applicability on a company level, Nightingale and Srinivasan's (2011) publication provide the means in form of methods and techniques which make the new principles actionable. The authors integrate the two established approaches of continuous and episodic organisational change into one concept to satisfy a company's stakeholder needs. Continuous change, often effectuated through bottom-up continuous improvement initiatives or employee suggestion systems concentrates on optimising local aspects of a company while episodic change represents a reaction to severe changes in the internal or external business environment and is typically triggered top-down. The combination of both change paradigms with the Lean approach strive to deliver Lean improvements on a company scale. The seven Lean principles promoted by Nightingale and Srinivasan (2011) seek to overcome the shortcomings of local improvement efforts by proactively bringing effective organisational change and systematically leveraging the stakeholders' value propositions.

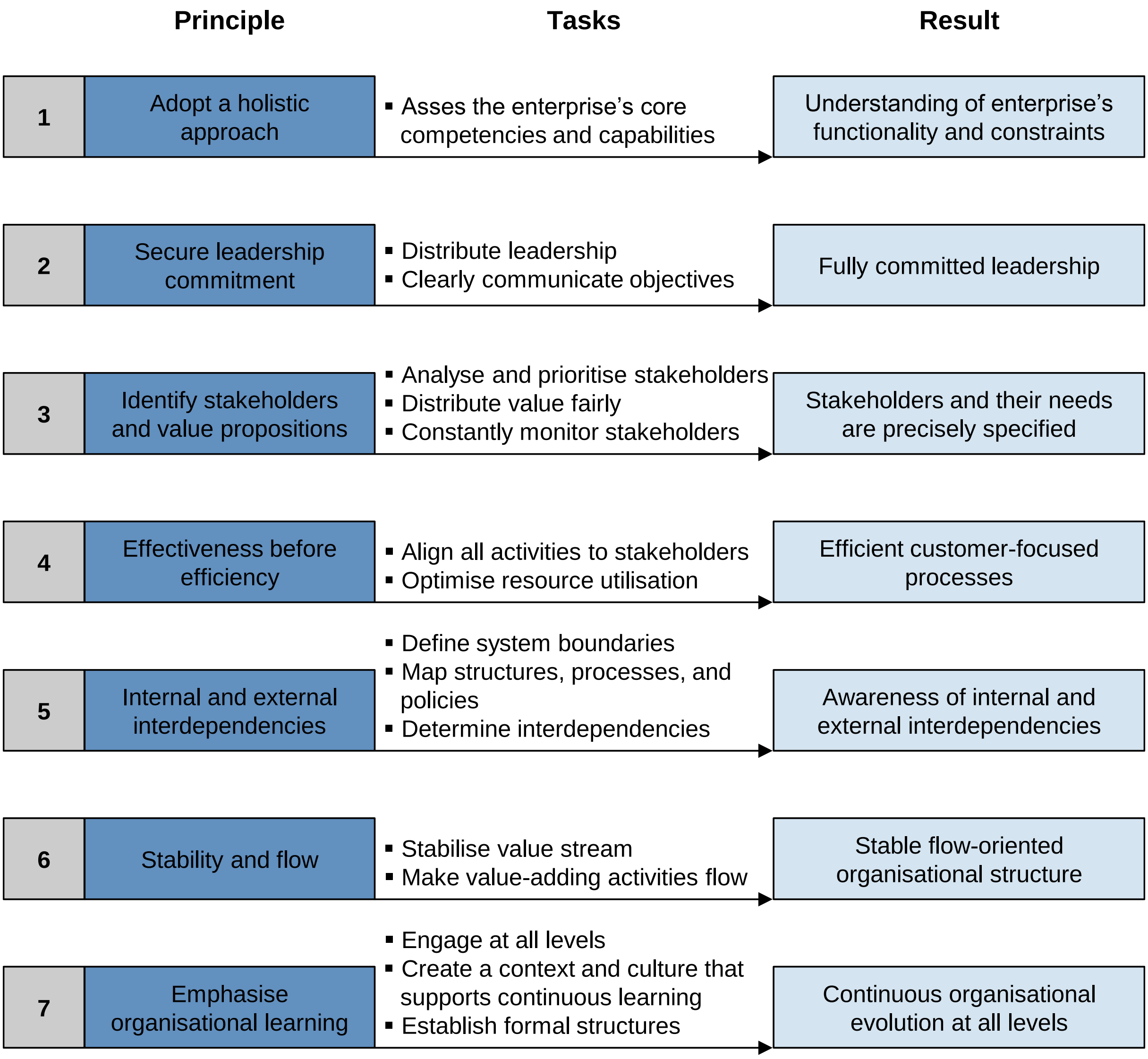

Figure 7: Summary of Nightingale and Srinivasan's (2011) Lean principles (Freudenberg, 2012)

Albeit the notion of principles may suggest a clear division of the Lean approach into a number of elements, the individual principles should not be considered isolated or independent and therefore not attempted to be introduced as such. On the contrary, the principles, which provide the philosophy behind the Lean approach, are tightly connected and often have synergetic effects which further supports the idea of treating them as an interconnected system of reinforcing elements (Hoppmann, 2009). Just as the Lean concept has been constantly developed further over time, the Lean principles reflecting the changing focus and scope of the Lean philosophy developed. Another aspect of this development that needs careful consideration during any debate is the differentiation between the Lean paradigm and its target dimensions, and the principles, methods, and tools related to it (Baines et al., 2006). A clear picture can be only drawn if considering the development of the Lean idea and distinguishing between the different levels.

2.1.4 Value

In the original Lean, value is defined as the inherent worth of a product as perceived from the customer point of view (Womack and Jones, 1996b), reflected in the price a company can ask for (Porter, 1985), and the size of the market demand (Marchwinski et al., 2008). In manufacturing, a company creates value through a number of activities for which some the customers are willing to pay for (value-added) and others which necessarily result from current work conditions (non-value-added) (Marchwinski et al., 2008; Ohno, 1988; Womack and Jones, 1996b). The value of a product is enhanced by optimising time, cost, and quality along the whole value stream (Hines et al., 2004).

The initial set of principles by Womack and Jones (1996b) defined value solely through the customer's lens. The customer in the Lean system, however, is not just the external customer but also the downstream customer within the company. When specifying customer value, Womack and Jones (1996b) recommend ignoring existing technologies and assets to avoid essential misjudgements. Such misjudgements may include prioritising shareholder demands over customer needs, attempts to maximise asset utilisation, or integrating an unnecessary amount of technical features into a product. According to Womack and Jones (1996b), these distortions can be largely overcome if starting the process with capturing an exact definition of what the customer is willing to spend money on, of what he values. As the same authors remark, delivering ‘the wrong good or service in the right way is *muda*’ (Japanese for waste) (Womack and Jones, 1996b, p.19).

After having specified value, the company needs to produce and deliver the customer value which translates into manufacturing and delivering the desired product at the right price, place, and time (Oakland, 2003). This ambitious target requires the entire company and all its involved functions to realign all activities to the end customer who is willing to pay for their efforts. Yet, not every department may grasp the definition of customer value and instead may develop their own notions of value such as maximising asset utilisation, advancing careers, driving profits, etc. These, from a company point of view, quite selfish interpretations of value are prone to contradict with each other and often do not serve the best interests of the company (Womack and Jones, 1996a). Consequently it does not suffice to just grasp the idea of what the customers’ value, their requirements, preferences, and expectations also have to be communicated along the whole value stream. The task of capturing, disseminating, and delivering customer value becomes even more challenging if a company operates in a heterogeneous market with a diverse set of customers (Hoppmann, 2009).

Addressing unfavourable developments of organisations which used the Lean approach exclusively to reduce costs sometimes even at the expense of quality, Murman et al. (2002) stressed the significance of value creation. Additionally, in an attempt to lever Lean to a company level, Murman et al. (2002) shifted the focus away from the internal downstream and paying external customers to all relevant stakeholders. Consequently, a company embracing a more contemporary understanding of Lean not only seeks to deliver value to the customer, but also to all other relevant stakeholders such as its workforce, shareholders, suppliers, and maybe even partners, and local communities. Lingering on this idea, this rethinking implies that stakeholder value cannot be exclusively increased by optimising the traditional time, cost, and quality triangle. A company is now required to deliver intangibles to other interest parties such as employees by increasing job satisfaction through job enrichment, for example by assigning additional responsibilities, creating learning opportunities, etc. (cf. Herzberg, 1968). Maximising profit for shareholders, increasing job satisfaction and creating learning opportunities for employees become of relative equal importance when applying Lean from Murman et al.'s (2002) perspective. Albeit not returning profits in a clear cut way sold products do, Murman et al. (2002) regard addressing the latter mentioned more intangible stakeholder issues as very important since they benefit the company indirectly in various ways. Business strategists Porter and Kramer (2011; 2015) base their hotly debated concept of shared value on a similar idea. The authors define shared value as 'policies and operating practices that enhance the competiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates' (Porter and Kramer, 2011, p.66). Analogue to Murman et al. (2002), Porter and Kramer (2015) regard social problems as opportunities to create a competitive advantage and realise business innovation.

Nightingale and Srinivasan (2011) retain the understanding of stakeholder value and make the stakeholders, who provide value to and derive value from the company, the centre of organisational change. Their continuous engagement with the company needs be procured by reasonably delivering on their needs and expectations (Nightingale and Srinivasan, 2011). As previously stated by Murman et al. (2002) and according to Philips et al. (2003), stakeholders are not of equal importance to a company and the value they receive is normally not uniformly apportioned (Gibson, 2000). Analogue to Murman et al. (2002), Nightingale and Srinivasan (2011) recommend to determine all relevant stakeholders, prioritise them according to their importance to the company, and capture their idea of value by performing a stakeholder analysis using employee surveys, market analyses, and other techniques for capturing the necessary information. Since value is not equitably shared among the stakeholders, the authors emphasise finding a fair balance to procure the stakeholders' continued engagement in the company. Similar to other managerial concepts, the target needs to be the constant increase in stakeholder value. Considering the dynamic nature of stakeholders, Nightingale and Srinivasan (2011) advise to continuously monitor all relevant stakeholders following their initial assessment. Newly emerging stakeholders as well as changing value perceptions such as environmental sustainability or social responsibility need to be identified early since they quickly lead to fundamental changes in the business environment.

2.1.5 Waste

The concept of waste is often referred to in the Lean context with the word *muda* (Japanese for waste) and is consensually defined as all elements which only absorb costs without adding value (Bicheno, 1998; Imai, 1997; Morgan and Liker, 2006; Ohno, 1988; Womack and Jones, 1996b). Toyota's Chief Engineer Taiichi Ohno strongly influenced the understanding of waste by categorising all forms of wasteful activities found in manufacturing into seven groups (Figure 8). This understanding of waste became commonly known as the 'seven wastes' (cf. Bicheno, 2004; cf. Hines and Rich, 1997; cf. Macomber and Howell, 2004; cf. Marchwinski et al., 2008; cf. Murman et al., 2002; cf. Rother and Shook, 2003; Shingo, 1989). Ohno's (1988) seven waste categories consist of *defects* in products, unnecessary *movement* of people, unwarranted *transport* of goods, *overproduction* of goods, *inventories* of parts and products waiting for further processing, unnecessary *processing*, and *waiting* of employees for an upstream process to finish. The categories, however, were often perceived as too narrowly defined to the manufacturing environment in which Ohno (1988) created this taxonomy. Consequently, a number of researchers and practitioners added extra types of waste to adapt this concept for their purposes. Figure 8 offers a number of examples from different industries.

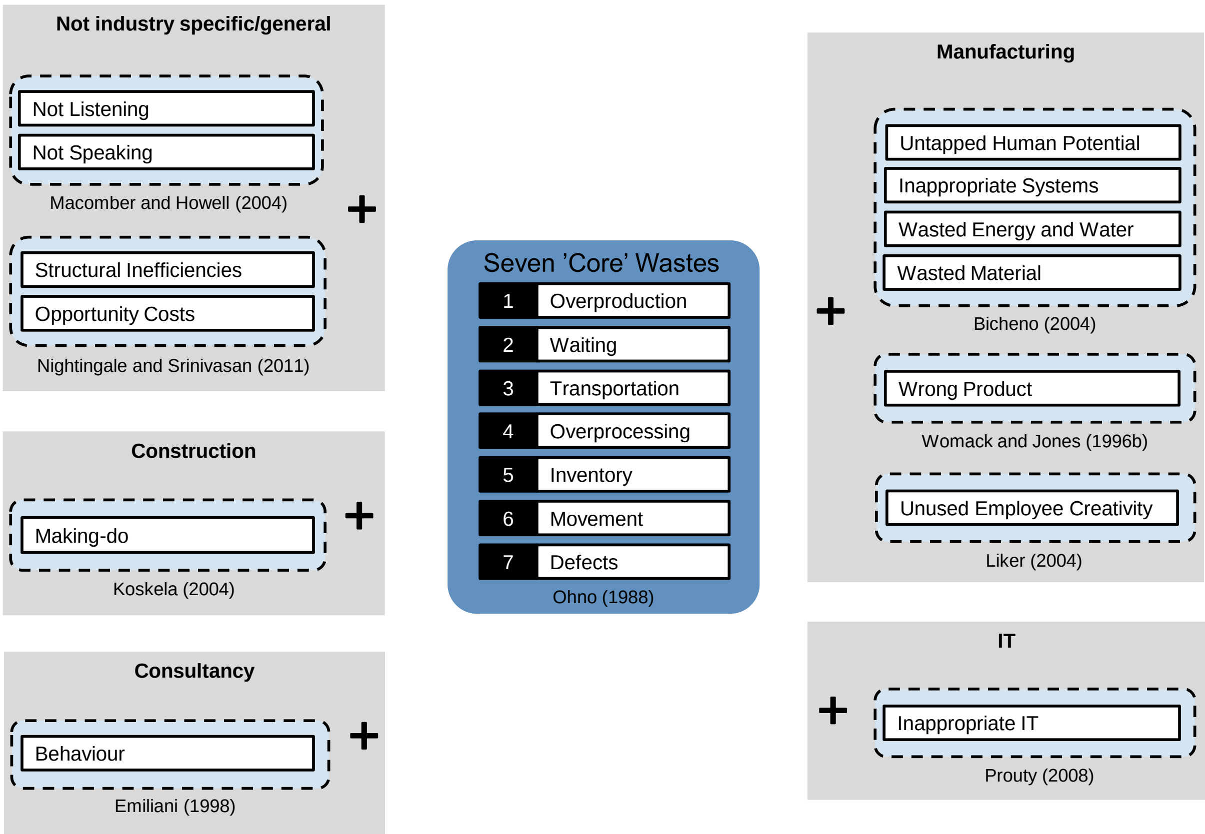

Figure 8: Waste categories

Looking closer at the different waste categories it becomes apparent that for most cases[8] the core remains the seven waste types initially defined by Ohno (1988).

Based on Ohno's (1988) observations but regardless of the taxonomy, Womack and Jones (1996b) further distinguish between activities which do not add value but are required to maintain operations (type one *muda*) and those which are not adding value and are not necessarily required and can therefore be immediately eliminated (type two *muda*) (Marchwinski et al., 2008; Womack and Jones, 1996b). The former type of wasteful activities may not create value for the customer but could help the company controlling and managing their activities or are simply unavoidable with current production assets or technologies, such as the collection of performance data or the quality control after certain process steps (Bicheno, 2004; Marchwinski et al., 2008). Type one *muda* is easy to add but hard to remove and hence should be prevented where possible or reduced to a minimum through automation, simplification, standardisation, and the application of suitable technologies (Bicheno, 2004). Type two *muda*, on the other hand, is typically easier to detect and remove and therefore should be the starting point for waste elimination initiatives as their removal greatly helps to picture the value stream and offers quick wins (Bicheno, 2004; Marchwinski et al., 2008; Womack and Jones, 1996b).

Regardless of the evolutionary stage of Lean, the elimination of waste is regarded as a key factor within the Lean concept to achieve the core objective cost reduction (Monden, 1983;

[8] In addition to the complementing waste categories mentioned in Figure 8, Bicheno (2004) translates the seven wastes exclusively for services into duplication, unclear communication, delay, opportunity lost, unnecessary inventory, unnecessary movement, and errors.

Ohno, 1988; Sugimori et al., 1977). Ohno (1988) even goes as far as characterising Lean as ‘a method to thoroughly eliminate waste and enhance productivity’ (Ohno, 1988, p.54). And as waste elimination not only cuts costs but also reduces lead times (Ohno, 1988), it is considered to be far more important than driving process efficiency (Bozdogan, 2010). Although this focus has gradually shifted towards value creation, waste and its removal maintained a prominent role in the contemporary perception of the Lean concept (see section 2.1.2).

2.2 Product Development

This second section of the literature review starts off by providing a detailed account of the PD environment in its historical context and how managerial practices and organisational structures have adapted to cope with these changes. This first part provides a firm foundation for as to how and why companies have arrived at today's prevalent structures and management practices. The subsequent section explains and discusses the three most predominant product development process models currently in use across industries. The last part of this section introduces current best practices and presents a number of examples to pave the way for their implementation into the theoretical framework developed in chapter 3.

2.2.1 Product Development Context and Management Responses

Research and development has been the focus of academic research for many decades and has been investigated in different contexts and ever changing economies and environments (Nobelius, 2004). Throughout the transition from the 1950s booming markets to today's fiercely competitive global business environment, the way in which companies organise and manage their PD activities has been subject to major changes (Christensen, 2002; Larson, 2007; Nobelius, 2004; Rothwell, 1994; Takeuchi and Nonaka, 1986; von Zedtwitz et al., 2004). In an attempt to make sense of these changes, numerous researchers have categorised relatively distinct features and patterns in PD into evolutionary phases, often referred to as 'generations' (e.g. Ahmed and Shepherd, 2010; e.g. Amidon Rogers, 1996; e.g. Miller and Morris, 1999; e.g. Niosi, 1999; e.g. Rothwell, 1994; e.g. Roussel et al., 1991). Although this taxonomy bears limitations as it tends to generalise or oversimplify many aspects and overall seeks to define distinct time periods which in reality have no clear-cut boundaries, the concept of generations is easy to understand and communicate. Hence it is implicitly used in the remainder of this section to describe the business environment, the changes it has undergone over time, and the main features companies have adapted to cope in a constantly evolving market. Each paragraph will start by detailing the most distinct features of the corresponding phase and finish with the managerial practices and techniques which have been predominantly adapted to deal with the previously described changes in the business environment. It shall be noted, however, that often a company cannot be placed in a single generation due to its diverse character, age, demographics, research intensity, the industry it operates in, and so forth (Nobelius, 2004).

Triggered by two major oil crises in the 1970s, organisations throughout the world had to cope with a high degree of inflation, increasingly saturated markets, and growing unemployment. These market changes gave rise to a wave of consolidation and rationalisation across industries (Rothwell, 1994). Resulting resource constraints made it increasingly important to control and reduce costs (Miller, 1999) thus necessary to eliminate wasteful activities on a process level (Galbraith, 1973) and overall increase the success rate of time and cost-intensive innovation projects (Rothwell, 1994). A number of studies investigating the development process (e.g. Cooper, 1980; e.g. Langrish et al., 1972; e.g. Myers and Marquis, 1969; e.g. Rothwell, 1976; e.g. Szakasits, 1974; e.g. Utterback et al., 1975) enabled companies to abandon the often employed 'strategy of hope', in which PD was largely intuitive and isolated, and transform their development processes into a number of manageable and repeatable activities aligned with organisational targets (Amidon Rogers, 1996; Research Technology Management, 2011; Roussel et al., 1991). A main feature of this new innovation process was a strong formal link between marketing and PD that allowed tying development capabilities closer to customer needs (Cooper, 1979; Dunn and Harnden, 1975; Gupta et al., 1986; Hauser and Clausing, 1988; Hutt and Speh, 1984; Nobelius, 2004; Rothwell et al., 1974; Xie et al., 1998).

After a period of economic recovery and with the emergence of a new generation of information technology-based (IT) equipment, such as CAD supported engineering, companies reset their focus to global manufacturing strategies to cope with increasingly internationalised markets and ever fiercer growing competition (Ahmed and Shepherd, 2010; Bessant, 1991). In reaction to a growing global economy and in pursuit of a working global strategy, many small (Rothwell, 1991) and large companies began forming strategic alliances (Contractor and Lorange, 1988; Dodgson, 1994; Hagedoorn, 1990), often supported and encouraged by local governments (Rothwell and Dodgson, 1992). This situation was intensified by increasingly shortened product lifecycles and a growing awareness of superior Japanese PD performance which allowed companies, such as Honda, Nissan, Sony, and Toyota, innovating more effectively and efficiently than their Western competitors (Clark et al., 1987; Cusumano and Nobeoka, 1992; Rothwell, 1994). Especially the Japanese automotive industry served as a benchmark industry for the new time-based development paradigm (Clark et al., 1987; Clark and Fujimoto, 1991b; Cusumano and Nobeoka, 1992; Stalk, 1988). Time-to-market was recognised as a rich and untapped source of competitive gain (Burt and Soukup, 1985; Smith and Reinertsen, 1991; Stalk, 1988) which was mainly accessed through integration and parallelisation (Ahmed and Shepherd, 2010; Nobelius, 2004; Rothwell, 1994; Takeuchi and Nonaka, 1986). The integration efforts went far beyond the previously clearly defined interfaces between marketing and development: horizontally, it now encompassed integrating all involved functional departments, now also including purchasing (Burt and Soukup, 1985; Fox and Rink, 1978), engineering (Takeuchi and Nonaka, 1986), manufacturing (Dean and Susman, 1989; Whitney, 1988), as well as finance (Smith and Reinertsen, 1991) and vertically closely interacting with and integrating suppliers at an early stage in the development process (Liker et al., 1996; Rothwell, 1994). The second salient feature of Japanese companies is the parallel rather than sequential execution of processes (Ahmed and Shepherd, 2010; Rothwell, 1994). Translated into concepts, this approach to PD became known as simultaneous engineering, concurrent engineering, or set-based concurrent engineering (SBCE) (Ward et al., 1995). A clear differentiation between these three terms will be made in detail in section 3.2.3 and 3.2.5.

Under the pressure of a growing number of regulations, shortening product lifecycles, and technological advancements, especially in information and communication technology, the task of managing an increasingly complex process for more and more sophisticated products in a globalised world became more and more difficult (Jelinek et al., 2012; Jelinek and Bean, 2010). These developments eroded the boundaries between functional departments and the outside world even more and made the management of interfaces and coordination of activities a key role of PD (Amidon Rogers 1996; Jelinek et al., 2012; Nobelius, 2004). After the previous horizontal integration of all involved functional departments, companies now strive to increase their vertical integration by closely interacting with customers, competitors, distributors, etc. (Amidon Rogers, 1996; Nobelius, 2004). This vertical integration and the remaining commitment for strategic networks as coping mechanisms to compete in an increasingly consolidated, dynamic and internationalised business environment is enabled and supported by the advancements in information and communication technology which allow collaborating across geographic boundaries and accessing the global talent pool (Jelinek et al., 2012). All of the previously mentioned developments only heightened the importance of the already widely adapted features, such as integration and parallelisation, and only nurtured the need for short, effective, and efficient development cycles (Rothwell, 1994). The advent of modern information and communication technology and the increasing computerisation allow for the electronification of the entire development system. Traditional face-to-face interaction was largely replaced by parallel processing through electronic means and the sharing of knowledge in the spirit of a collaborating and learning organisation greatly stimulated by advancing technology (Ahmed and Shepherd, 2010). Previously tacit knowledge became a new asset which needed to be made explicit and managed to make the most out of an ‘e-integrated’ development process (Amidon Rogers, 1996).

Throughout the previous decades the complexity of the PD process as well as the products under development has continuously risen. One of the more recent drivers for complexity includes the challenging desire of today’s customers for customised products which meet their individual and unique needs (Ahmed and Shepherd, 2010; Schuh, 2013). Other drivers in a horizontally and vertically integrated company operating in a global market include the fact that, compared to the early days, numerous more aspects have to be considered (e.g. after-market, environmental, industrial design, interoperability) and more actors have to be interacted with (e.g. purchasing, marketing, manufacturing, finance, customers, suppliers, distributors, partners, and competitors) while maintaining an effective and efficient product development process delivering products at the intended quality in a set timeframe. Nobelius (2004, p.374) further points out that the ‘need for taking more aspects into account is driven by product and technology complexity; the demand to cooperate with more actors is driven by larger technological investments and rational specialization; and the necessity of efficient and effective commercialization of new technology is driven by rate-of-return demands and the cost of being late’. Beyond these challenges, companies have to continuously renew and expand their product portfolio through incremental innovation as well as develop and open up new markets with breakthrough innovations. All these changes and developments render the likelihood of a single company possessing all these capabilities and content to satisfy the unique demands of their customers very low (Ahmed and Shepherd, 2010). Although many companies in the past have coped with this situation by acquiring the necessary capabilities and knowledge by imitating competitors, constructing networks and strategic alliances as well as strategically acquiring new firms (Chesbrough, 2006), a number of factors, such as the increasing number and mobility of skilled workers as well as availability of venture capital, have eroded the underpinnings of the traditional closed innovation model and compelled companies to strive towards a more open and flexible approach of innovation (Chesbrough, 2003; Gassmann and Enkel, 2004). Chesbrough (2006) explains open innovation as the antithesis to the traditional closed innovation model which sought through vertical integration to internally develop, produce and distribute new products. In one sentence, the author defines open innovation as 'the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively' (Chesbrough, 2006, p.1). According to Ahmed and Shepherd (2010), open innovation evolved from partners in networks and strategic alliances who willingly participated in shared product development projects. Within the open innovation model it can be further distinguished between an outside-in, inside-out, and a coupled process. Companies choosing an outside-in process integrate external knowledge through joint ideation processes with customers and suppliers, joint business developments, acquiring intellectual property licenses, venturing, spin-ins, and acquisitions. Companies adopting an inside-out process externalise their knowledge through making use of product development services, licensing-out, spin-offs and divestments. This approach is often adopted since the company possessing the idea or knowledge needs to develop and commercialise their product faster than they internally could or simply because it lacks the required capacities and capabilities to do so. A coupled process in open innovation is a customised combination of both inside-out and outside-in processes tailored towards the requirements of a company (Gassmann and Enkel, 2004). While some authors argue that open innovation merely represents and repackages past findings and concepts, in short is just 'old wine in new bottles' (Trott and Hartmann, 2009), it offers in its current interpretation and today's business environment significant benefits. Possibly most noteworthy is a successful adopter's ability to leverage external PD capabilities enabling the company to extend its capabilities and reach for new ideas and technology while concentrating its own resources to in-house development projects. As a consequence, companies can greatly enhance their internal development performance and grow their revenue through selling and licensing-out of otherwise unused intellectual property (Ahmed and Shepherd, 2010).

2.2.2 Process Overview

Companies increasingly focus on PD as their competitive lever in a complex, fast-paced and highly-competitive world (Ahmadi et al., 2001; Cooper, 1990; Sheu and Lee, 2011). Nepal et al. (2011) identify a well working PD process as a key to survival of manufacturing companies in a global economy. Process models have been determined to play a significant role in this context (Yadav et al., 2007). Implicit or informal processes often lead to unreliable and inconsistent decisions, which in turn drive costs and typically significantly increase time-to-market (Ahmed and Shepherd, 2010). The literature offers myriad models to structure product development (cf. Cooper, 1983; cf. Saren, 1994). But despite the large academic interest in PD structures, the important issue of how companies should go about implementing contemporary product PD remains largely under-investigated. Considering the diversity of companies and industries as well as the inherent intricacies of PD processes, Calantone et al. (1995) and Harmancioglu et al. (2007) assert that there is no general solution to this problem. To address the issue of implementation, the following discussion reviews the most established development process models in order to be able to later detach itself from the numerous process models and break them down into basic generic components common across PD models.

The predominant solution of best practice companies for structuring development activities and most widely used form of PD process is the traditional and sequential Stage-Gate®[9] System (Cooper et al., 2004c; Hauser et al., 2006) which is sometimes also referred to as the waterfall, phase-gate or life-cycle process (Unger, 2003). This generic system for structuring product development found great attention during the late 1980s and early 1990s during which it was implemented by many industries (Holmes and Campbell, 2004; Nepal et al., 2011). Although phase models have been around for decades, it was not until 1957 when Johnson and Jones (1957) firstly presented the notion of stages and fix decision points. Gate systems of various forms became common practice in PD and Cooper (1990) presented his Stage-Gate® system with gates serving as screening and decision making procedures (Christiansen and Varnes, 2009). The Stage-Gate® model divides the PD process into a number of discrete stages in which the actual development activities are carried out and gates at which the quality of the work is assessed with a set of deliverables (Cooper, 1990). Upon positive review during the screenings, the PD project moves from one phase to the next. During the individual stages, when the actual development is carried out, there might be many iterative loops necessary until the development project meets the screening criteria. Should the product in development find itself unable to meet the screening criteria at some point or the activities in one phase fundamentally alter the inputs or outputs from a previous stage, the project is either discarded or has to iterate back

[9] This term is a registered trademark of the Product Development Institute (http://www.prod-dev.com), co-founded by Dr Robert G. Cooper and Dr Scott J. Edgett.

across phases. The latter mentioned cross-phase iterations are often very time-consuming and usually generate expensive rework. This inflexibility to cross phase boundaries is a major disadvantage, especially if product specifications are poorly understood at the outset of the project or change throughout it (Unger, 2003). The Stage-Gate® model also proves disadvantageous if a company prioritises speed and time-to-market over quality control and additional features (Ahmed and Shepherd, 2010; McConnell, 1996; Rosas-Vega and Vokura, 2000). The mentioned disadvantages, however, can also serves as the Stage-Gate® model's strengths in a different situation. This is particularly true when technical risk is high thus where there is a high need for documentation and quality control and when project requirements are well understood in the beginning. Rigid product specifications provide a clear focus and allow all involved parties to work towards a well-defined goal. In a stable project environment where the need for quality control and error-avoidance is high, for example technology for nuclear reactors or space exploration, the traditional sequential Stage-Gate® is a very attractive choice (Unger, 2003).

Depending on size and risk of a development project as well as the company or division, a Stage-Gate® system typically comprises of three to seven stages (Cooper, 2008). The standard model, however, consists of five stages and five gates as depicted in Figure 9 (Ahmed and Shepherd, 2010; Cooper, 1990).

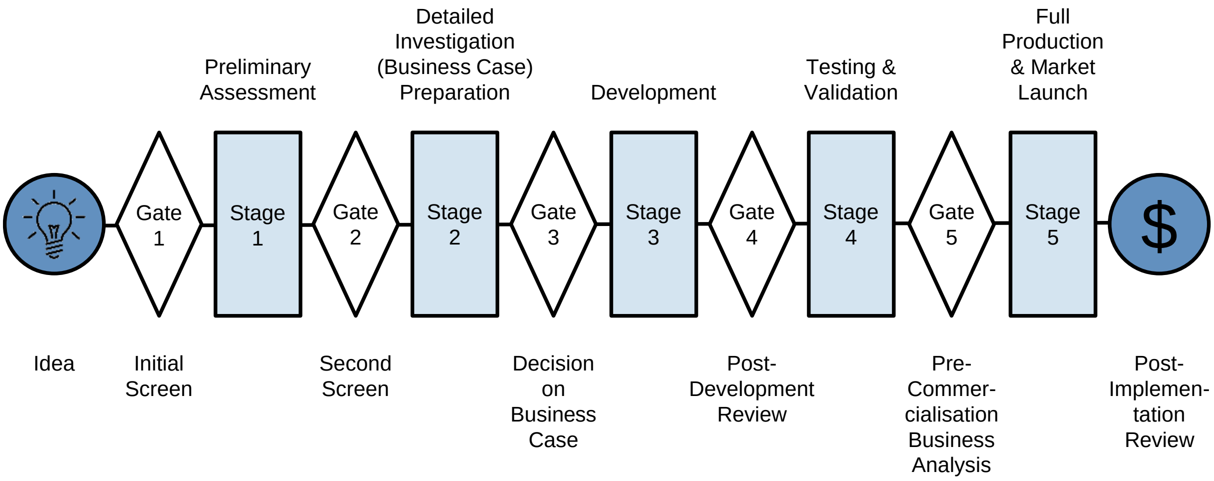

Figure 9: Typical Stage-Gate® model (Cooper, 1990)

The spiral model as depicted in Figure 10is a risk-driven approach that breaks the overall development project into multiple mini projects which span across several development phases (McConnell, 1996; Unger, 2003). Each mini project or iteration focuses on one or more risks until all major risks have been addressed. After all the major risks, whether they be poorly understood specifications, technological problems, etc., have been dealt with, the spiral model resembles in its last loop the Stage-Gate® model without the often as burdensome perceived need for excessive documentation (Boehm, 1986, 1988; McConnell, 1996). Proponents of the spiral model assert that the early and systematic elimination of all major risks reduces expensive and often time-intensive rework, therefore reducing overall development time and cost. The radial dimension in Figure 10 represents the cumulative costs while the angular dimension stands for the individual stages of the development project. The project starts in the middle of the spiral with a commitment for the first iteration and the determination of objectives, alternatives and possible constraints. As it spirals outwards it moves through the next phases during which alternatives are evaluated, risks identified and resolved, the actual development work is carried out and the verification of the next-level product begins. The iteration concludes with the planning of the next phase before it starts over again tackling the next major risk. As the development project is spiralling outwards and coming with each loop closer to a satisfactory end-state, the costs for the project increases (Boehm, 1988; Unger, 2003).

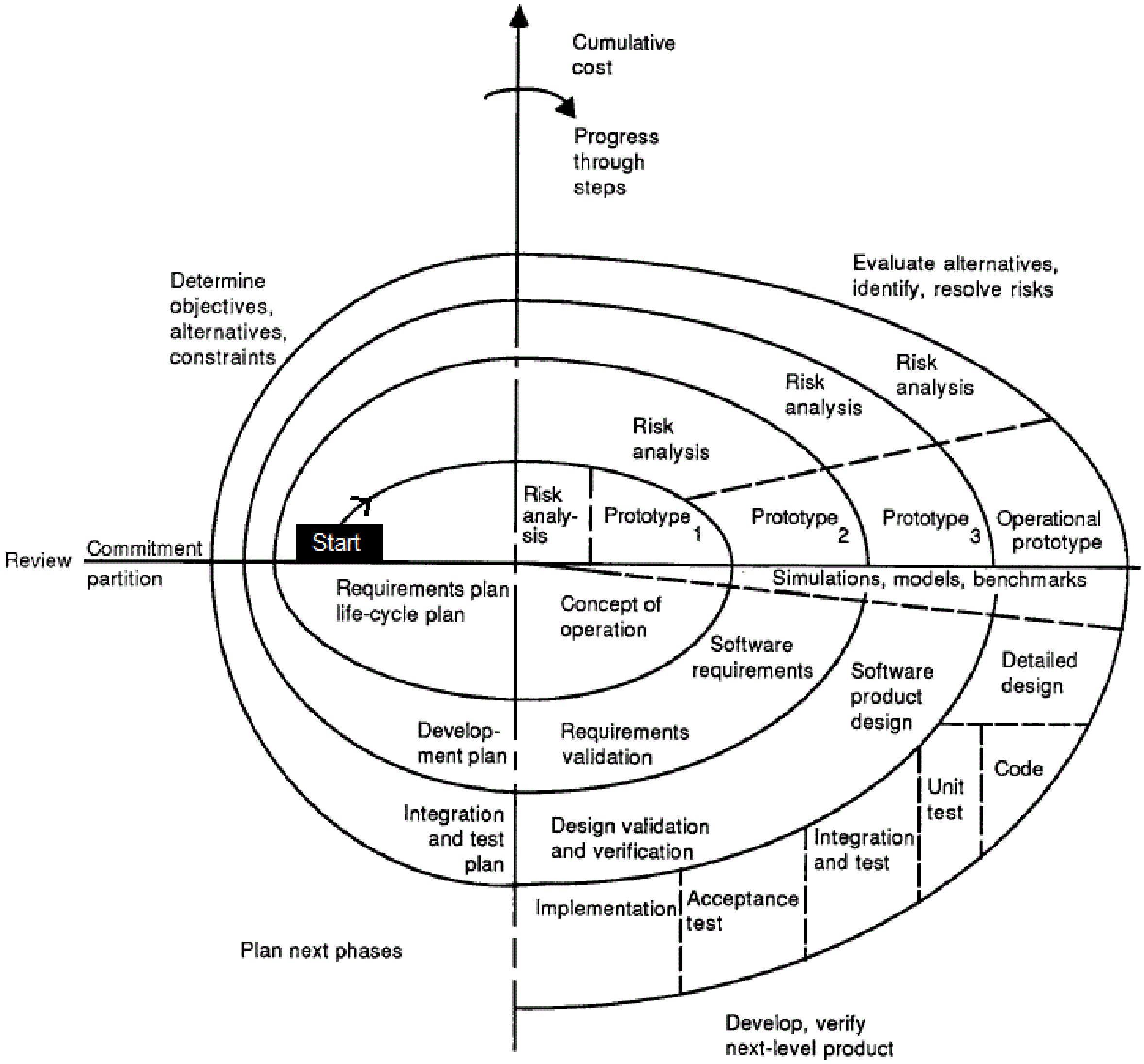

Figure 10: The Spiral product development model (adapted from Boehm, 1988)

Boehm (1988) developed the spiral model to address the software industry's problems with the prevalent waterfall or Stage-Gate® model. The author made a conscious effort to go away from the document-driven waterfall approach towards a model that is more flexible, especially with regard to cross-phase iterations, and generally more suited for a risky dynamic environment with uncertain starting conditions or changing project requirements (Boehm, 1988; Gilb, 1988). It is under these vague and unpredictable conditions in which the development team operates in 'white space'[10] with the stakeholders where the spiral model plays to its full strength (Boehm, 1988; Ahmed and Shepherd, 2010). The model, however, comes not without its shortfalls. Since the spiral model is a more complex version of the waterfall model it evolved from, it requires more administrative attention and experience to drive a development project successfully through the phases of the model. It is also with its strong emphasis on risks that the spiral model heavily relies on the risk assessment expertise of the development team. And although this model frees up valuable time and flexibility by going away from the document-driven screening gates, it is the lack of documentation which can have severe negative effects (Boehm, 1988). These include but are not limited to the inability for inexperienced developers to adequately review aspects of the project, a lacking transparency as well as a severely hampered ability to learn from previous projects and reuse already accumulated knowledge. In a relatively stable market environment and a project in which product features can be clearly defined and specifications determined early on, the spiral model would fold right away into a traditional waterfall model since it leaves out the initial risk eliminating loops and directly arrives in the last most outer iteration of the model (Boehm and Bose, 1994).

[10] The 'white space' represents an area of opportunity where neither the stakeholder nor the developers understands the need or how it can be appropriately addressed (Ahmed Shepherd, 2010).

The last predominantly employed process model is a concurrent relative of the sequential Stage-Gate® or waterfall model, the development funnel (see Figure 11) (Ahmed and Shepherd, 2010). Among its most prominent features, the development funnel starts out with a number of different ideas or possible solutions which are evaluated and pursued in parallel and screened in regular intervals until they converge into a single product. In the beginning, the product ideas start with very few detailed requirements and a high degree of uncertainty. As soon as those ideas enter the development funnel, they are equally exposed to the exacting scrutiny of the concept definition and evaluation phase. In this stage of the development project, the financial investment to evaluate and correct the different ideas is at its lowest point while the degree of freedom is at its maximum. As the project progresses and the company commits to a design option, the costs are largely determined by the design choice while the degrees of freedom quickly go down and the costs of correcting significantly rise (Boehm, 1981; Thomke and Fujimoto, 2000). Based on this rationale, companies employing this process model shift a lot of their efforts to the early stages of product development. As with the sequential Stage-Gate® model, the individual ideas in the development funnel are examined according to their projected financial, technical, and marketing performance in regular intervals at predefined screening points to determine whether to internally proceed with or terminate an idea (Ahmed and Shepherd, 2010). Clark and Wheelwright (1993) identify three major challenges when transitioning from a traditional sequential model to the development funnel. The first is to open up the development process to a large array of ideas. A development funnel can only work effectively if the company makes efforts to expand its knowledge base and seeks access to new information in order to stimulate the ideation process thus increase the number of new product ideas. Mining research laboratories, making use of university relationships, involving marketing and manufacturing, collaborating with suppliers and customers, and generally adopting aspects of an outside-in open innovation process often yield a great number of inputs. After widening the mouth of the development funnel, the second challenge lies in gradually narrowing the funnel's neck (Clark and Wheelwright, 1993). Management has to ensure a detailed enough investigation of the ideas to enable the review boards to make a choice based on hard facts without over-burdening the development teams in the early stages while keeping the workload in subsequent phases steady (Schuh, 2013; Ward et al. 1995). The German researchers Schuh et al. (2007) have demonstrated that in most development projects a design option is selected too early, inviting problems caused by eliminating solutions based on intuition, perception, and experience. To avoid this problem, product ideas are typically evaluated using checklists and are often supported by a business case to ensure its consistency with the company's financial and strategic goals while making the best use of its development resources (Ahmed and Shepherd, 2010; Clark and Wheelwright, 1993). The last major challenge lies in ensuring that the pursued ideas deliver on the objectives which have been agreed upon when the development project has been approved. This fairly general challenge is applicable to all development projects independent of the process model employed and according to Clark and Wheelwright (1993, p.295) '…considers how and when product or process specifications should be developed, when they should be modified, and how the process can be managed…'.

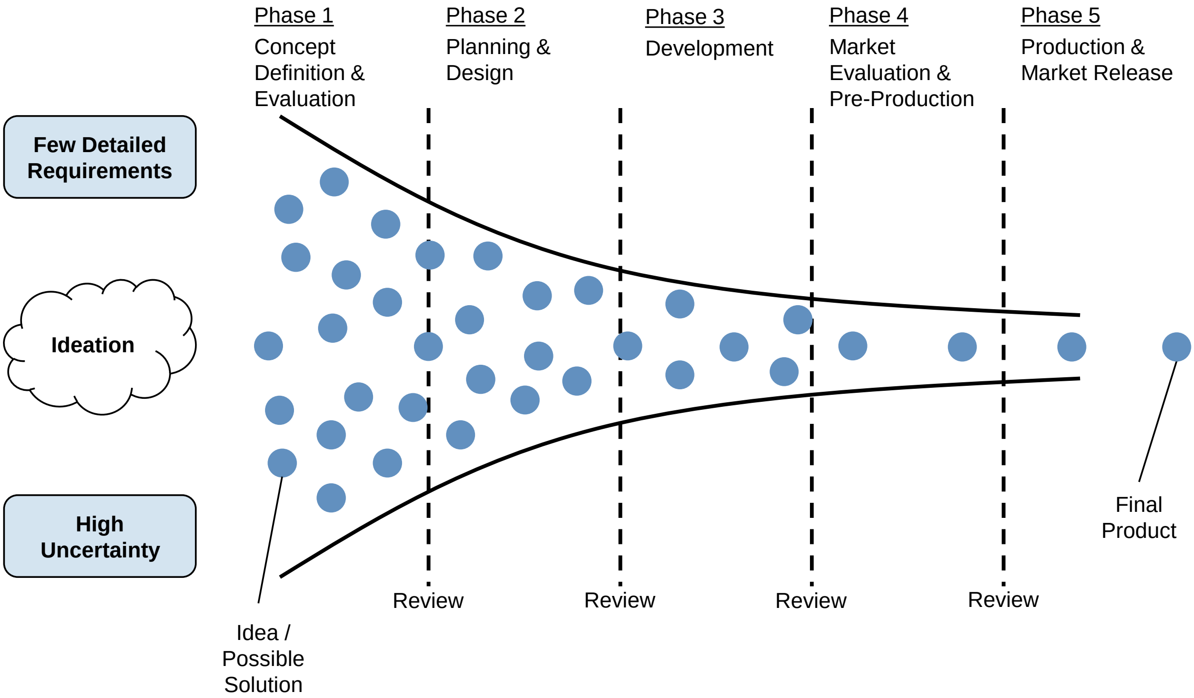

Figure 11: Development funnel (adapted from Ahmed and Shepherd, 2010; Clark and Wheelwright, 1993)

It is important to highlight that the above presented generic process models cannot simply be applied but need to be tailored to the needs of a company and their strategic aspirations operating in a specific business environment and industry and should be further adapted to the needs of the development project (Ahmed and Shepherd, 2010). Products a company is very familiar with, products which will only see incremental changes to it or those which are inherently easy to develop do not require the scrutiny of a full blown development process. It is only when a company steps out of its comfort zone and delves into the unknown or seeks developing highly complex or otherwise particularly demanding products that a fully-fledged process model finds justification in terms of the time and money invested.

All three of the presented process models serve a company to ensure their products are brought to market on time, overall increase business performance by keeping development cycles short and reduce costs while managing the development projects consistent to an agreed business plan in accordance with the strategic targets of the company. Independent of the process model employed, Ahmed and Shepherd (2010) have determined a number of distinct components they all generally share:

- A structured development process serving as a framework for all development activities and tasks and which further sets all evaluation criteria for the screening phases, determines schedules as well as primary tasks and allocates at least all the critical resources.
- A team of senior managers who oversee ongoing and future development projects by setting priorities, generally resolving issues and particularly across projects as well as making go/no-go decisions
- Cross-functional development teams empowered by a ‘product champion’, well supported by resources, operating towards clear goals and reporting to the all-overseeing board of senior executives
- Fixed and formal review points representing major decision points in the process and defining the most significant milestones at which the board of senior managers decides on resources, funding and project schedules proposed by the cross-functional teams

2.2.3 Best Practices in Product Development

Based on Camp’s work (1989) at Xerox, who is often referred to as ‘the father of benchmarking’ (Nelson, 2008), Kahn et al. (2012, p.180) define best practice as ‘technique, method, process, or activity that is more effective at delivering a particular outcome than any other technique, method, process, or activity within that domain’. Many companies seeking to improve their development processes turn to identifying and adopting best practices to replicate the success of best performing organisations (Dooley et al., 2002). Since product development performance has been recognised as a key factor to overall business performance, a number of studies (e.g. Cooper, 1995, 1998; e.g. Dixon and Duffey, 1990; e.g. Little, 2005; e.g. Paulk, 1993) have been undertaken to determine best practices across industries. Most noteworthy among recent studies are Markham and Lee's (2013) publication delivering the results of the Product Development and Management Association's (PDMA) latest large-scale study from 2012[11], Cooper et al.'s (2004a, b, c) work reporting American Productivity and Quality Center's (APQC) study[12] on performance and best practices in PD as well as Kahn et al.'s (2012) article. The latter seeks to compliment previous large-scale studies through qualitatively examining what PD practitioners perceive as best practices as compared to what has been identified in previous quantitative investigations to constitute superior methods, techniques, processes, and activities. In addition to these academic studies, best practices can be easily accessed by companies through professional networks and associations, private research as well as contingent workers such as freelancers, temporary contract workers, consultants and other independent professionals who either have specialised in providing best practices or have been exposed to them thus accumulated relevant knowledge (Matusik and Hill, 1998).

It shall be noted at this point, that the remainder of this section only presents a part of those best practices which fall into the scope of this work as detailed in section 1.4. Hence, it will exclude

[11] The PDMA has investigated best practices in PD for over 20 years starting with its first research project published by Page in 1993. Since the first round, the PDMA has gradually expanded the breadth and depth of their studies and published the results of the second study in Griffin (1997) and of the third round in Barczak et al. (2009).

[12] APQC's latest study from 2010, published in detail in Edgett (2011), could not be accessed due to resource limitations posed to this work.

best practices discussing tools and practices on an operational level, such as Markham and Lee's (2013) portfolio management tools, social media tools to gather technical information and solve problems, market research tools, etc., as well as those which do not sit well with the core character of this work, including for example environmental sustainability aspects.

The best practices presented in the following only serve as examples at this point and will not be further discussed here. This section is intended to provide some context and pave the way for the integration of the findings of the best practice studies into the LPD framework discussed in chapter 3. Table 1 presents an excerpt of the identified 131 best practices while Appendix A provides a full account of Markham and Lee (2013), Cooper et al. (2004a, b, c) and Kahn et al.'s (2012) best practices relevant to this work. These will be incorporated into the discussion about the different elements of the framework presented in the next chapter to enrich the nascent LPD research with most recent findings from the broader and well-researched product development area.

Kahn et al., 2012	Markham and Lee, 2013 (2012 PDMA study)	Cooper et al., 2004a, b, c (2003 APQC study)
Strategy	**Strategy**	**Strategy**
Clearly defined and organisationally visible PD goals	Use specialised global PD tools	PD plays a role in business goals
The organisation views PD as a long-term strategy	Manage transnational transfer of ideas	Strategic arenas are defined
PD goals are clearly aligned with organisation mission and strategic plan	Manage multinational PD project teams	Clearly defined PD goals
PD projects and programmes are reviewed on a regular basis	Manage PD idea creation globally	Long-term commitment to PD
Opportunity identification is ongoing and can redirect the strategic plan real time to respond to market forces and new technologies	Develop global sustainable advantages	Strategic buckets of resources
	Leverage the firm's unique ability	Product roadmap in place
	Global collection of the voice of the customer	
	Leverage the firm's global assets	
	Manage the firm's global PD portfolio	
	Segment/select market, design positions	
	Leverage the firm's organisational culture	
	Global competition	
Climate and culture	**Climate and culture**	**Climate and culture**
Top management supports the PD process	Failure is understood	Climate supports entrepreneurship and innovation
Management rewards and recognises entrepreneurship	Managers establish objectives	Product champions recognised/rewarded
Cross-functional teams underlie the PD process	Objectives in performance review	PD team is rewarded/recognised
PD activities are intrafuntionally coordinated by formal and informal communication	Recruiting parameters in innovation potential	Employees understand PD process ideas-to-launch
	Effective communication externally	Open communication among employees across functions/locations
	Innovation and risk-taking are valued	Business climate is not risk averse - invest in future some projects
	Open to constructive conflict	No punishment for product failure
	Effective communication internally	Resources available for creative work
		Skunkworks and unofficial projects encouraged
		Time-off for creative work
		New product idea suggestions rewarded/recognised
		New product idea suggestion scheme in place
Process	**Development Tools**	**Process**
A common PD process cuts across organisational groups		Emphasis on pre-development homework
Go/no-go criteria are clear and predefined for each review gate		Project performance measurement
The PD process is flexible and adaptable to meet the needs, size, and risk of individual projects	*Author's note: Considers only operational aspects which lie beyond this resaerch's scope.*	Process performance measurement
The PD process is visible and well documented		Tough and demanding go/no-go decision points
The PD process can be circumvented without management approval		

Table 1: Excerpt of best practices in PD

While the sheer definition of best practices presented at the outset of this section suggests their generalisability by pointing out their superiority over other techniques, methods, processes, or activities, some researchers argue that they vary from company to company and evolve over time in the context of their business environment (Murray et al., 2002). Davidson et al. (1999) and Loch (2000) are more specific in concluding that, while it is important to have best practices in place, their success is mainly determined by how they are adapted to the individual company and its strategic innovation needs. Consequently, companies seeking to improve their development performance will likely be unable to reap the full rewards of best practices if they are not tailored towards their specific needs. Barczak et al.'s (2006) study's results provide further cause for caution when adapting best practices by concluding that for-profit organisation best practices might not be well-suited for non-profit organisations. Notable differences for non-profit companies include, but are not limited to, a stronger focus on the ideation process rather than concentrating on the subsequent phases such as concept development, project analysis, and business evaluation. Non-profit organisations also place a heavy emphasis on flexibility, the organisation's mission, the powerful influence of sponsors, and typically struggle in assessing their development programmes long-term success (Barczak et al., 2006).

2.3 Lean Product Development

This last section of the literature review discusses in detail LPD and its two core concepts. Initially, the first section discusses the evolution of LPD starting with its abstraction and translation into what became known as LPD and finishing with most recent developments of this management philosophy. The detailed review of LPD from its first identification by Western researchers to today's research frontiers paints a comprehensive picture of this nascent research area. After putting LPD into its historical context, the following section addresses the important concept of 'value', how it can be defined in product development and identified to serve its purpose in the LPD approach. The last part comprehensively reviews LPD's second core concept 'waste'. Since LPD focuses on maximising value and minimising waste, this last section goes into great detail on how the 'waste' concept has been translated into the PD environment and names a number of examples to make this concept more tangible in a knowledge-based context.

2.3.1 Evolution of Lean Product Development

As researchers and practitioners alike became increasingly aware of the superiority of Japanese manufacturing practices (see section 2.1.1 for more detail), their interest in Eastern product development techniques was sparked. Aware of the crucial influence of product development performance on competitiveness, Harvard researchers Clark, Chew and Fujimoto laid the basis for LPD with their 1987 (Clark et al., 1987) published study 'Product Development in the World Auto Industry' (Hoppmann, 2009). Their comparative study of 29 PD projects clearly concluded that Japanese automobile manufacturers outperform the competition in North America and Europe by far, especially in engineering hours and development lead time (Clark et al., 1987). Looking through a process lens, they required a smaller input to achieve a greater output and therefore must have a more effective and/or efficient PD process. The authors hypothesised the reason to lay in a strong supplier involvement in the development process, the role of a powerful authoritarian project manager steering multifunctional teams and the increased utilisation of overlapping development phases (Clark et al., 1987). Although some of these ideas have been recognised before, they were now aggregated under one common heading, Lean Product Development (Karlsson and Ahlström, 1996).

Driven by changes in the business environment, time-to-market was recognised as a rich and untapped source of competitive gain (Burt and Soukup, 1985; Smith and Reinertsen, 1991) which translated into a paradigm change in product development. Especially the Japanese automotive industry served as a benchmark industry for the new time-based research and development paradigm (e.g. Clark et al., 1987; e.g. Cusumano and Nobeoka, 1992; e.g. Stalk, 1988). Inspired by a number of studies on the innovation process (Rothwell, 1994), companies abandoned the often employed largely intuitive and frequently too unfocused push strategy and transformed their development processes into a number of manageable and repeatable activities aligned with organisational targets (Amidon Rogers, 1996; Research Technology Management, 2011).

Increasingly aware that Japanese companies were using their techniques to push their competitive advantage – time – (Burt and Soukup, 1985; Smith and Reinertsen, 1991; Stalk, 1988) and driven by the market forces, academia and industry set out to investigate the particulars of Japanese development practices. After Clark et al.'s (1987) initial attempt to explain Japanese PD productivity superiority, Womack et al. (1990) conducted further studies to identify the reasons for the significant performance difference between Lean and traditional PD. While the publication of 'The machine that changed the world' had a strong impact on

Western production methods, it also coined the term ‘Lean Product Development’ and identified four basic design methods that contribute to Japanese superior performance: a powerful project leader, fully committed team members, simultaneous development, and early communication (Womack et al., 1990). Subsequent research paid much attention on the concept of overlapping stages, simultaneous development as well as the identification and development of promising methods to shorten time-to-market (Hoppmann et al., 2011; Liker et al., 1996). Cusumano and Nobeoka (1992) exemplified the concept of overlapping development activities with the on average early start of Toyota’s advanced engineering (development of major functional parts) within only one month of starting the concept-generation phase and four months before product planning. Clark et al.’s (1987) hypothesis that overlapping development stages significantly affect lead times was confirmed by subsequent studies by Clark and Fujimoto (1989b), Cusumano and Nobeoka (1992) as well as Fujimoto, 1989 (Hoppmann, 2009).

The result was the expansion of the characteristics previously identified by Womack et al. (1990). Liker et al. (1996) and Ward et al. (1995), however, partly questioned the role of simultaneous engineering in Japanese PD since Toyota neither intensely communicated its development efforts with its suppliers nor collocated its teams. After experimenting with automating design processes (Ward and Seering 1989a, b) as well as conducting detailed investigations into Toyota’s PD practices, Ward et al. (1995) developed the concept of set-based concurrent engineering (Hoppmann, 2009; Hoppmann et al., 2011). The theory describes Toyota’s counter-intuitive approach of considering a broad range of possible designs and delaying certain decisions until empirical data allows for an informed decision. This approach, although looking wasteful at first sight, yields high efficiency and performance (Ward et al., 1995) and was an important impulse for researchers to revise and expand existing LPD concepts. A key development in subsequent years was the transition of the understanding of LPD as a mere set of tools to a coherent concept. Among the most significant concepts that emerged are those of Morgan and Liker (2006), Ward et al. (2007), Schuh et al. (2008b)[13] as well as Hoppmann et al. (2011). Table 2 lists the most established concepts and their core elements but without going into a detailed discussion of the single components.

LPD elements	Clark et al., 1987	Womack et al., 1990	Karlsson and Åhlström, 1996	Morgan and Liker, 2006	Brown, 2007	Ward, 2007	Hoppmann et al., 2011	Schuh, 2013
1	Strong Project Manager	Leadership	Supplier Involvement	Customer Value Definition	Use of Design Sets	Entrepreneurial System Designer	Strong Project Manager	Strategic Positioning
2	Supplier Integration	Teamwork	Simultaneous Engineering	Front-loading	Information and Process Flow	Teams of Responsible Experts	Specialist Career Path	Clear Prioritisation
3	Cross-functional Teams	Communication	Cross-functional Teams	Leveled Process Flow	Continuous Improvement	Set-based Concurrent Engineering	Workload Leveling	Roadmapping
4	Overlapping Phases	Simultaneous Development	Functional Integration	Standardisation	Process Monitoring	Cadence, Pull, Flow	Responsibility-based Planning and Control	Product Architecture Design
5			Heavyweight Team Structure	Chief Engineer System	Value Stream Mapping		Cross-project Knowledge Transfer	Product Range Optimisation
6			Strategic Management	Balance Functional Expertise and Cross-functional Integration	Standardisation		Simultaneous Engineering	Design Space Management
7				Technical Expertise	Concurrent Design		Supplier Integration	Value Stream Optimisation
8				Supplier Integration			Product Variety Management	Data Consistency
9				Continuous Learning and Improvement			Rapid Prototyping, Simulation and Testing	Multi Project Management
10				Build a Culture of Excellence			Process Standardisation	Innovation Controlling
11				Adapt suitable Technology			Set-based Engineering	Release Engineering
12				Communication				Continuous Improvement
13				Integrate Tools				

Table 2: Existing LPD frameworks and their elements

[13] Schuh et al.'s (2008b) work was later extended and the revised framework published in an article by their colleagues Krumm and Schittny (2013). The full framework in its last development stage along with its key concepts was subsequently published in Schuh (2013).

As Table 1 illustrates, the existing LPD frameworks differ significantly in their focus and scope (León and Farris, 2011). The lack of a generally accepted concept creates ambiguity in the comprehension of LPD, represents a severe obstruction for advancing this nascent research area (Hoppmann et al., 2011; Schuh et al., 2008a), and hinders practitioners in their implementation efforts (Hoppmann, 2009). In an attempt to solve this problem, Hoppmann et al. (2011) consolidated the most established frameworks in one overarching concept. Their research, however, bears a number of limitations. First and foremost, data was exclusively drawn from LPD literature without considering the rich and fruitful discussion centring around product development and innovation management or, more generally spoken, the wider product development research area. A first investigation in this direction has shown that there is a significant overlap in practices and techniques. Under consideration of the latest developments of the Lean concept, findings in these areas, such as the best practices presented in section 2.2.3, could provide an important input for the LPD research stream. Hoppmann et al.'s (2011) focus on LPD literature, however, links their study empirically to a rather small sample of a quite narrowly-defined population and excludes perspectives from the wider research and development community (Hoppmann et al., 2011). Further limiting the aforementioned study is its consideration of Schuh et al.'s (2008) framework which has undergone significant changes and developed into one of the most elaborate frameworks and has been published in its latest if not final stage in Schuh (2013). A second major limitation bears the research setting in which the study has been conducted. Although partly carried out at the well renowned MIT, Hoppmann et al.'s (2011) study was entirely based on Hoppmann's diploma thesis (Hoppmann, 2009) thus naturally constrained in its resources. Without questioning the quality of their work, it is the author's impression that the previously described task requires an academic investigation based on long-term considerations without the constraints of an in average six months diploma thesis. Or put differently, Hoppmann et al.'s (2011) exploratory study asks to be reconsidered on a broader basis and extended beyond its limitations. Therefore, current research urgently calls for a comprehensive comparison of existing concepts including perspectives from the wider PD research community and considering recent developments in the previously described Lean research area (Hoppmann et al., 2011; León and Farris, 2011). This call is answered by the first research question the work at hand seeks to thoroughly address.

In addition to the lack of a consensual framework, evidence suggests that many companies struggle to implement LPD (Hoppmann, 2009; León and Farris, 2011; Schuh et al., 2008b). Although the application of Lean practices to product development is increasingly focused by organisations since PD plays a key role in defining customer value and yields great potential for improvement in terms of time, cost, and quality, many companies have yet to find a systematic approach to LPD implementation (Hoppmann et al., 2011; Karlsson and Åhlström, 1996; León and Farris, 2011; Schuh et al., 2008b). The transferral of Lean Thinking into a highly complex and interwoven knowledge-based environment such as PD, however, is far more difficult than changing material-based production processes (Morgan and Liker, 2006). But apart from the inherent difficulties of such a transformation process, the reasons why practitioners struggle to implement Lean Thinking can be reduced to three main factors. Firstly, as mentioned previously, there is currently no consensual LPD framework. The availability of a number of frameworks that greatly differ in the number and kind of elements they consist of and the emphasis they are putting on the single elements creates much uncertainty among practitioners about the models' suitability for their business needs (León and Farris, 2011). Secondly, the relationships between the single LPD elements remain severely under-investigated (León and Farris, 2011; Hoppmann et al., 2011). Consequently, Hoppmann et al. (2011) urgently call for empirical research on the component interdependencies at a system level that would allow formulating general recommendations for an effective implementation order. The investigation into the interrelationships and interdependencies between the individual LPD elements constitutes the second gap this research is addressing.

And thirdly, except for Hoppmann's (2009) diploma thesis, there is no generalisable quantitative empirical study on the introduction of LPD. Existing approaches are mostly limited to general change management aspects (Kennedy, 2003) thus lack a sufficient level of detail or neglect the highly interwoven character of a LPD system. Furthermore, these implementation recommendations are often based on intuition as they were only treated as an add-on to the description of LPD elements or were built around best practices identified in case studies and thus lack generalisability (Hoppmann, 2009). And, to be remembered, all these implementation recommendations are solely tailored towards the individual understanding and interpretation of the LPD model and therefore specific to the corresponding model. The need, expressed by León and Farris (2011) as well as Hoppmann et al. (2011), to develop generalisable implementation recommendations based on an all-encompassing LPD framework, which has been uplifted by the input from the wider PD research area, and a sound understanding of inner workings of a highly-dynamic and tightly-interwoven LPD framework constitutes the third and last research objective this study is seeking to address.

The research at hand addresses these intrinsically tied three hindering factors by a thorough investigation based on a broad literature base and analysing with generalisable primary data collected using a questionnaire.

2.3.2 Value in Product Development

Product development spans across a range of functions and defines the gap between market opportunity and start of production (Browning, 2003). Its objective is to transform a large variety of ideas and expectations in a constrained environment into a marketable product (Radeka, 2013; Reinertsen, 1999). Under the pressure of today's business environment this must be achieved as cheaply and as quickly as possible (Ahmadi et al., 2001; Cooper, 1990; Sheu and Lee, 2011). In an effort to meet these requirements, scholars in the LPD research area suggest focusing on minimising waste (Hines and Rich, 1997; Haque and James-Moore, 2002; Haque, 2003; Oppenheim, 2004) or maximising value (Browning, 2000, 2003; Ward, 2007) to drive effectiveness and efficiency under the Lean paradigm in product development (León and Farris, 2011). Without taking such an absolute position, it can be argued that it does not really matter whether a company focuses on enhancing value or decreasing waste, as the result would still be the relative increase of value and the relative decrease of waste at the same time. Taking this thought a step further, it is probably the right mix of value enhancing and waste reducing activities that must be found to give consideration to the strongly varying organisational conditions.

Nonetheless, a company needs to deliver sufficient value relative to its competitors to have an edge in the marketplace (Radeka, 2013). Therefore an organisation needs a working definition of value to guide their efforts (McManus, 2005). The definition of value in product development, however, strongly varies across the literature[14] (cf. Chase, 2001). Common themes across these

[14] Chase (2001) discusses a range of definitions in detail.

definitions are customer orientation and reasonable resource employment. But the sole focus on the end customer has proven insufficient in a marketplace shaped by an increasing number of interest groups (Browning, 2000). Just as Lean has shifted its focus towards all key interest groups (see section 2.1.1 on Lean targets), stakeholder theory, which discusses and advocates 'legitimate interests of all appropriate stakeholders' (Donaldson and Preston, 1995, p.67), has left its mark in product development. Entering the challenging complex and often conflicting arena of multiple stakeholders in product development has proven beneficial for companies (Talke and Hultink, 2010; Wind and Mahajan, 1987). Although the incorporation of customers and other market issues has received much attention (Adams et al., 1998; Kahn, 2001; Moorman, 1995; Schuh et al., 2008b), the integration of the voice of stakeholders and how companies can deal with the tension that will arise from conflicting interests in the PD context remains severely under-investigated (Driessen and Hillebrand, 2013). Driessen and Hillebrand (2013), who are a notable exception, suggest that companies should systematically identify key stakeholders for product development, implement and use mechanisms to coordinate market and nonmarket stakeholder issues, and employ prioritisation principles which assure that issues are addressed accordingly. This process has to be constantly repeated as the composition of stakeholders and their idea of value constantly changes (Browning et al., 2002; Chase, 2001; Nightingale and Srinivasan, 2011; Slack, 1999).

After knowing what is expected from the final product, i.e. having defined value from the stakeholders' point of view, product development now has to bring this idea to life in the most effective and efficient way. Hereby, the dependencies among the individual activities within product development define a more or less rigid sequence (Burns and Stalker, 1961; Clark and Wheelwright, 1993; Nightingale, 2000). This network of activities forms a 'problem-solving and knowledge-accumulation process' (Browning et al., 2002, p.444) in which one activity creates the input for the subsequent activity (Eppinger et al., 1994). Unlike in manufacturing, in product development value is added by creating and meaningfully processing information that in the end will amount to the ‘recipe’ for the final product; the creative and iterative process culminating in a feasible, marketable, and manufacturable product which addresses stakeholder needs while coping with an increasingly dynamic business environment. The key to a Lean product development process is to holistically optimise the productivity of all value creating activities which, among other things, is a function of the quality of information being used and created (Browning, 2003).

2.3.3 Waste in Product Development

Negele et al. (1999) characterise product development processes as dynamic, iterative, innovative, creative, closely coupled, interdisciplinary, very parallel, communication and planning intensive, risky, and uncertain. Consequently, there is a large array of factors that might affect the successful outcome of a PD project. Taking the Lean perspective, performance is to a large degree directly depending on waste (Hines and Rich, 1997; Haque and James-Moore, 2002; Haque, 2003; Oppenheim, 2004; Pessôa et al., 2008) and its presence a symptom of one or more processes offering potential for improvement with regard to effectiveness and efficiency (Oehmen and Rebentisch, 2010). According to a number of studies, predominantly conducted in the aerospace and defence industry, 60-90% of the total charged time is being wasted, with around 60% idle tasks at any given time (Browning, 1999, 2000; Chase, 2001; Graebsch et al. 2007; Joglekar and Whitney, 1999; McManus, 2005; Millard, 2001; Oppenheim, 2004). While some of these studies show lacking scholarly rigour, they are sufficiently consistent to offer a comfortable degree of confidence (Oppenheim, 2004).

Regardless of the exact number of wasted time, it is apparent that product development has much to gain by specifically addressing waste.

In its core, waste in PD is no different to waste in any other function: it is ‘all elements […] that only increase cost without adding value’ (Ohno, 1988, p.54). While this overarching notion holds true, there are fundamental differences between material-based processes such as manufacturing and knowledge-based processes such as PD. In production, raw materials and parts are physically transformed whereas in product development it is predominantly the meaningful processing of information that creates value (Oehmen and Rebentisch, 2010; Ward, 2007). In respect of this intrinsic difference, a number of researchers have applied themselves to investigating the Lean concept of waste in the PD context (e.g. Anand and Kodali, 2008; e.g. Bauch, 2004; e.g. Graebsch, 2005; e.g. Graebsch et al., 2007; e.g. Kato, 2005; e.g. McManus, 2005; e.g. Millard, 2001; e.g. Morgan 2002; e.g. Morgan and Liker, 2006; e.g. Pessôa et al., 2008; e.g. Pessôa et al., 2009; e.g. Slack, 1999; e.g. Ward, 2007). Some researchers directly applied Ohno’s (1988) seven waste categories to product development (e.g. Fiore, 2005; e.g. McManus, 2005; e.g. Millard, 2001; e.g. Morgan and Liker, 2006; e.g. Womack and Jones, 1996b), whereas others adopted this material-based taxonomy and extended it by various categories (e.g. Bauch, 2004; e.g. Kato, 2005; e.g. Pessôa et al., 2009; e.g. Slack, 1999) or even went as far as completely replacing them (e.g. Morgan, 2002; e.g. Ward, 2007). Some typical examples are presented in Figure 12. Overall, the product development waste typologies do not deviate from Ohno’s (1988) way of thinking about waste but reflect the particularities of a knowledge-based process (Pessôa et al., 2008).

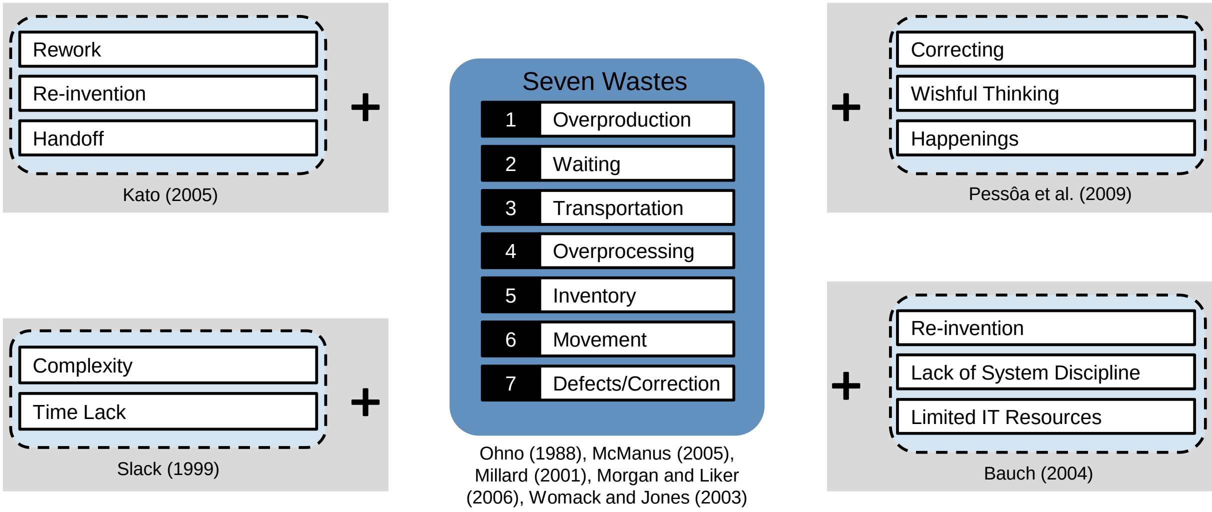

Figure 12: Example of waste categories in product development

In an attempt to condense previous work in this field, Oehmen and Rebentisch (2010) subsumed existing waste categories in eight different classes in their extensive 2010 study. Although some authors (e.g. Mascitelli, 2007) doubt the usefulness of such categories as every company offers a unique set of challenges, they are often perceived as helpful means to challenge established ways of thinking and sharpen the awareness for suboptimal conditions. Oehmen and Rebentisch's (2010) most recent work in this area drew on an extensive literature review by Pessôa, Serring and Rebentisch (Pessôa et al., 2008; Pessôa et al., 2009) and developed a new taxonomy which classifies waste into 'overproduction of information', 'over-processing of information', 'miscommunication of information', 'stockpiling of information', 'generating defective information', 'correcting information, waiting of people', and 'unnecessary movement of people'. For a more detailed discussion of waste in product development and some detailed examples refer to the work of Bauch (2004), Graebsch (2005), Graebsch et al. (2007), Oehmen and Rebentisch (2010), and Slack (1999).

2.4 Concluding Remarks

The foregoing literature review has been organised in three sections, Lean, product development, and Lean Product Development, to provide a clearly structured and detailed discussion of the theoretical concepts which have a direct impact on the remainder of the work or have been considered vital for a deep reaching understanding.

The discussion centring around the evolution of Lean has shown how companies in post-war Japan were forced to make the most of what they had. The adverse market conditions of an economy ridden by scarcity and Toyota's resolve to compete in the automotive industry on a global scale gave rise to the Toyota Production System. After many years of development, this implicit system has gained Toyota a significant competitive advantage which has firstly been recognised by Western academics and practitioners in the late 70s and early 80s. Intensive studies of Toyota's practices led to the gradual abstraction and adaptation of TPS and became widely known as Lean or Lean Production. Since its widespread adoption in the Western economies, Lean has spread beyond the automotive industry and further increased its scope and reach. These developments have changed the face of Lean which, amongst others, is reflected in its changing target dimensions, evolving principles, and developing concepts of value and waste. While the principles of modern day Lean reflect its status of a company-wide system with a far deeper reach and broader scope compared to its initial interpretation (cf. Womack et al., 1990), the target dimensions have drifted away from its sole focus on waste elimination and included value creation as well as eliminating organisational misalignments and securing strategic objectives. Simultaneously, the idea of value as understood from the end customer's point of view has developed into a stakeholder affair and now seeks to meet the demands of not just the customers but also the shareholders including workforce, partners, and other interest parties of significant stance. In the course of Lean's adoption in industries outside the automotive industry, the scope of waste has grown beyond the seven wastes to fulfil a changing set of requirements. The entire discussion on Lean intended to paint a comprehensive picture of this widely-adopted approach to lay a firm foundation for the inquiry into its offspring, LPD, provide a point of reference and comparison, and to contextualise the environment of the research object under investigation.

The subsequent section on product development shifted the focus away from the material-based production environment and discussed the internal as well as external factors which have shaped PD. In an attempt to lead a comprehensive discourse on today's managerial practices, a historical approach was taken to chronologically discuss the changes in business environment and how companies have adapted to cope with a constantly evolving market. Throughout this discussion, there were numerous implicit touching points with LPD such as the adoption of the time-based paradigm in the 70s, the horizontal integration of all involved functions, or the vertical integration of customers, suppliers, and distributors. After having arrived at today's main market forces and how they have shaped contemporary PD practices, the emphasis was placed on modern development processes and more precisely the detailed discussion of the Stage-Gate® process, spiral model, and development funnel. While the discussion of contemporary managerial development practices and techniques yielded a point of comparison and contextualised Lean development practices discussed at a later point, the review of the most established development processes lays the foundation for a number of subsequently addressed concepts such as concurrent engineering, set-based design, and front-loading. The section on general product development aspects concluded in identifying a number of large-scale best practice studies which will inform the later proposed LPD framework thus enrich the nascent LPD research area with findings from the wider PD environment.

The chapter concluded by focusing on the object of research – Lean Product Development. The discussion on Lean practices in PD starts with the realisation of Western researchers and practitioners that Japanese development practices yield superior performance. Considering the evolution of Lean as well as the history of Western development practices, the discourse on LPD is well-embedded into its point of origin, Lean, and the context it will be placed in, Western product development. It should be highlighted that Toyota did not develop LPD as a self-contained system in its own rights but simply pushed the ideas and ideals which have shaped TPS throughout the entire company. The strong emphasis on emulating Japanese production practices, however, has left LPD largely unnoticed. Once the putative panacea of Lean Production started to spread and companies realised that Japanese development practices outperformed their own innovation efforts, the West started detailed investigations into LPD. As the discussion on the history of PD has demonstrated, Japanese development practices have been studied and adapted by Western academics and practitioners prior to the first dedicated LPD studies, but after the success of Lean, LPD became a system and later an area of research in its own right. Similar to Lean, LPD was initially comprehended as a collection of loosely connected methods and tools which, as the understanding grew, gradually became a highly-interwoven, wide and deep reaching system. This development gave rise to a number of interpretations of what constitutes a LPD framework which consequently hindered many companies seeking to embrace Lean practices in PD and generally posed a major obstacle in this nascent research area. At this point, the research at hand seeks to advance the current research frontier by subsuming existing approaches into an all-encompassing framework which further draws on the fruitful discussions and findings from the wider PD research area and including the best practice studies presented earlier in the chapter. After the proposal of this comprehensive LPD framework in the next chapter, the work at hand sets forth to empirically investigate external influence factors as well as internal relationships to deepen the understanding of its inner dynamics and pave the way for implementation guidelines which aim at supporting companies struggling to introduce LPD in their product development environment. Addressing these three previously identified objectives will close a number of gaps which have been outlined and discussed in detail throughout the discussion on the history of LPD. Subsequently, the core concepts of value and waste are transferred from the material-based production environment into the intricate field of PD to heighten the awareness of what LPD is seeking to leverage and respectively trying to eliminate thus deepening the understanding of the driving logic behind LPD.

Equipped with a firm understanding of the theoretical background of Japanese development practices, conscious of the context in which LPD was discovered and will be placed in, and aware of the current research frontier, the next chapter will mainly focus on addressing the first research question and propose a comprehensive LPD framework.

3 Lean Product Development Framework

The following chapter is divided into three parts which first present and discuss the existing frameworks and the employed methodological approach with which they are combined into the new proposed LPD framework discussed in much detail in the second part of the chapter. Before the concluding remarks at the end, the chapter presents the interrelationships between the elements of the proposed LPD framework which have been extracted from contemporary LPD literature.

3.1 Theoretical Framework Development

In the following two sections, the basis will be laid for the development of the LPD framework. At the outset, the existing LPD frameworks will be discussed in their order of publication with regard to the research context in which they have been developed in, the data they are based on, and some higher level features. This section will refrain from a discourse on the individual elements of the frameworks since they will be detailed when describing the proposed framework later in this chapter. After the existing LPD frameworks have been presented, the subsequent section will explain the chosen methodological approach to combine these frameworks into a new coherent whole, while considering the latest developments in the wider PD research area.

3.1.1 Existing Frameworks

The preceding discussions on Lean, product development, and Lean Product Development have shown a number similarities, especially with respect to their common historical roots but also highlighted fundamental differences between the material-based production environment where Lean has been discovered by Western researchers and the far more uncertain and iterative knowledge-based environment of PD and LPD. Researchers, such as Morgan and Liker (2006), Nightingale and Srinivasan (2011), as well as Schuh (2007) have recognised the general applicability of the Lean principles, the guiding philosophy underpinning the Lean framework, while realising that their application to PD needs to be tailored towards the special needs and requirements of its knowledge-based context. Consequently, the methods and tools which support Lean efforts and targets in production cannot be blindly transferred into PD but must be reconsidered and abstracted on a higher level. As a result, most authors have chosen to investigate LPD at Toyota, other Japanese companies, such as Honda and Nissan, as well as at those companies which have been heavily influenced by the former (Hoppmann, 2009). The currently existing frameworks of LPD which form the basis for the inclusive framework the work at hand seeks to bring forward, will be discussed in the order of their publication in the remainder of this section.

The first work on LPD, although not coined this way yet, has been made public by Clark et al. (1987) in an academic journal in 1987. Their study sought to identify international differences in product quality and productivity in the introduction of new products by investigating 20 automobile companies in Japan, Europe, and the United States. Within these companies, Clark et al. (1987) compared 29 product development projects by means of observing, interviewing, and surveying hundreds of people over a seven-year fieldwork period. Their findings were unambiguous: the Japanese companies under investigation outperform their competitors in

Europe and the United States in lead time, the time it takes from project launch to market introduction, and engineering hours spent on development projects. Put in concrete numbers, the authors have found that automobile companies in Europe and the United States require on average around 62 months and roughly 3.5 million engineering hours to complete a development project while their Japanese competitors launched a comparable product in just under 43 months using only 1.16 million engineering hours. Put differently, Japanese companies developed and launched an automobile 31% faster while relying only on around a third of the manpower. In the automobile industry in which development costs are relatively high and amount to a substantial resource commitment, these performance differences provide a substantial competitive advantage. Further investigation into these findings have led the authors to conclude that the Japanese PD productivity superiority can be largely attributed to the integration of their supply base and the way development projects are organised and managed. Clark et al. (1987) further detail the latter stating that the most successful Japanese projects employed a heavyweight project manager leading cross-functional development teams which intensively communicate. They also recognised that Japanese companies develop their products in overlapping stages rather than largely pushing a development project through a number of sequential phases like their Western competitors at that time. The importance of overlapping stages, or simultaneous or concurrent engineering as it will be known as later, has been confirmed by further analyses of the same data set (Clark and Fujimoto, 1989a, b) and additional studies (Cusumano and Nobeoka, 1992; Fujimoto, 1989).

The next investigation into LPD was launched in 1985 with the foundation of the International Motor Vehicle Program when Clark et al. (1987) were still out in the field collecting data. Womack et al. (1990) based their publication on a five-year study which set out to investigate the entire range of activities necessary to manufacture an automobile. This task was taken up by an international team of 55 researchers who have published over 116 research monographs based on a rich data set compiled in interviews, observations, and questionnaires. Womack et al. (1990), the three programme leaders, have drawn on this data as well as the aforementioned publications and made their interpretation available in their ground-breaking book 'The machine that changed the world' in 1990. Although the authors have focused much of their attention on the manufacturing aspects of Lean, they have also devoted 33 pages to various aspects of LPD. Although more detailed, their findings are largely identical to Clark et al.'s (1987) and contribute Japanese development performance superiority to the large-project leader[15] who assembles and manages a small cross-functional team which communicates intensively and commits to formal pledges to avoid conflicts about what has been agreed upon earlier in the process. Congruent with Clark et al.'s (1987) findings, the authors also contributed Japanese performance advantage to executing development processes simultaneously rather than employing a sequential process model. Womack et al. (1990) further identified Japanese companies to attribute a lot of manpower to the early stages of PD, so the large-project manager can confront the most difficult trade-offs early in the project (Womack et al., 1990).

In subsequent years, Karlsson and Åhlström (1996) conducted a study into a mostly European-based company producing electrical and mechanical office equipment. The authors observed and facilitated the company's transitioning efforts to a LPD system in four development projects over the course of more than two years. Based on their research background in industrial engineering and Lean, Karlsson and Åhlström (1996) identified various interrelated

[15] The large-project leader, called *susha* in Japanese, is merely another term for Clark et al.'s (1987) heavyweight project manager and can therefore be used synonymously.

elements of LPD which they introduced to the company in weekly seminars and workshops. After injecting academic knowledge into the transitioning process, the authors collected data through interviews, direct observation, and content analysis of development project documents. The largely qualitative data formed the basis of their own, newly-developed interpretation of a LPD framework – a heavyweight project manager, cross-functional teams, simultaneous engineering, supplier involvement, functional integration rather than coordination, and the strategic management of the project (Karlsson and Åhlström, 1996). Essentially, Karlsson and Åhlström (1996) extended Clark et al.'s (1987) as well as Womack et al.'s (1990) frameworks by the notion of systematically aligning development projects with a company's long-term strategic goals thus rallying the whole company behind a common cause in striving towards strategic goals.

Following Womack et al.'s (1990) publication, academia was far more interested in understanding and abstracting the Toyota Production System, which became known as Lean (Production), than investigating Japanese development practices (Morgan and Liker, 2006). Hence, research into LPD stagnated. Nevertheless, an array of researchers built on the aforementioned studies and focused on understanding the previously identified elements of LPD in an effort to close the development performance gap between Japanese companies and their Western competitors. Next to communication routines as well as cross-functional integration, a lot of attention has been focused on supplier integration and concurrent engineering, the simultaneous execution of development activities. The single elements of an LPD framework, however, will not be discussed here, but throughout the following section 3.2 when the proposed LPD framework is laid out in detail.

The publication of the next LPD framework marked an important stepping stone towards truly understanding the sum of Japanese practices which have been labelled LPD by Western academics. More than 15 years after 'The machine that changed the world' has delivered the undeniable message to a wide audience of researchers and practitioners that Japanese practices yield better performance both in manufacturing as well as product development, Morgan and Liker (2006) published 'The Toyota product development system' in 2006. Building on the extensive research base of their colleagues at the University of Michigan and after more than two years in the field, Morgan and Liker (2006) were the first to elevate Japanese development practices to a holistic system of interrelated elements. In more than 1000 hours of interviews conducted at twelve different sites in Japan and the United States, the authors compared Toyota's development system to the development practices of one of the Big Three[16]. Their findings culminated in thirteen principles which form their sociotechnical LPD framework subdivided into three categories – people, process, and technology. Morgan and Liker's (2006) extensive publication attributed five principles alone to the 'people subsystem', as the authors refer to their umbrella term under which they allocate the different principles. The authors' heavy emphasis on the 'people subsystem' extends previous frameworks far beyond heavyweight project managers and cross-functional teams and now integrates central aspects of today's LPD frameworks, such as learning and knowledge transfer, continuous improvement, and building a culture in which LPD can thrive. Morgan and Liker (2006) also highlight the importance of front-loading, i.e. shifting much of the PD effort to the outset of a development project (a detailed discussion follows in section 3.2.5), while Womack et al. (1990) merely briefly mentioned this concept in their 'teams' category. Throughout his time in

[16] In the United States, the major automotive companies General Motors, Chrysler, and Ford are often referred to as the Big Three. Similarly, the same label has been extended to the major Japanese companies Toyota, Honda, and Nissan as well as Germany's Big Three, Volkswagen, BMW, and Daimler.

the field, Morgan also adapted value stream mapping, a tool crucial for identifying value-adding activities and exposing wasteful aspects of a process, to the PD environment thus paved the way for a systematic evaluation of development processes. Crucially, Morgan and Liker (2006) also put heavy emphasis on the importance of standardisation as the foundation of continuous improvement, knowledge transfer, speeding up non-value adding activities, and overall foster predictability and reliability of reoccurring tasks which lend themselves to standardisation.

One year later, in 2007, Brown published the findings of an independent study into over 400 manufacturing companies. The online survey was complemented by additional telephone interviews to probe into the following three categories: the degree to which Lean has been deployed in PD, future plans to improve PD using Lean principles, and perceived benefits of already implemented LPD elements. Brown's (2007) study, which largely drew on North American respondents, aimed at identifying best practices to lever LPD in an effort to provide an accessible, practitioner-friendly framework for LPD. It should also be highlighted that Brown (2007) extended previous studies, with the exception of Karlsson and Åhlström's (1996) work which investigated an office equipment company by including other manufacturing industries such as aerospace and defence, industrial equipment, and consumer electronics. While the study yielded interesting results by benchmarking various aspects of companies' LPD efforts, it identified a number of best practices which are stated to have a large impact on LPD performance, and proposed the easily-accessible PACE framework[17], it did not significantly contribute to previous LPD frameworks in terms of depth and scope.

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[17] Brown's (2007) PACE framework combines external and internal Pressures, strategic Actions, a company's organisational Capabilities, and technological Enablers in one framework.

In the same year, Ward (2007) published posthumously ‘Lean Product and Process Development’, a book based on his manuscript from 2001. In his work, Ward (2007) aggregates his extensive knowledge and describes LPD to be based on four principles – entrepreneurial system designer, teams of responsible experts, SBCE, and cadence, pull, and flow. These four ‘cornerstones’ of Ward’s (2007) LPD framework, combined with what the author considers the major pieces of the value stream – organisational structure, manufacturing system, and suppliers – are rigorously aligned towards the customer. In his framework, Ward (2007) not only presents the reader his detailed understanding of set-based concurrent engineering, a concept he has pioneered in his earlier publications (e.g. Ward and Seering, 1989a, b; e.g. Ward et al., 1995), but also reintroduces the concepts of cadence, pull, and flow. Pull and flow are two of the original Lean principles advocated by Womack and Jones (1996b) which now surface again after their first appearance in Morgan and Liker’s (2006) LPD framework, to highlight the importance of a company’s internal capability to quickly and flexibly react to a downstream pull (work is pulled within the company by a downstream need rather than scheduled by a third party) and to level the workload and smoothen the workflow in order to avoid over- and underutilisation of resources and create a predictable process. In addition, development projects are staggered to establish cadence and further support a company’s effort to level the workload.

Building on Hoppmann’s M.Sc. thesis written at the University of Braunschweig in collaboration with the MIT (Hoppmann, 2009), Hoppmann et al. (2011) published a framework comprising of eleven elements in 2011. The framework as well as its limitations have been previously discussed in detail in section 2.3.1. In short, Hoppmann et al. (2011) build on the quantitative survey conducted during Hoppmann’s (2009) M.Sc. thesis and established their LPD framework by exclusively focusing on LPD literature published prior to 2009. In addition, Hoppmann et al. (2011) extended the LPD knowledge base by probing into the relationships between the single elements of their LPD framework.

The most recently published framework considered for the LPD framework proposed in this work was published by Schuh in 2013. Together with his colleagues from the RWTH Aachen University in Germany, Schuh has investigated LPD practices for more than a decade and is counted among the pioneers of LPD in Germany. Schuh's (2013) LPD framework is based on the broad knowledge base established at the RWTH Aachen University over the years and the studies conducted during this time. Most notably among the studies is the 2007 survey of 143 manufacturing companies in Germany (Schuh et al., 2007) which has laid the foundation for their LPD framework first published at a conference in 2008 by Schuh et al. (2008b). Since then the framework has been continually developed further by both Schuh's colleagues from the RWTH Aachen University and the consulting firm Schuh & Company founded in 2001. This conjoint effort has culminated in Schuh's (2013) book which describes his LPD framework in much detail and backed up by numerous examples. Analogue to Morgan and Liker (2006), Schuh (2013) has chosen to subdivide his LPD framework consisting of 12 principles into four categories – clear prioritisation, early structuring, easy synchronisation, and secure adaptation. Within each of these four fields of activity there are three principles which are aligned with the original Lean principles defined by Womack et al. (1996b).

The aforementioned eight frameworks form the basis of the in section 3.2 proposed LPD framework. The following Table 3 lists and contrasts the previously introduced frameworks and illustrates their significant difference in content and scope by listing their individual elements. The frameworks are organised in the order of their publication from the earliest on the left hand side to the most recent on the far right. Comparing the amount of elements which to a certain extent offer an impression of their comprehensiveness and considering that Ward's

(2007) publication is based on his 2001 manuscript, it is apparent that the LPD frameworks have increased in their scope over the years. Morgan and Liker's (2006) framework represents a notable exception to this phenomenon. This increase of elements and rising complexity of the LPD frameworks might be attributed to a growing understanding of Japanese development practices and the system in which those practices are embedded.

LPD elements	Clark et al., 1987	Womack et al., 1990	Karlsson and Åhlström, 1996	Morgan and Liker, 2006	Brown, 2007	Ward, 2007	Hoppmann et al., 2011	Schuh, 2013
1	Strong Project Manager	Leadership	Supplier Involvement	Customer Value Definition	Use of Design Sets	Entrepreneurial System Designer	Strong Project Manager	Strategic Positioning
2	Supplier Integration	Teamwork	Simultaneous Engineering	Front-loading	Information and Process Flow	Teams of Responsible Experts	Specialist Career Path	Clear Prioritisation
3	Cross-functional Teams	Communication	Cross-functional Teams	Leveled Process Flow	Continuous Improvement	Set-based Concurrent Engineering	Workload Leveling	Roadmapping
4	Overlapping Phases	Simultaneous Development	Functional Integration	Standardisation	Process Monitoring	Cadence, Pull, Flow	Responsibility-based Planning and Control	Product Architecture Design
5			Heavyweight Team Structure	Chief Engineer System	Value Stream Mapping		Cross-project Knowledge Transfer	Product Range Optimisation
6			Strategic Management	Balance Functional Expertise and Cross-functional Integration	Standardisation		Simultaneous Engineering	Design Space Management
7				Technical Expertise	Concurrent Design		Supplier Integration	Value Stream Optimisation
8				Supplier Integration			Product Variety Management	Data Consistency
9				Continuous Learning and Improvement			Rapid Prototyping, Simulation and Testing	Multi Project Management
10				Build a Culture of Excellence			Process Standardisation	Innovation Controlling
11				Adapt suitable Technology			Set-based Engineering	Release Engineering
12				Communication				Continuous Improvement
13				Integrate Tools				

Table 3: Existing LPD frameworks and their elements

3.1.2 Framework Development

The framework proposed in the next part of this chapter does not offer a literature review of the LPD research area in its traditional sense. Baines et al. (2006) as well as León and Farris (2011) have published detailed literature reviews of this nascent research field, outlined its current trajectory, and proposed a number of opportunities for future research. The focus here lies, as previously stated, on the consolidation of existing frameworks and integration of their elements into a coherent whole which is further complemented by best practices and the fruitful discussion from the wider product development research area as discussed in section 2.2.3. Thus the remainder of this chapter effectively sets out to answer the first out of three research questions posed in section 1.3. After discussing existing frameworks in the preceding section, this part of the chapter details the methodological approach taken to create the LPD framework.

Within the limitations of this work, the following analysis cannot scrutinise the Lean principles underlying the individual frameworks and their elements nor the data and logic which have led to their development. It is therefore acknowledged that this investigation heavily relies on the quality of the work it is based on and that, by combining the previous work in this field into a new LPD framework, it merely brings together the established knowledge base and only extends it by answering the first research question through including findings and best practices from the wider PD research area. It shall be highlighted, however, that the consolidation of the LPD research into the following framework, its enrichment with the findings identified in the best practice studies presented in section 2.2.3, and the inclusion of the dynamic PD research area is considered by Hoppmann et al. (2011), who has limited his framework to LPD literature exclusively, as well as León and Farris (2011), who have published the most recent literature review of this research area, to be an important step towards developing a coherent theory of LPD.

This part of the study employs a content analysis and applies it to the LPD publications which have been previously discussed and are listed in Table 3 listed to systematically filter and aggregate data from qualitative information (Neuendorf, 2002). The literature proposes, depending on the objective behind the approach, different ways of conducting a content analysis. Since the analysis aims at extending the base of LPD theory, an approach found in grounded theory was considered appropriate in this context (Charmaz, 2006; Strauss and Corbin, 1998). Grounded theory has quickly become a widely-employed theoretical framework for analysing qualitative data (Bryman and Bell, 2011). Strauss and Corbin (1998, p.12), who have pioneered grounded theory, define it as ‘theory that was derived from data, systematically gathered and analysed through the research process. In this method, data collection, analysis, and eventual theory stand in close relationship to one another’. To allow the systematic analysis of the large amount of data contained in the presented eight LPD frameworks, this approach suggests to code the data during the collection process, divide it into concepts, classify it, and translate it into a new framework (Corbin and Strauss, 1990).

The work at hand tries to largely free itself from the conceptual boundaries set by previous LPD frameworks and the definition of their elements by inductively approaching the eight primary sources. The inductive approach is chosen since existing frameworks greatly vary in their focus, the content covered, and scope in terms of number of elements (León and Farris, 2011). In other words, since there is no established theory and valid measurements which can be tested by deductively testing hypotheses, literature recommends to inductively approach the data without preconceived categories (Saunders et al., 2009). Chinn and Kramer (2003) as well as Shiu et al. (2009) broadly describe the inductive approach to content analysis as systematically moving from specific items and statements to broader, more general themes and categories. In an effort to approach the large amount of qualitative data provided by the eight primary sources in a methodologically sound manner, this work follows the tried and tested approach to inductive qualitative content analysis described in various publications on research methods (c.f. Bryman and Bell, 2011; c.f. Elo and Kyngäs, 2008; c.f. Franzosi, 2008; c.f. Krippendorff, 2013; c.f. Neuendorf, 2002) and outlined in the following.

In the first phase, what Elo and Kyngäs (2008) call the preparation phase, a unit of analysis is selected. The unit of analysis can range from a single word to sentences and whole themes (Bryman and Bell, 2011). Due to a lacking measurement framework and the diverse character of themes and concepts under investigation, the identification of single words is likely to result in a highly-fragmented dataset (Graneheim and Lundman, 2004). Single words are therefore deemed as a too narrow unit of analysis not best suited for the content under investigation. Instead, a more interpretative approach is taken to investigate the thematically clustered data. Hence, the unit of analysis is selected to be statements consisting of one or more sentences which describe an aspect, a characteristic, or a feature of an LPD element. To avoid putting the identified statements into the prescribed categories by the individual authors, the statements are separated to reflect only individual aspects, characteristics, or features of LPD elements.

In the next phase, the data as a whole needs to be systematically organised to prepare the final stage, its analysis. The organisation is conducted in five steps as proposed by Elo and Kyngäs (2008): the data needs to be openly coded, the identified headlines are then collected on a coding sheet, grouped to collapse the headlines into themes, which are subsequently categorised into broader and more general groups, and finally abstracted to formulate main categories representing the individual LPD elements. The first step of open coding aims at breaking down the large amount of qualitative data into smaller, more manageable segments. Throughout this process the relevant raw statements in form of quotes, are extracted from the sources and freely labelled without concern for the categories' further usage. The individual statements might be coded with one or multiple labels to keep an open mind when analysing the data and to stay clear of any preconceived categories (Benanquisto, 2008). Subsequently, the collected quotes are compiled in a coding sheet which provides an overview of the defined labels and forms the basis for the following abstraction process during which these headlines are grouped, categorised, and further abstracted if necessary. Burnard (1991, p.462) breaks down the aim behind the abstraction process to the reduction of the amount 'of categories by 'collapsing' some of the ones that are similar into broader categories'. This step is repeated until a sensible and workable level of abstraction has been reached (Burnard, 1991). Dey (1993), however, advises to exercise caution since creating higher order categories is not just about collapsing labels into groups, but also about judging when classifying which statements or smaller order groups belong together and which do not. Hence, great care needs to be taken when defining higher order groups to avoid the caveats of using pre-defined categories. Once a satisfactory and reasonable level of abstraction has been reached, the individual categories are prepared to be analysed and, in this case, to be critically discussed in the LPD context and wider PD literature and to be moulded into a LPD framework.

On an operational level this means that the eight publications listed in Table 3 serve as the primary source for the LPD framework. The choice of primary sources is, with the exception of Kennedy's (2003) publication, based on Hoppmann et al.'s (2011) study on which this work is partially building on. Hoppmann et al.'s (2011) sample choice has been repeatedly reviewed and deemed suitable since it does include all published LPD frameworks which are empirically well-grounded and developed using the scientific method (see section 1.1 for publications which have not been included). The only exception constitutes Kennedy's (2003) work which has been excluded after careful consideration since it does not notably set itself apart from Ward (2007) on which Kennedy (2003) has based the technical part of his publication on. In addition to its redundant content, Kennedy's (2003, p.5) work is largely based on his 'interactions with many people dedicated to improving product development methodologies'. In other words, Kennedy's (2003) work is heavily influenced by Ward (2007), who has personally mentored him, and predominantly based on his experiences at Texas Instruments and overall lacks the empirical base to be considered in the work at hand. It should also be highlighted that while Hoppmann et al. (2011) use Schuh et al.'s (2008b) conference proceedings as a primary source, the framework proposed in the next part of this chapter integrates Schuh's (2013) most recent and far more detailed publication[18] on LPD. The publications considered as primary sources are thoroughly scanned for quotes, consisting of one or more sentences, describing the various aspects, characteristics, and features of potential LPD framework elements. Throughout this process, a total number of 267 quotes ranging from one to five sentences have been compiled and documented. These quotes have been classified using 19 labels which in turn have been carefully collapsed into nine categories (see Table 4). Due to the relatively low number of labels and the low level of abstraction needed to achieve a reasonable amount of higher order categories, the process of grouping, categorising, and further abstraction has been executed in one pass.

Table 4 summarises the previously mentioned 19 labels, comments on the nature of statements they consider, and illustrates in which LPD elements they have converged in. As outlined by Dey (1993), the creation of higher order categories requires careful judging since it involves a qualitative thus subjective process step during which the individual labels are assigned to

[18] 'Lean Innovation' by Schuh has been published in 2013 and is currently only available in German language.

groups. In most instances such as the grouping of ‘organisational structure’, ‘career path’, and ‘motivation’ into the LPD element ‘teams’ or the consolidation of ‘supplier integration’ and ‘outsourcing’ into the framework component ‘supplier integration and relationship’, the abstraction process was clear without ambiguity. Furthermore, the unique character of established and well-published on concepts such as the ‘strong project manager’, ‘concurrent engineering’, ‘set-based design’, as well as ‘continuous improvement’ played an important role in unambiguously forming well-defined LPD elements. On close inspection of the individual labels and content of the statements they cover, only ‘quality’ and ‘standardisation’ have been identified to be attributable to either ‘process management’ or ‘product variety management’. The literature’s strong focus on process standardisation as well as assurance and promotion of quality through procedural means, however, tipped the case in favour of ‘process management’. This is not to say that statements which have considered quality and standardisation aspects of ‘product variety management’ are disregarded. In both cases, in which a clear-cut allocation could not be made, the labels have been allocated to the LPD element they predominantly cover with its content (‘process management’) while the individual statements which sit better with ‘product variety management’ have been considered there.

Number	LPD Element	Label	Comment
1	Strong Project Manager	Project Management	Details all aspects of managing, organising, and coordinating a Lean development project.
2	Teams	Organisational Structure	Incorporates structural considerations such as cross-functionality, integration, and colocation of development teams.
		Career Path	Describes strategies and practices surrounding recruitment, training, and career advancement in Lean companies.
		Motivation	Includes motivational aspects w hich bind development team members to the project and foster commitment.
3	Concurrent Engineering	Concurrent Engineering	Considers all aspects of parallel processing.
4	Supplier Integration and Relationship	Supplier Integration	Concentrates on Japanese supply chain considerations including size of supply base, nature of relationship, integration into development project, and contractual pracitices.
		Outsourcing	Contains outsourcing practices and guidelines such as black box engineering.
5	Set-based Design	Front-loading	Accommodates practices surrounding the idea of shifting development efforts to the early stage of a development project.
		Set-based Concurrent Engineering	Focuses on all aspects of the core concept SBCE pioneered by Ward et al. (1995).
6	Communication and Know ledge Transfer	Communication	Factors in various dimensions of effective communication such as frequency, mode of communication, and sharing of preliminary information, in a LPD environment.
		Know ledge Management	Accounts for modes of accumilating, storing, sharing, and maintaining a know ledge base w hich meet the requirements of a LPD project.
7	Process Management	Process Management	Incorporates all general considerations of structuring and managing a Lean development process.
		Value Stream	Includes various aspects of the Lean value stream concept in PD.
		Quality	Describes procedural means to maintain and improve the quality of the PD process and its products.
		Waste	Considers process features w hich help minimising w aste.
		Standardisation	Details the role of standardisation in a Lean development process.
8	Product Variety Management	Product Managament	Takes general product management practices into account but largely focuses on complexity management approaches advocates in LPD literature.
9	Continuous Improvement	Continuous Improvement	Focuses on the core concept of continuous improvement in LPD.
		Culture of Excellence	Contains various organisational culture aspects such as fostering entrepreneurial thinking and developing a context in w hich problems can be admitted and Lean Thinking sustained.

Table 4: Summary of labels and their allocation to the LPD elements

The LPD elements formed by the labels listed in Table 4 have been carefully named to avoid prompting preconceived notions which might not represent the actual component well, while maintaining a description which portrays the Lean character of the framework without being too abstract or specific. The naming process has been approached iteratively and the individual components have been repeatedly changed throughout the formulation of the forthcoming discussion of the LPD framework proposed in this work. The names listed in the table above represent the best conceivable trade-off between the previously mentioned dimensions.

The framework will be complemented by the rich discussions in PD literature as well as best practices from the wider PD research area which have been identified in three large-scale studies. Namely, these studies include Product Development and Management Association's longitudinal comparative performance assessment study carried out in 1990, 1995, 2004 as well as 2012 and of which the latest results have been summarised and published by Markham and Lee (2013), the American Productivity and Quality Center's study undertaken in 2003 and published in Cooper et al. (2004a, b, c) and finally Kahn et al.'s (2012) complementary study. The enrichment of LPD by considering the full breadth of PD literature and including the findings of the previously mentioned best practice studies addresses Hoppmann et al.'s (2011) call and intents to strengthen the nascent LPD research stream with closely related and noteworthy large scale studies. Best practices which have not found their place in the framework will offer valuable insight as to where this concept might develop to or how it can be effectively complemented by other measures (see section 6.4).

3.2 Theoretical Framework

The extensive content analysis has led to the development of an LPD framework consisting of nine different elements. The names of these elements have been carefully chosen to concisely describe the core idea behind the LPD components while trying to avoid potential associations with preconceived concepts. Table 5 lists the nine elements of the proposed LPD framework in its left column and indicates with a check mark which of the considered existing LPD frameworks has covered the corresponding component in whole or part. Furthermore, the nine LPD elements are ordered by extensiveness which adds another dimensions to the table. Extensiveness is an often employed interpretive concept in qualitative research, particularly in focus groups, which measures how many people, in this case publications, have covered a specific topic thus provides a quasi-quantitative measure of agreement on a topic (Krueger and Casey, 2015; Robert and Yeager, 2004; Shiu et al., 2009).

LPD elements	Clark et al., 1987	Womack et al., 1990	Karlsson and Åhlström, 1996	Morgan and Liker, 2006	Brown, 2007	Ward, 2007	Hoppmann et al., 2011	Schuh, 2013
Strong Project Manager	✓	✓	✓	✓		✓	✓	✓
Communication and Knowledge Transfer	✓	✓	✓	✓	✓		✓	✓
Teams	✓	✓	✓	✓		✓	✓	
Concurrent Engineering	✓	✓	✓		✓		✓	
Set-based Design				✓	✓	✓	✓	✓
Process Management				✓	✓	✓	✓	✓
Supplier Relationship and Integration	✓		✓	✓			✓	
Continuous Improvement			✓	✓	✓			✓
Product Variety Management							✓	✓

Table 5: LPD frameworks and their elements sorted by extensiveness

As the discussions in the preceding chapter on the history of Lean, PD, and LPD have shown, there are a number of touching points and congruencies such as the horizontal integration of all involved departments, parallelisation development processes, and establishment of close vertical ties. Consequently, a number of aspects have been widely-applied in the broader PD research area and cannot be regarded as being exclusive to LPD. The coherent framework of exclusive and commonly-shared elements, however, as practiced by Toyota and abstracted from it, retains its unique character.

The remainder of this second part of the chapter details the individual LDP elements separately to provide a comprehensive and well-structured discussion of the single components which make up this newly proposed framework. It should be noted, however, that despite discussing the LPD elements individually, they should not be considered in isolation but as parts of a closely-interrelated and highly-dynamic framework.

3.2.1 Strong Project Manager

In their study of PD performance in the global automotive industry, Clark and Fujimoto (1987) introduced the 'heavyweight project manager' and hypothesised him to play a significant role in Toyota's product development practices. Subsequent studies (e.g. Karlsson and Åhlström, 1996; e.g. Sobek II et al., 1998, 1999; e.g. Womack et al., 1990) confirmed this hypothesis and a strong or, to use the aforementioned term, heavyweight project manager[19] has established its position as an integral part of LPD (cf. Haque and James-Moore, 2004; cf. Hoppmann et al., 2011; cf. Kennedy, 2003; cf. Morgan and Liker, 2006; cf. Oppenheim, 2004; cf. Schuh et al., 2008b; cf. Ward et al., 2007).

As opposed to a 'traditional' lightweight project manager who is largely restricted in its rights and responsibilities to a small, often functionally-tied aspect of a development project, the heavyweight project manager bears responsibility for the overall success of the product in development (Liker and Morgan, 2006). His area of responsibility ranges from concept creation to market introduction (Ballé and Ballé, 2005; Cooper et al., 2004a; Morgan and Liker, 2006). At the outset of a development project, he is actively involved in analysing the competition and conducting extensive market research to clearly define customer value which he then translates into goals for the individual involved functional departments and constantly checks that the set targets are met (Cooper et al., 2004a, c; Hoppmann et al., 2011; Kahn et al., 2012; Markham and Lee, 2013). Put differently, he captures the voice of the customer[20], disseminates it to all

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[19] The synonymously used terms heavyweight project manager and strong project manager have established in the West to more or less describe the role of Toyota's chief engineer. LPD literature typically does not distinguish between the three titles and consequently all three terms are commonly used synonymously.

[20] The voice of the customer or voice of customer, is a term commonly used to describe a customer's expectations, preferences, wants, and needs.

involved functions and makes sure that the final product meets customers' expectations and preferences (Ballé and Ballé, 2005; Cooper et al., 2004c; Markham and Lee, 2013). The strong project manager (SPM) coordinates the whole PD project from its initiation to market launch and all involved specialists from the different functional departments (Ballé and Ballé, 2005; Cooper et al., 2004a). He specifies their objectives, sets target costs and makes important component choices to ensure that the concept is precisely translated into technical specifications and details (Ballé and Ballé, 2005; Cooper et al., 2004c; Markham and Lee, 2013). In his role as a coordinator, the traditional field of expertise of a project manager, he promotes and drives the project and aligns all parties through frequent and direct communication. He sets the overall time frame and sees to its adherence on a high project level (Ballé and Ballé, 2005; Morgan and Liker, 2006). In his role, the SPM greatly supports the development team, empowers its members, and leave day-to-day activities to the functional specialists (Cooper et al., 2004a). As a technical expert, however, he also exerts profound influence on the definition of technical details and solves, as ultimate authority, technical problems (Cooper et al., 2004a; Hoppmann et al., 2011).

As project manager and technical expert who solely owns and leads the development project, the SPM is responsible for finding a proper balance between the business and the engineering case (Oppenheim, 2004); to deliver the maximum value to both the company and the customer (Morgan and Liker, 2006). The goals of the development project are aligned with the company's mission and strategic plan and the SPM maintains this alignment (Kahn et al., 2012). In order to be able to live up to this role, he is surrounded by a team of loyal specialists who complement his expertise without departmental selfishness (Oppenheim, 2004). On the qualification side, he ideally is multi-lingual and multi-disciplined with great technical depth, an eye for the bigger picture and leadership skills (Ballé and Ballé, 2005; Liker and Morgan, 2006). At Toyota, this position is being held by the brightest engineers who have many years of hands-on experience in different departments and therefore acquired a profound knowledge of all critical sub-systems and have a sound understanding of the company, its culture and structure (Ballé and Ballé, 2005; Liker and Morgan, 2006 ; Sobek II et al., 1998). Subtly underlining the chief engineer's importance and ownership in a development project at Toyota, employees often refer to the product as 'his car' or in the case of the first-generation Prius' chief engineer Takeshi Uchiyamada as 'Father of the Prius' (Morgan and Liker, 2006).

Positioned within a company's hierarchy, the SPM typically is of equal or slightly higher rank than the managers leading the functional departments (see Figure 13) (Clark and Fujimoto, 1991a; Sobek II et al., 1998). Albeit supported by top management (Cooper et al., 2004a; Kahn et al., 2012), his authority is, with exception to his small team of assisting experts, purely informal; he does not wield any authority over the specialists from the individual functions (Ballé and Ballé, 2005; Morgan and Liker, 2006; Sobek II et al., 1998). So the SPM does not steer the development project in the classical sense. He must 'persuade' other involved engineers to help him realise his vision for the product. This can be only achieved when operating from a strong standpoint of credibility. The great technical depth hereby serves as the main source for his informal authority (Sobek II et al., 1998). This quite atypical position of power, however, leaves the heavyweight project manager exposed to overly bureaucratic procedures, conservative methodologies and managers following a hidden agenda using their organisational influence. All three have shown to have a negative impact on the project outcome and therefore should be avoided (Oppenheim, 2004; Sobek II et al., 1998). However, a functional manager can also use his formal authority positively through challenging the strong project manager's decision and present the case in front of their superiors to avoid possibly far reaching mistakes (Sobek II et al., 1998).

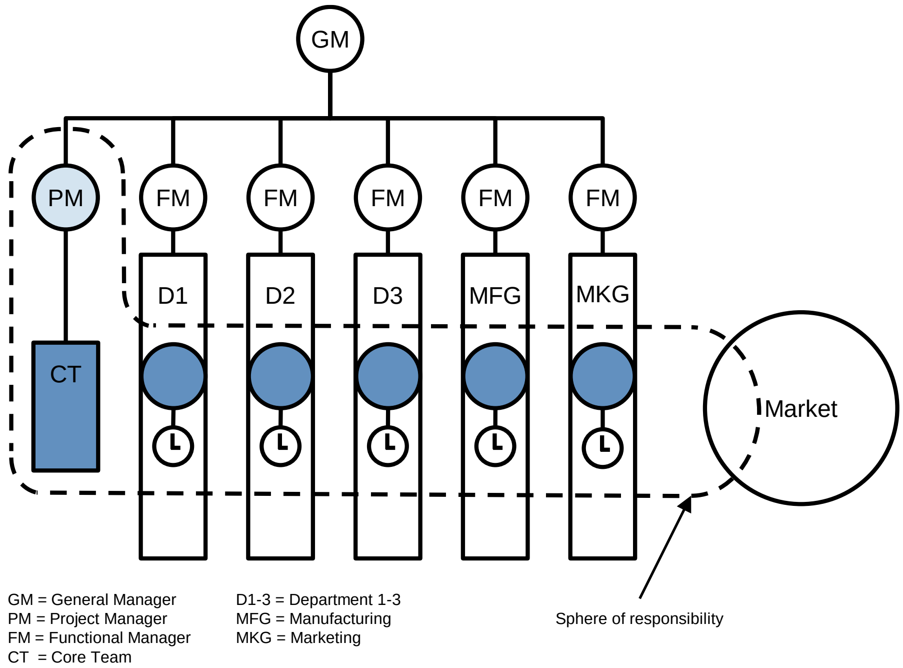


Figure 13: LPD organisational structure (Clark and Fujimoto, 1991a)

3.2.2 Teams

Toyota was inspired by the work of Drucker (1955) to introduce the concept of cross-functional management in the early 1960s (Koura, 1991). Amongst others, Drucker (1955, p.179) explored the, at that time prevalent structural principles for organising firms, product-focused and functional organisations, and asserted that 'federal decentralisation and functional decentralisation are complementary rather than competitive'. The combination of both approaches became known as the matrix organisation and spread rapidly in business settings with a strong project focus such as research and development (Knight, 1976).

Toyota developed the cross-functional management approach primarily to strengthen their coordination efforts in an attempt to cope with growing intricate organisational structures and a rapidly evolving product portfolio of increasingly complex products (Koura, 1991). As depicted in Figure 13 and detailed in section 3.2.1, in Toyota's development projects the SPM assembles a relatively small team from all relevant functions, ranging from marketing, design, various engineering departments all the way downstream to production (Clark et al., 1987; Cooper et al., 2004a; Karlsson and Åhlström, 1996; Kahn et al., 2012; Morgan and Liker, 2006; Womack et al., 1990). This team of functional experts is put together at the outset of the project and typically remains in this setting for the duration of the whole development project and sometimes even beyond that point to ensure a smooth market launch (Cooper et al., 2004a; Karlsson and Åhlström, 1996; Womack et al., 1990). Each team member is under full control of the heavyweight project manager despite the sole informal nature of authority.

The different functional areas of the development project are integrated rather than merely coordinated; they work together and not alongside each other (Clark et al., 1987; Cooper et al., 2004a; Karlsson and Åhlström, 1996; Morgan and Liker, 2006). The integration of specialised activities is extremely beneficial as it promotes a coherent overall solution with system requirements in mind instead of developing optimal partial solutions that amount to an all in all suboptimal system (Clark et al., 1987). In addition, meetings and direct contacts partly render special functions such as liaison functions and product planning redundant and thus free up resources for coordination through facilitating collaboration towards a common goal communicated by the heavyweight project manager. Karlsson and Åhlström (1996) assess physical proximity, i.e. working together in a designated space for the project, as the main facilitator for functional integration. It should be highlighted, however, that despite the cross-functional team sharing a work place each team member retains strong ties with their departments. This ensures a valuable knowledge transfer which keeps both ends up-to-date with the latest developments and thus prevents loosing contact with the research frontier of their field and facilitates finding solutions in the functional departments and other development projects (Womack et al., 1990). The main focus of the team members, however, is retained on the PD project (Cooper et al., 2004a).

Next to integration, another important dimension of cross-functional teams is the degree of specialisation. Breaking down activities in specialised tasks is a vital step towards parallelisation and shortening the critical path of the development project as will be examined in more detail in section 3.2.3 (Clark et al., 1987). Furthermore, specialisation permits setting the focus on the achievement of expertise which is a key factor for accelerating problem-solving cycles (Karlsson and Åhlström, 1996). Profound technical competence is typically developed and fostered among specialists sharing a functional domain (Hoppmann et al., 2011). Womack and Jones (1994) illustrate functions as schools which constantly accumulate and disseminate knowledge and best practices. Haque and James-Moore (2004) as well as Ward et al. (2007) share this idea about the role of functional departments. In Lean companies, engineers are assigned to technical positions for a relatively long time (Ward et al., 2007) and often follow designated career paths which promote building technical competence (Lenders et al., 2007). At Toyota, those university-trained engineers that have passed a rigorous hiring process start their career path at the assembly line (Morgan and Liker, 2006; Womack et al., 1990). They then rotate through a variety of departments for about one year, exposing them to the whole range of activities involved in making a car. Subsequently, they are assigned to their technical departments in which they are trained in their ordinary functional roles to qualify for the tasks of a development project (Womack et al., 1990). This fosters personal commitment as the team members' career prospects depend on the success of the project (Cooper et al., 2004a). If they have been able to proof themselves they go back to their departments and, if worthy, to additional academic training to prepare for more demanding roles in advanced projects (Womack et al., 1990). This career path design which focuses on the acquisition of deep technical knowledge and intensive on-the-job training is supported by a mentoring scheme (Morgan and Liker, 2006; Ward et al., 2007) which helps to unfold the mentees' potential through identifying and developing areas for improvement in regular interviews over a period of more than six years (Sobek II et al., 1998).

The previously described two main dimensions of a well working cross-functional team, vertical integration and technical competence, are about finding a balance between trade-offs. On one extreme end of an unbalanced matrix organisation there are highly skilled and knowledgeable specialists with a lack of communication between functional areas; on the other end of the continuum are specialists isolated in vertically integrated teams which gradually loose the technical expertise to develop increasingly technologically demanding and complex products. Toyota strikes a balance between these extreme scenarios through carefully nurturing technical competence within the functional departments and then imposing the heavyweight project management structure on the various domains to align their efforts towards the customer and the overall product (Morgan and Liker, 2006).

3.2.3 Concurrent Engineering

Traditionally, the development process is a well-defined list of mostly independent activities which are executed subsequently[21] (see Figure 14) (Changchien and Lin, 2000; Hoppmann et al., 2011; Randhawa and Burhanuddin, 1998). Independent of the process model used, a concept would be typically developed after the ideation process has finished; it would then be evaluated, its modules and components designed, tested and finally integrated. Once the whole product has been assembled it would be tested again and if all goes to plan and no further design iterations are needed serve as the basis for production planning (Hoppmann et al., 2011). Due to the independent nature of the single activities and their sequential execution, this approach carries an inherent lack of consideration for up- and downstream activities which in turn often results in multiple excessive design iterations and costly modifications (Changchien and Lin, 2000).

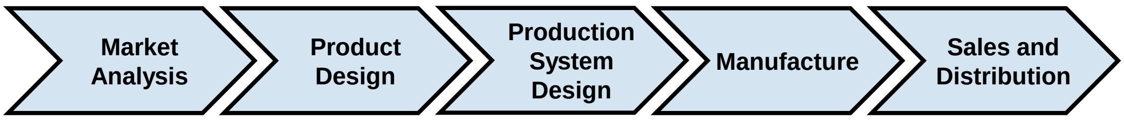


Figure 14: Classic linear model (Ahmed and Shepherd, 2010)

In contrast, in concurrent engineering[22] (CE) the individual design phases are not executed sequentially but concurrently where one phase overlaps with another (see Figure 15) (Ahmed

[21] The sequential product development process is sometimes also called 'over-the-wall' approach (cf. Shina, 1991; cf. Soundar and Bao, 1994) where one office (department) receives the work or project from the previous office and hands it over the wall to the next without knowing what happened before or after the own involvement.
[22] In Japan referred to as 'doki-ka' (Ahmed and Shepherd, 2010).

and Shepherd, 2010; Brown, 2007; Haque and James-Moore, 2004; Hoppmann et al., 2011; Karlsson and Åhlström, 1996; Schuh, 2013; Wu et al., 2010). CE, synonymously often also referred to as simultaneous engineering (cf. Hoppmann et al., 2011; cf. Karlsson and Åhlström, 1996; cf. Soundar and Bao, 1994), however, is by far no new concept and neither one that is exclusive to the automobile industry nor LPD literature. This approach has received significant interest since the late 1970s from both academia and industry (Changchien and Lin, 2000) and was pioneered in the Western world in the U.S. defence and automobile industry (cf. Clark et al., 1987; cf. Reddy et al., 1991; cf. Winner et al., 1988; cf. Womack et al., 1990).

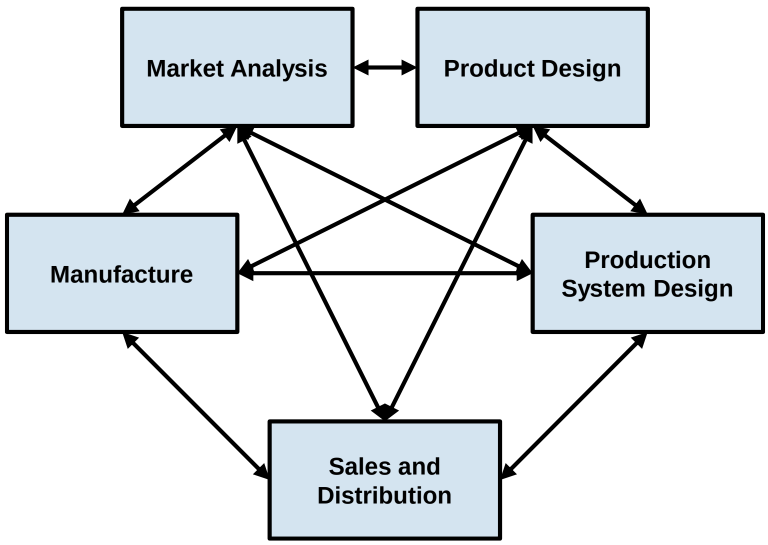


Figure 15: Concurrent Engineering model (Ahmed and Shepherd, 2010)

Winner et al. (1988, p.v) who coined the term CE (Ahmed and Shepherd, 2010) from the U.S. 'Institute for Defense Analyses' provide one of the original and frequently quoted definitions of CE (Haque and James-Moore, 2004):

'Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements.'

Haque and James-Moore (2004) deduce from this definition that CE is not just about the parallelisation of engineering processes through their integration, but about considering the whole value stream including suppliers, marketing, service, and customers throughout the project to drive performance and foster employees' understanding of the PD process (Cooper et al., 2004a). CE brings a multitude of considerations to the early stages of a development project, thus front-loads it with essential information which not only determine the project but also the life-cycle performance of the product. Morgan and Liker (2006, p.260) summarise, 'the essence of simultaneous engineering is bringing downstream considerations to the table early in the development process'.

However, the breaking-down of the complex development cycle into specialised tasks including 'market analysis, conceptual design and development, material selection, process planning, production, information and process control, quality and process monitoring, and costing' (Randhawa and Burhanuddin, 1998, p.4) and involving them in the early stages of the project also allows the execution of different processes in complete simultaneity or at least with a significant overlap – the degree of simultaneity (Clark and Fujimoto, 1991b): machining experts are able to start the design of the machine centres and determine the appropriate tools, process planning experts begin laying out the production sequence, assembly experts anticipate potential assembly difficulties and so forth (Shenas and Derakhshan, 1994). Morgan and Liker (2006), Shenas and Derakshan (1994), Ward et al. (1995) as well as Womack et al. (1990) provide detailed examples of CE in the automobile industry and partly compare them to the established procedures of other players in the same market.

The integration of all involved functions and the simultaneous execution of processes have been demonstrated in various studies to result in significant benefits for the company. Winner et al.'s (1988) results of their extensive investigation for the U.S. 'Department of Defense', summarised in their 1989 publication (Pennel et al., 1989), as well as Soundar and Bao (1994) report profound improvements in all three, development time (overall lead-time, transition time from design to production), cost (total life-cycle costs, design costs through reduced design iterations, manufacturing costs, reduced costs through design simplification and inventory control, costs for rework and scrap) and quality (decreased process variability, reduced defects, fewer design iterations, less quality control personnel, generally more robust designs and production processes). Winner et al. (1988) provide a detailed account of where these improvements were achieved, which consequences they had, and how they translated in terms of performance measures. Further, Clark and Fujimoto (1991b), Ward et al. (1995) and Womack et al. (1990) report, from a Lean perspective, significant improvements through overlapping hitherto sequential activities and integrating the entire value stream's information early in the project.

To reap these benefits, however, all functions must show a high degree of anticipation regarding the constraints and needs of the up- and downstream activities (Womack et al., 1990) which is achieved through a broad value stream understanding, repeated review meetings with all relevant functions, a formalised process which evaluates design proposals with regard to their manufacturability and assembly compatibility, as well as intensive communication to allow the information to flow inter- and intrafunctionally (Clark et al., 1987; Hoppmann et al., 2011; Kahn et al., 2012; Womack et al., 1990). Changchien and Lin (2000, p.252) emphasise the latter stating that the key to CE '…lies in the simultaneous consideration of design information throughout the product development life cycle…'. A detailed discussion of this aspect will follow in section 3.2.6.

It is for the formerly mentioned benefits that Haque and James-Moore (2004) are able to report a number of studies which demonstrate the wide spread acceptance CE has found across industries. Ahmed and Shepherd (2010, p.430) describe it as 'the norm of practice' of today. However, it shall be noted that overlapping multiple processes comes at the price of increased process complexity, ambiguity and a heightened demand for control. In combination with a low tolerance for risk this might pose a serious challenge for implementing CE (Karlsson and Åhlström, 1996).

3.2.4 Supplier Relationship and Integration

The Japanese Lean approach to managing the supplier base is characterised by a relatively small amount of suppliers with which the automobile manufacturers (henceforth OEMs) have built long-term relationships of a partnerial and collaborative nature (Aoki and Lennerfors, 2013; Binder et al., 2008; Clark, 1989; Clark and Fujimoto, 1991b; Dyer and Ouchi, 1993; Hines, 1994; Hoppmann et al., 2011; Liker and Choi, 2004; Liker et al., 1994; Merli, 1991; Moyano-Fuentes and Sacristán-Díaz, 2012; Rich and Hines, 1998; Ro et al., 2008; Ward et al., 2007). This arrangement in which buyers and suppliers form close associations has a long tradition in the Japanese economy and became known as 'keiretsu'[23] (Aoki and Lennerfors, 2013; Dyer and

[23] The Japanese term 'keiretsu' defies translation but if literally rendered into English could be 'succession' in terms of entities linked together similar to links in a chain (Flath, 2014).

Ouchi, 1993; Ro et al., 2008). Within the keiretsu system it is typically differentiated between the bank-dominated horizontal keiretsu and the manufacturing-focused vertical keiretsu (Dow et al., 2011; Schonberger, 2007) although this distinction represents a generalisation of a complex business network with significant overlap between horizontal and vertical groupings (McGuire and Dow, 2009). Due to the focus of this work, the remaining discussion will concentrate on vertical keiretsu.

The traditional vertical keiretsu has been intensively studied in the 1980s (Aoki and Lennerfors, 2013) and frequently cited as *the* model for effective buyer-supplier relationships (cf. Cusumano and Takeishi, 1991; cf. Dyer and Ouchi, 1993; cf. Liker et al., 1994; cf. Lincoln and Shimotani, 2009; cf. Ro et al., 2008; cf. Womack et al., 1990). Numerous studies (e.g. Asanuma, 1989; e.g. Dyer, 1996; e.g. Womack et al., 1990) have demonstrated the advantages in innovation terms and efficiency of the close and collaborative relationships and have painted a picture of economically rational business networks (Lincoln and Shimotani, 2009). This form of keiretsu, however, has increasingly come under pressure in Japan's economic crisis in the 1990's (Ahmadjian and Lincoln, 2001; Aoki and Lennerfors, 2013). As a result, large OEMs such as Honda, Nissan and Toyota have initiated drastic cost-cutting programmes in which they partly turned their back to long-term suppliers and made use of the cheaper 'megasuppliers' (Aoki and Lennerfors, 2013). This led to weakening ties in the vertically linked business groups (Dow et al., 2011; McGuire and Dow, 2009; Wako and Ohta, 2005) and some authors even go as far as speaking of the demise of the traditional keiretsu system (cf. Ahmadjian and Lincoln, 2001; cf. Lincoln and Shimotani, 2009).

This, however, is not to say that keiretsu has vanished; quite the opposite, it has evolved to embrace the new environment of the business groups and hybridised in various trajectories. Aoki and Lennerfors (2013) have studied the transformation of the vertical keiretsu into the ‘new, improved’ or, as Wako and Ohta (2005) put it, ‘half-open’ keiretsu over a 20 year period. The latter term characterises the new system quite well in the sense that it has maintained some aspects of the traditional, closed keiretsu but has opened up to a degree, which is not necessarily ‘half’, and integrated supply chain governance characteristics based on the standards of Western companies. This includes the previously mentioned sourcing of parts from outside the keiretsu system, i.e. from megasuppliers which are able to offer parts at very low prices due to their highly effective processes. Leaving the traditional single sourcing strategy partly behind allows the OEM to keep costs down while adding sourcing flexibility. This induces harsh competition into the keiretsu network since the OEM now sets the target prices for their long-term sourcing partners at a level that can compete with the large global part suppliers. Another feature of the new keiretsu system is the growing demand of OEMs for integrated component systems rather than just individual parts. The outsourcing of whole modules further helps not only reducing costs but also developing time while remaining a high quality level (Aoki and Lennerfors, 2013).

An early study by Clark and Fujimoto (1991b) has illustrated that Japanese automobile manufacturers source out a relatively large portion of the development activities for functional parts and subassembly systems compared to their competitors in the U.S. and Europe. To investigate this aspect further, they also provided a useful classification of transactions depending on the supplier’s product development capability and level of involvement in the OEMs development process. The three broad types are based heavily on the work of Asanuma (1989) and categorise parts into (1) supplier proprietary, (2) black box, and (3) detail-controlled parts. The first category represents parts which have been entirely developed by the supplier and are ordered by the customer as an off-the-shelf catalogue product (Clark and Fujimoto, 1991b). The third category, detail-controlled parts, is on the other end of the spectrum of supplier responsibility and applies to those cases for which most of the engineering work have been done in-house by the OEM. Quite often with this type of parts, the OEM provides the supplier with the drawings, and sometimes even with a process setup and the necessary tools and equipment, which reduces the supplier to 'nothing more than a provider of production capacity' (Fujimoto, 1999, p.136). The second category, black box parts, stands for parts for which the customer provides basic design input such as interface details, exterior shapes and cost/performance requirements, but that are typically predominantly developed by the suppliers (Clark and Fujimoto, 1991b; Cusumano, 1985). This allows the OEM to exploit supplier expertise and workforce while maintaining control of the basic design features. Once the suppliers have accumulated ample expertise they gain a competitive edge over their direct rival and the OEM benefits through high quality parts or systems at low prices (Clark and Fujimoto, 1991b). At this point the OEM needs to tread carefully, especially if complex systems are outsourced, since the supplier is likely to have developed technical core competencies which cannot be easily imitated which in turn would generate high switching costs and risks for the OEM. Consequently, the negotiation power of the customer erodes and if no internal control of the product is kept by the OEM, the assembler might reach a point of dependency (Clark and Fujimoto, 1991b; Ro et al., 2008). In an effort to avoid the erosion of negotiating power, secure the success of the project, and maintain valuable technological capabilities and a competitive advantage, Japanese companies evaluate parts with regards to criticality in the aforementioned aspects before making an outsourcing decision (Hoppmann, 2009). Where in Western arm-length relationships the exploitation of such a situation seems to be at hand, Japanese relationships appear to endure these tensions. Ro et al. (2008) attribute this to the keiretsu system in which a long-term relationship is established based on trust, fair trade, mutual benefit and a degree of direct control through equity holdings in the supplier. The heavy usage of ever more complex black box parts has been recognised as a key success factor (Fujimoto, 1999; Liker et al., 1994) of Japanese supplier relationships and quickly black box parts became the predominant product type which an increasing number of companies makes use of (Karlsson et al., 1998).

Ward et al. (1995, p.54) argue that the degree of responsibility given to the supplier in the development process is depending on ‘the supplier’s engineering capability, past performance record, complexity of the part, the degree to which the part interfaces with others, the stability of the technology, and so on.’ To allow for the effective development of integrated component systems, OEMs encourage suppliers in developing them through providing knowledge and involving them in the early stages of the development project (Aoki and Lennerfors, 2013; Lincoln and Shimotani, 2009). Despite the common notion that OEMs in the keiretsu system rely on single sourcing, it is wrong to assume that keiretsu suppliers, not even in the traditional system, do not face fierce competition (Clark and Fujimoto, 1991b; Fujimoto, 1999), especially if they are involved in technology-intensive parts and systems (Ward et al., 1995). Most suppliers have to compete with one or more companies over a lengthy period of six to twelve months (Clark and Fujimoto, 1991b; Fujimoto, 1999; Liker et al., 1995; Rich and Hines, 1998) not only from within but nowadays also from outside the keiretsu network (Aoki and Lennerfors, 2013). This selection process, sometimes called ‘development competition’, is the Japanese prevalent form of competition and could be compared to the bidding process of some Western suppliers (Fujimoto, 1999). Part of the selection process is the presentation of viable solutions to the OEM’s development challenges which ‘include working prototypes and a great deal of test data, with comparisons to existing and/or alternative designs’ (Ward et al., 1995, p.56). In an empirically grounded iteration process of presenting solutions, exchanging ideas and discussing potential improvements, the solution space is constantly narrowed down culminating in a single part or system that best meets the needs of the OEM. For a more detailed discussion of this process, also referred to as set-based design, refer to the next section 3.2.5 and for more information on Toyota's pre-sourcing arrangements see Ward et al. (1995). The early and intensive supplier involvement in the development project in which key suppliers are often granted physical space at the OEM and integrated early in the project into the cross-functional development teams foster communication and knowledge exchange and ensure right first time[24] (Aoki and Lennerfors, 2013).

Despite these new characteristics which open up the exclusive buyer-supplier relationships, induce competition, and lead to a shift in development responsibility, the new keiretsu still maintains features of the traditional system. A most notable difference to the often employed Western arm's-length supplier strategy in which the OEMs use their bargaining power to squeeze their suppliers, the relationships within a keiretsu network are based on trust as well as cooperation and often involve a great amount of educational support which helps suppliers to improve their capabilities and allow delivering the demanded products in a cost and time effective manner (Aoki and Lennerfors, 2013; Pérez Pérez and Martínez Sánchez, 2002; Sako, 2004). These symbiotic relationships have even appeared to have improved to a point where one could argue that OEMs opened up their networks to allow their established supplier base, and hence the whole keiretsu system, to absorb the innovations of their global competition. Another noteworthy aspect of a keiretsu system which greatly exemplifies the trusting relationships is the ambiguous nature of the contracts governing their cooperation. Instead of

[24] The phrase 'right first time' came up in the quality movement and describes an effort to minimise defects or errors.

pinning the suppliers contractually down, Japanese contracts often include rather general statements and not specific targets. Where Western companies often set specific targets for prices and annual price reductions, Japanese companies incentivise cost reduction through sharing the benefits with their suppliers. This only serves as a brief example of the Japanese approach to buyer-supplier contracts. The general belief appears to be that by formulating specific targets, companies are only encouraged to meet these targets but not to exceed them. OEMs in a keiretsu network, however, expect their suppliers to constantly give their best and not just to meet contractual targets but to strengthen the position of both the buyer and supplier within the global business environment (Aoki and Lennerfors, 2013). Asanuma (1989) argues that this contracting style characterised by high-trust, implicit targets and tacit knowledge-sharing is particularly suitable to govern key suppliers who collaborate on new and customised products. In addition to this form of contract, the mutual interest in the success of the other party is not infrequently bolstered by asymmetric equity holdings of the OEM in the supplier (McGuire and Dow, 2009; Ro et al., 2008). McGuire and Dow (2009) argue that vertical shareholdings suggest a motive for strong control and reflect a convincing, long-term commitment in critical suppliers (Williamson, 1983). Ahmadjian and Oxley (2013) support existing studies (e.g. Clark and Fujimoto, 1991b; e.g. Dyer, 1996; e.g. Dyer and Nobeoka, 2000) and emphasise that equity affiliated suppliers are more flexible and responsive to their customer's needs even under fluctuating demand conditions. They also highlight the importance of safeguarding supply relationships in the light of the prevailing outsourcing trend of ever more sophisticated and complex parts and systems (Ahmadjian and Oxley, 2013).

3.2.5 Set-based Design

It has been established practice in the automobile industry and beyond to develop products following an approach sometimes referred to as 'hill-climbing process' or 'point-based design' as Ward et al. (1995) put it (see Figure 16 for a generic illustration). Both descriptions take their name after the sequential character of the development process where each successive design solution is another iteration towards the optimal or aspired solution at the end of the process or at the top of the hill to pick up the formerly mentioned analogy. This sequential process takes the product idea from its concept development to production through various departments (Sörensen, 2006). Passing through the different functions and phases sequentially, however, highlights a problem related to the narrow-minded, function-based approach to problem solving as discussed in section 3.2.3. Having been taught this process and somewhat stuck in this way of approaching design problems, practitioners and researchers alike have put great emphasis on speeding up the iterations (problem-solving cycles), reducing the amount of iterative loops, doing it the right first time or freezing design specifications early to optimise the development process (Ward et al., 1995). Morgan and Liker (2006) as well as Sörensen (2006) demonstrated that the iterative point-based design is a common theme among Western automobile manufacturers and that Japanese engineers employ a vastly different approach to solving design problems.

Figure 16: Point-based design phases (Ulrich and Eppinger, 2012; Sobek II et al., 1999)

Ward et al. (1995), an array of four researchers from the University of Michigan termed the Japanese approach ‘set-based concurrent engineering’ (SBCE) in their study which was shared with the public audience in their 1995 publication ‘The second Toyota paradox’. However, the author of the work at hand has chosen to refer to this concept as ‘set-based design’, a term introduced earlier by Ward and Seering (1989a, b), to delineate it from and avoid any confusion with the previously detailed concept concurrent engineering. Set-based design was established at Toyota in 1993 with the starting of the development of the Prius in the Global 21 initiative (Schuh, 2013). For a detailed account of this initiative and how set-based design was developed, refer to Itazaki (1999) or Liker (2004) for a more concise Lean-centred description. Design-sets are different technological solutions for product parts, subsystems or modules which are simultaneously developed over a relatively long period and all serve to solve the same design problem (Brown, 2007; Schuh, 2013; Sörensen, 2006). The planning and evaluation of different technological solutions take a relatively long time and are, especially when under time pressure, quite contra-intuitive. Most companies would select the next best solution that would supposedly do the job and often experience the downside of having chosen too quickly in later stages of the project (Schuh, 2013). Schuh et al. (2007) have demonstrated that in most development projects a design option is selected too early inviting problems caused by eliminating other potential solutions based on intuition, perception and experience; in short subjectivity. These findings are supported by Ward et al.’s (1995) early observations and stand in sharp contrast to common knowledge which says that the decisions made in the early stages of the project have the greatest impact on cost and quality (Clark and Fujimoto, 1991b). The set-based approach requires detailed investigations of a variety of alternatives to determine the best solution based on hard facts (Schuh, 2013; Ward et al. 1995). Morgan and Liker (2006, p.50) summarise, ‘slower decision making leads to steady convergence, forced premature decisions drive rework'. Since a number of alternative design solutions have been eliminated based on objective data, Toyota does not revise a design solution once it has been selected (Hoppmann 2009) which keeps product specifications stable thus creates certainty for other functions in an otherwise fluent process (Cooper et al., 2004c). Ward et al. (1995) add at this point that the exploration of many different design solutions routinely includes radical design solutions which compete with established ideas and concepts in an empirically grounded selection process thus giving breakthrough designs a fair chance to stand their ground. Adding to this aspect of the discussion, Brown (2007) as well as Schuh (2013) state that set-based design offers innovation, radical or not, with reduced risk since a wide array of alternative solutions is explored and the concept selection process is based on a well-documented evaluation process.

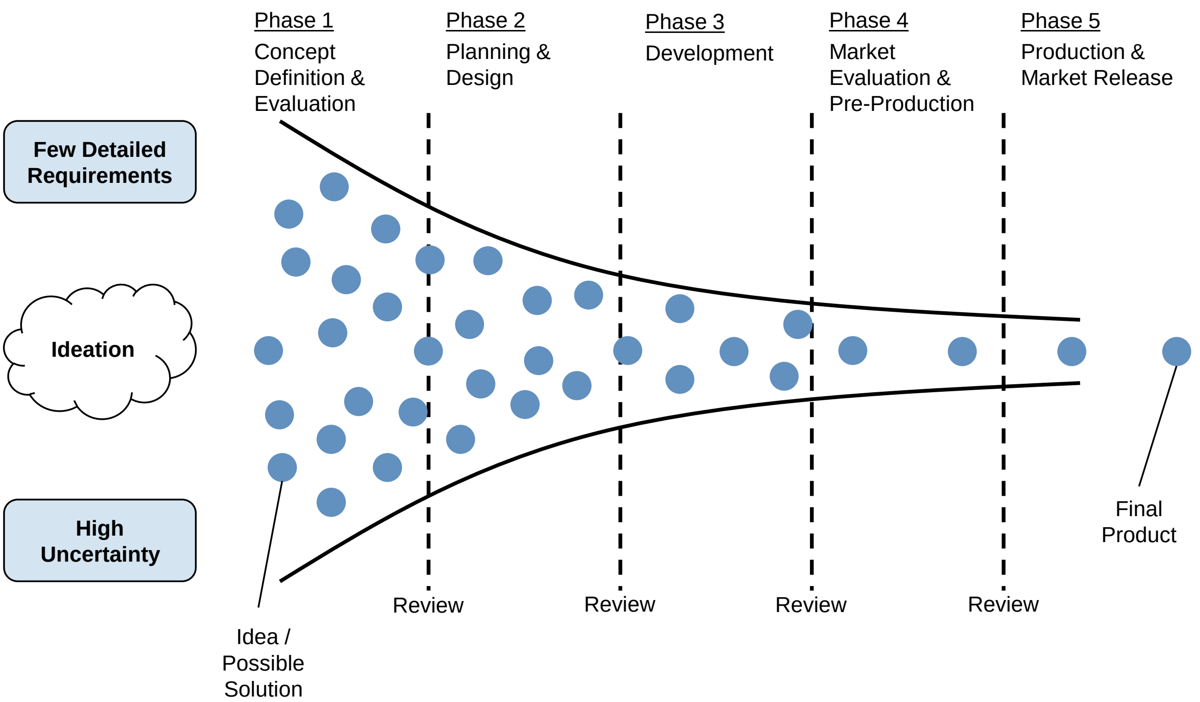


Figure 17: Set-based design approach in a development funnel (adapted from Ahmed and Shepherd, 2010; Clark and Wheelwright, 1993)

In summary, it can be said that in this regard set-based design is fundamentally different to the iterative point-based process which is focused on modifying an often prematurely chosen design solution (Ward et al., 1995) rather than exploring and developing a wide set of alternatives and eliminating unsuitable design concepts only based on empirical facts. Asides from this difference, the consideration of various perspectives is very important to end up with a well-rounded product which is not only optimised to fulfil the needs of just one department but the whole value stream; design, engineering and manufacturing have to work together to develop an appealing and high quality product which is also producible. This is supported by a holistic mind-set which not only looks at the problem at hand but considers a product as a system consisting of parts, subsystems and modules which all have to seemingly work together. Consequently, considerable energy has to be put into design interfaces to accommodate for the interrelationships between components and great attention has to be paid at the downstream manufacturing processes (Morgan and Liker, 2006). Ward et al. (1995), for instance, report Toyota's intense use of checklists which help auditing design solutions with regard to the company's capabilities such as the styling process with the development of manufacturable designs. The checklists compiling the company's technological capabilities represent an essential tool for communication and are reviewed whenever new technology is introduced thus reframe the design space for forthcoming projects. This low-cost approach to determining manufacturability dramatically reduces conflicts between design and production and further ensures that future projects start off with a well-documented knowledge base which includes the lessons learned and best practices from previous developments (Ward et al., 1995). A more detailed account of what the checklists comprise of and how they are used can be found in Sörensen (2006). Morgan and Liker (2006, p.50) conclude the focus should be 'on system *compatibility* before individual design *completion*'. According to the same authors, this way of thinking is a key determinant for keeping engineering changes at a minimum (Morgan and Liker, 2006). To support this maxim it is essential to have very active and intense communication suitable to this development approach (Ward et al., 1995) as discussed in detail in the next section 3.2.6. At Toyota, this approach is not a mindless application of processes and methods but reflects what is considered correct problem solving (Schuh, 2013). As of Sörensen's publication in 2006, Toyota is the only known company in the automobile industry to have implemented set-based design to its full extent. Earlier accounts of Toyota's unique position in this regard include Clark and Fujimoto (1991b), Sobek II (1997), and Sobek II et al. (1999).

Schuh (2013) systematically describes Toyota's rather abstract holistic problem solving process philosophy through their concept of solution space management. In mathematics, solution space defines the set of all possible solutions to a given problem. Translated into the PD context, the solution space is the scope of design solutions for a problem within the development project. The management of the solution space is the systematic reduction of possible solutions over time to enhance effectiveness and efficiency in PD. Possible design solutions are gradually excluded based on time, cost, and quality targets set by the involved stakeholders and often evaluated through detailed tests (Schuh, 2013). The description of Schuh's (2013) concept not only summarises the previous discussion but also highlights once more that the set-based design approach shifts much of the PD effort to the early phase of a project; a concept known as front-loading (Morgan and Liker, 2006; Sehested and Sonnenberg, 2011; Thomke and Fujimoto, 2000).

Front-loading shifts 'the identification and solving of [design] problems to earlier phases of a product development process' (Thomke and Fujimoto, 2000, p.129). This concept repositions the established link between product development performance and problem-solving capabilities to the early stages of a development project (cf. Clark and Fujimoto, 1989a; cf. Thomke, 1998; cf. von Hippel, 1990). It is based on the rationale that much of a project's costs are determined in the early stages while the degrees of freedom are high and the costs of correcting low. As the project progresses and the company commits to a design option, the costs are largely determined by the design choice while the degrees of freedom quickly go down and the costs of correcting significantly rise (Boehm, 1981; Thomke and Fujimoto, 2000). The relationship of these three factors is qualitatively depicted in Figure 18. Smith and Reinertsen (1991) as well as Flores and Chase (2005) add to the rationale, stating that front end improvements have significant potential for shortening lead time at the least expense.

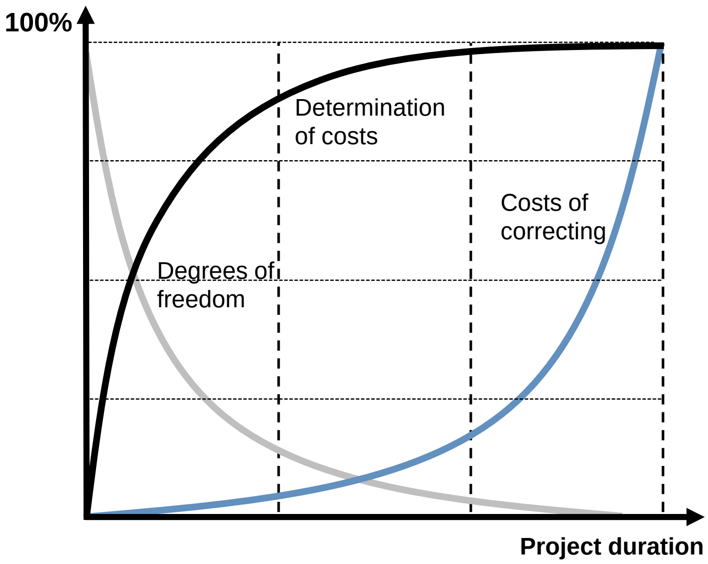


Figure 18: Behaviour of costs in a PD project (Flores and Chase, 2005; Fraunhofer IAO, 2010)

This argument of shifting much of the development effort to the early stages of an project largely coincides with the quality maxim 'right first time' or put in shop-floor language 'measure twice – cut once' (Morgan and Liker, 2006). Set-based design follows this principle in delaying design decisions through thoroughly exploring the design space until it can objectively exclude inferior solutions based on empirical data (Ward et al., 1995). Front-loading, however, is not just exploring different solutions concurrently but according to Thomke and Fujimoto (2000) as well as Morgan and Liker (2006) a more complex concept encompassing a number of approaches of which set-based design is only one. Thomke and Fujimoto (2000) also consider other approaches such as project-to-project knowledge transfer, leveraging technologies for rapid problem-solving (e.g. computer-aided design (CAD), computer-aided engineering (CAE), rapid prototyping) and buyer-supplier relationships as part of front-loading. While the previous section 3.2.4 has, amongst others, described the early integration of suppliers into the first stages of a PD project to enhance problem-solving capabilities, knowledge transfer and process technologies will be discussed in the subsequent sections. Morgan and Liker (2006) set the scope of front-loading to encompass project planning as well as cross-programme front-loading in terms of making use of platforms, modules and shared architectures as discussed in the section 3.2.8. This is to show that front-loading is a broad, multiple approaches encompassing concept of ambiguous scope. Due to its diverse nature it has been considered appropriate to allocate and discuss its putative features elsewhere in this framework for the sake of structure and clarity.

3.2.6 Communication and Knowledge Transfer

The environment in which communication occurs, the media used and the content and context of it, has changed dramatically over the past years.

A typical pattern in a sequential point-based structured development project (see section 3.2.3 and 3.2.5) is characterised by a batch mode of communication where at the end of a process a collection of information, for example in form of design records, reports, etc., is formally handed over in a meeting to the downstream process for further processing (see top of Figure 19). The flow of information is unilateral, i.e. without any feedback from the downstream process, and the information being transferred is considered final by the upstream process (Clark and Fujimoto, 1991b). This pattern of communication can be supported by arguments such as communication between development teams usually requires cost and time (Loch and Terwiesch, 1998) and, if communication is growing in frequency, costs rise significantly (Ha and Porteus, 1995). Additionally, the ease of management and simplicity of unilaterally handing information downstream in batches speaks in favour of this approach to managing communication. In theory, this approach should decrease risks in design rework (Clark and Fujimoto, 1991b) and as communication is aggregated in a single hand-over event, often a stage gate review, the cost for communication should be kept at a minimum. In practice, however, this thinking has proven to be flawed due to lacking downstream considerations and the consequently high number of iterative design loops which in turn increase the need for more communication and generally drive rework as pointed out in section 3.2.3.

When introducing CE thus allowing different development phases to overlap, the pattern of communication has to change to address the heightened coordination effort and counter the increased uncertainty and potential for rework (Clark and Fujimoto, 1991b; Lin et al., 2010) (second from the top Figure 19). A number of studies have shown that overlapping can cause substantial rework thus take up significant engineering capacity and especially when the overlapped phase bears a lot of uncertainty, for instance due to a lacking knowledge base, and are strongly building on each other, CE can become unfavourable (Lin et al., 2009; Loch and Terwiesch, 1998). To compensate for these negative effects, a sole batch mode information transfer strategy should be abandoned and broken down into a more fragmented and frequent mode of communication (Lin et al., 2010). However, since communication is costly and takes away time from the actual development work, a trade-off has to be found (Morgan and Liker, 2006; Terwiesch et al., 2002). In addition to the frequency of communication, Terwiesch et al. (2002) highlight the importance of what is communicated rather than how often. This aspect delves into the discussion whether information should be withheld until it is finalised and sanctioned by the upstream process giving the downstream process a solid base to start from or if preliminary information should be passed on to downstream processes indicating the direction the upstream process is taking. The previously mentioned authors investigating preliminary information exchange conclude that waiting for information to be finalised foregoes the time advantage gained through CE but relying too heavily on preliminary information might cause rework. Terwiesch et al. (2002) shed more light on the underlying trade-offs between preliminary information exchange and other aspects and conclude that a combination between the two reap the most benefits. When passing on preliminary information employees in general and engineers in particular might be reluctant due to perfectionist attitude or if exposed to a hostile environment to avoid blame for incompetence or sloth (Clark and Fujimoto, 1991b). At this point the discussion links into the idea of integration (see section 3.2.2) and the need for a problem-solving supporting setting.

If CE is now supported with a bilateral instead of unilateral exchange of preliminary information in form of feedback by downstream processes or an extended ideation process, a company can start to expect significant results (Clark and Fujimoto, 1991b) (see second from bottom Figure 19). Clark and Fujimoto (1991b) as well as Lin et al. (2010) state that given the increased uncertainty and the higher potential for rework it might well be that introducing CE without having bilateral communication could be disadvantageous. The former authors even go as far as describing overlap without bilateral information despite the previously described increased frequency of (one-way) communication is little more advantageous than the point-based sequential approach with a final information transfer at the end (Clark and Fujimoto, 1991b). Bilateral communications addresses the often obscure ways of design change interrelationships (Ward et al., 1995) through allowing for mutual adjustment to take place which in consequence makes a holistic development or optimisation of a design solution which takes the interests and limitations of all involved processes and stakeholders into account possible (Clark and Fujimoto, 1991b). Due to the constant feedback the communication and information from the outset of the project remains true instead of being nullified by downstream veto and simply gets more detailed as the project progresses (Ward et al., 1995). As overlap increases the need for a problem-solving culture in which integrated functions work together through more intimate and informal communication on a basis of trust and mutual adjustment rather than against each other, for instance through a formal veto authority such as manufacturing sign-off, becomes increasingly important. Toyota answers this need for integration with regular formal meetings, collocation, as well as informal and intensive intrafunctional and interfunctional communication in a dialogue mode (Clark et al., 1987; Clark and Fujimoto, 1991b; Kahn et al. 2012) to foster productive and open communication among employees and across functions (Cooper at al., 2004a; Markham and Lee, 2013). For more information on the tools Toyota uses to communicate effectively and keep communication focused to avoid burdening the development teams with unproductive information see Mascitelli (2007) as well as Morgan and Liker (2006).

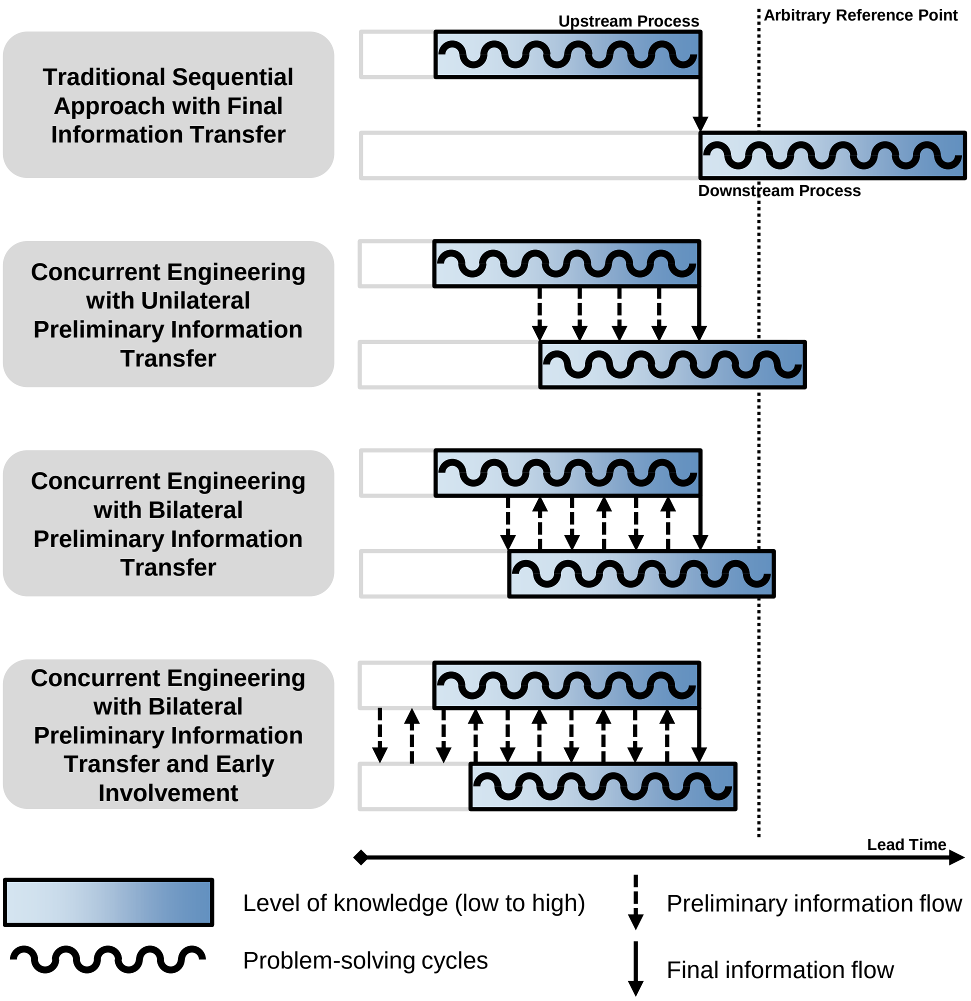


Figure 19: Communication approaches in sequential and concurrent engineering (adapted from Clark and Fujimoto, 1991b)

Close and bilateral communication with the customer has also been identified as a supporting factor for LPD with significant benefits (Markham and Lee, 2013). These direct discussions have shown to provide more accurate information to the company reacting to a market pull

(Karlsson and Åhlström, 1996). In their best practice study, Kahn et al. (2012) take it a step further and describe ongoing market research to specify and anticipate future customer needs a best practice in today's fast-changing markets. But whether a company decides to constantly monitor the market to be aware of changing customer needs and product opportunities, market research has been identified to be essential in defining a product (Cooper et al., 2004c). Beyond shaping the products requirements, features, and functional aspects, capturing and translating the voice of the customer also serves as a basis for the identification of waste as discussed in section 2.3.3 (Morgan and Liker, 2006). Wastes such as over-engineered products or missing but wanted product features only serve as an example of how a lacking understanding of the voice of the customer can lead the generation of waste. In order to accomplish the customer orientation which is so strongly advocated in LPD, customer value, as defined in section 2.3.2, needs to be communicated and operationalised throughout the entire development process to streamline all activities towards the customer (Morgan and Liker, 2006). Morgan and Liker (2006) recommend to translate the idea of customer alignment into praxis through breaking down high-level goals for the product into meaningful and workable lower-level objectives for the individual departments. In an effort to systematically approach this idea of communicating customer value through lower-level objectives, Schuh (2013) advocates the definition of transparent target hierarchies. In essence, Schuh (2013) recommends specifying one or multiple overall project targets, which are aligned to the customer and the company's strategy. These project targets, such as increasing turnover by 3%, represent the project's objectives of the highest order which need to be weighed to introduce a measure of importance, subdivided and itemised until they define meaningful and achievable low-level objectives, such as maintaining a carry-over rate of 50%. The communication of a transparent target hierarchy helps all involved employees to identify with the project and its objectives and facilitates addressing as well as solving possible conflicts early in the process. This clear definition of PD goals on multiple levels is well-aligned with Cooper et al. (2004b) as well as Kahn et al.’s (2012) best practice study results. The authors further suggest to make PD an integral part of the company by defining strategic goals which ensures long-term commitment.

On a different note, Ward et al. (1990) discuss the advantages of early bilateral communication for suppliers which include reducing the length of meetings, eliminating incentives to delay work and increasing trust. These positive outcomes are largely a consequence of well implemented integration mechanisms enabling effective and efficient collaboration, a good understanding of the preliminary information, and the set of possible design changes which could follow as well as a clear communication of design tolerances allowing suppliers to start working on a solution right away. The same authors report that despite common expectations, Toyota communicates fairly infrequently with their suppliers supposedly due to the way in which suppliers are managed and the design responsibility allocation (see section 3.2.4) (Ward et al., 1995).

In LPD, the different functions, however, are not just required to communicate frequently in formal and informal settings in a dialogue mode, i.e. bilaterally, but also early to front-load the development project with all relevant available data (see bottom Figure 19) (Kahn et al., 2012). For more details on front-loading see the previous section 3.2.5. In LPD, it is at the outset of a development project that the amount of involved people is highest to bring downstream consideration to the table when the project is most flexible and the cost for changes are lowest (Morgan and Liker, 2006). At this point the strong project manager synthesises existing data from prior projects, including previous post-launch review insights (Cooper et al., 2004c; Kahn et al., 2012), and resorts to the knowledge of the functional experts to confront all difficult trade-offs (Womack et al., 1990). All team members then sign formal pledges to adhere to what was agreed upon in the group which consequently means that all major resource conflicts arise early in the projects and not at its end (Womack et al., 1990). The success of early involvement or front-loading depends heavily on the existing knowledge base. The more knowledge there is available at the outset of the project, the more there is the project team can fall back on – the better informed these early trend-setting decision are (Clark and Fujimoto, 1991b). As mentioned in section 3.2.2, development team members at Toyota retain close relationships with their individual departments to maintain a steady knowledge transfer even if those cross-functional team members are collocated and therefore lack the physical proximity to their departmental colleagues (Womack et al., 1990). This is especially important since the deep reaching technical knowledge which has been built over the years is typically stored, developed, and shared within the individual functional domains (Hoppmann et al., 2011). In small companies, it can be often observed that the success of development projects heavily rely on the tacit knowledge employees have built over the years. Should these specialists retire, be deemed unfit to work for any reason, or simple change the employer without having been able to pass on their experience and knowledge, companies often experience a heavy loss in expertise. In addition to the aforementioned risks, large companies which have potentially more diverse product portfolios and a wider range of technological expertise they rely on, also often have to cope with frequently changing development team members. It is therefore imperative to learn from past experiences, good and bad, store this knowledge in an easily accessible and updateable way, and retrieve it whenever necessary (Cooper, 2004a; Mascitelli, 2007; Morgan and Liker, 2006; Hoppmann et al., 2011). The effective documentation of a company's experience in form of lessons learned and best practices not only prevents the wasteful act of regenerating knowledge (Hoppmann et al., 2011) but also allows retracing past design decisions helping to avoid making the same mistake twice (Ward et al., 1995). Minimising barriers to store, obtain, and update information plays a key role in the success of knowledge repositories. A frequently encountered example for a barrier which affects all three, the entering, retrieval, and updating, is the unsystematic mass storage on company servers. To facilitate the effective and efficient usage of knowledge repositories, the accumulated data should be clearly and logically organised (Hoppmann et al., 2011) and engineers should be incentivised and allowed sufficient time for sharing their knowledge with other employees (Oppenheim, 2004). Mascitelli (2007) further suggests to regularly reorganise and inspect existing data with regards to its correctness and timeliness to maintain data quality and sustain the usefulness of the knowledge repository. In practice, a company needs to draw on some form of tool to allow for the effective storage and retrieval of explicit knowledge. The wide variety of tools a company can employ ranges from deeply, in all processes integrated information technology solutions, such as product lifecycle management (PLM) systems[25], all the way to Toyota's simple yet effective checklists detailing its technological capabilities (see section 3.2.5) (Ward et al., 1995). For more information on how Toyota manages its explicit knowledge refer to Mascitelli (2007) as well as Morgan and Liker (2006).

Many companies focus on explicit knowledge due to its tangible character which allows it to be codified, transferred, and stored without significant loss (Morgan and Liker, 2006). In other words, mathematical equations, design proposals, prototype test results, and the like can be

[25] PLM is a management concept which stores and integrates all data and processes of a product over its entire lifecycle – from the first idea to its design, production, all the way to its recycling. In addition, PLM integrates all involved functions such as marketing, sales, design, and production, in a company and all internal as well as external suppliers along the entire supply chain (Bitzer, 2008). In other words, PLM integrates all explicit data and knowledge of a product vertically throughout the entire supply chain and horizontally across the whole lifecycle (Freudenberg, 2011).

written down, moved from device to device or printed out to be passed on, and stored in whichever system a company choses to employ. Despite the many advantages manageable knowledge brings with it, it is the explicit knowledge's tangibility which renders it reproducible thus imitable for the competition. This stands in stark contrast to the typically hard to transfer and often complex tacit knowledge. In an effort to clarify the somewhat difficult to grasp character of tacit knowledge, Morgan and Liker (2006) aptly quote the example of the apprenticeship tradition to share implicit, hard to define, and complex knowledge acquired over a lifetime of experience. This knowledge, which to a great extent makes the difference between apprentice and master craftsman, is being shared over an extended period in a close relationship. Dyer and Nobeoka (2000) identify tacit knowledge as a powerful source of competitive advantage. In an effort to get the most out of the available tacit knowledge and to preserve its competitive advantage, Toyota employs a multitude of measures to gather, disseminate, and utilise the expertise 'hidden' in its workforce. Combined, these measures form an intricate learning network spanning across the entire company and creating a culture with a heavy emphasis on its employees. For a detailed account of the measures Toyota employs to establish, maintain, and nurture its learning network refer to Morgan and Liker (2006).

3.2.7 Process Management

Compared to manufacturing, where materials are processed in a meaningful way, it is information in product development which constitutes the primary input and output of a PD process (Reinertsen, 2005). Consequently, looking through a value stream lens, it is information and its interim deliverables which primarily hold value in PD (León and Farries, 2011). This, however, is not to say that the more information a company has at hand the more value it holds; information is not intrinsically valuable, at least not from the economic perspective of a company. According to Browning et al. (2002), a company is only able to extract value from information if it is useful. Should a company receive useful information whether it is from a customer, business partner, supplier or any other imaginable source of useful information and independent of its approach to PD whether it employs a closed or open model and whether it reacts to a market pull or actively pushes a product to the market, the company then has to meaningfully process this information to transform its inherent value into stakeholder gain. Browning (2003) argues that similar to the flow of deliverables in a material-based environment it is the information flow in a knowledge-based environment which has a great influence on the amount of value that can be extracted from that information. A practical example should shed some light on this issue. A company which has access to a useful and valuable piece of information, such as a technology which, if speedily integrated into a product, could revolutionise the market and generate tremendous profit. If the company, however, not recognises the value of the technology and does not react to its discovery, it potentially loses a lot of its value should competitors move first with it to the market. A more relevant scenario for this discussion and one that is found in all industries, is the ineffective and inefficient processing of this information; its transformation from just information into a marketable product. Consequently, it can be argued that similar to manufacturing processes, the overall architecture and structure of the PD process and the way in which the different activities within this process interact, largely determines the process' value trajectory (Browning, 2003; León and Farris, 2011). Therefore, an effectively and efficiently structured and managed LPD process has a significant effect on overall development performance (Browning, 2001).

As stated previously, the idea of linking a process' structure and the way in which the activities within this process interact to development performance is not new (León and Farris, 2011). In 1992, Cusumano and Nobeoka (1992) reviewed a range of product development studies in the auto industry, including those conducted at Toyota, and arrived at the conclusion that overlapping stages (see section 3.2.3) as well as the way in which actors in a development process communicate (see section 3.2.6) greatly contribute to LPD performance. From a process modelling point of view, the most important factors which influence performance are the different activities and how they interact. Their interaction in terms of communication (see section 3.2.6), integration into cross-functional teams (see section 3.2.2) as well as the leadership by a SPM (see section 3.2.1) has been covered in detail in previous sections in this chapter. Furthermore, section 3.2.4 covered the nature of the supplier relationships a company, seeking to employ LPD, wants to strive for and how they can be integrated into a LPD process. After having covered a number of aspects which could be included in this section elsewhere in this chapter, the remainder of this section will firmly set its focus on two important features of a LPD processes – *standardisation* and *workload levelling*.

Product development processes naturally differ from industry to industry, company to company, and even project to project due to the way in which a company is structured and coordinates its activities, as well as the nature and inherent complexity of development projects. While this appears to be an inalterable fact at this point, Fiore (2005) and Morgan and Liker (2006) argue that numerous activities and tasks in the planning as well as execution of development projects are overall fairly similar. In an effort to reduce sources of error, drive down variability, formalise knowledge management, strengthen schedule discipline, and establish a starting point for continuous improvement, literature on LPD and best practice studies in PD research recommends the identification and standardisation of reoccurring activities and tasks and their formal documentation (Ballé and Ballé, 2005; Brown, 2007; Hoppmann et al., 2011; Kahn et al. 2012; Morgan and Liker, 2006). Standardised work has been a core principle in Henry Ford's mass production system and was adapted by Toyota in the early days of Lean as well as LPD and has been rigorously applied throughout the company (Ohno, 1988). Although some might argue that standardisation stifles creativity, Nilsson-Wittel et al. (2005) predict and Morgan and Liker (2006), who studied Toyota's development practices in great detail, prove that, if applied correctly, standardisation has great potential for speeding up necessary but non-value adding activities such as administrative tasks as well as value adding routine tasks such as simple CAD jobs, allow for their precise execution, improve their overall quality by fostering reliability and predictability, minimise waste and therefore save time and cost, and consequently free up time and money for creative tasks. These findings have been later confirmed by Brown's (2007) benchmark report on LPD. Cooper et al. (2004c) emphasise the importance creating space for creativity and providing resources to experiment with new ideas.

Spear and Bowen (1999) further identify that the employment of standardised activities and processes facilitates problem diagnosis, the analysis of root causes, as well as the development and deployment of countermeasures. Process standardisation also constitutes a main enabling factor for concurrent engineering as well as the structural basis for coordinating the parallel execution of cross-functional processes (Schuh, 2013). Standards, however, cannot be established and rigorously adhered to but need to be continuously challenged and improved as part of a, as detailed in the following section 3.2.9, continuous improvement effort to adapt to an ever changing environment and increase their overall quality (Morgan and Liker, 2006). Morgan and Liker (2006) list and explain a number of useful tools in their 2006 publication which can help practitioners in their effort to develop and deploy standards as well as support all involved parties in complying with already established standards. Ward et al. (2007) and Kennedy (2003) advice caution not to overregulate development processes which can quickly have negative consequences such as unnecessarily imposing administrative barriers, restricting personal responsibility thus eroding the much needed space for flexible, problem-oriented actions, and potentially stifling creativity. Results from Kahn et al.'s (2012) best practice study further recommend an adaptable and flexible development process which can be tailored towards the

Having no standards, however, often gives rise to problems on the other end of the spectrum such as waste, especially with regard to searching for information, unstructured activity flow, as well as interface problems (Schuh, 2013). A company therefore has to sensibly and flexibly engage with standardisation and constantly challenge existing standards to avoid the aforementioned negative consequences associated with having no or too little standards as well as those caused by overburdening the LPD process through overregulating development activities.

The second pillar of LPD process management which has not yet been detailed elsewhere in this chapter and is therefore discussed in this section is the levelling of workload. Workload levelling is deeply rooted in the Lean as well as LPD concept and can be attributed to the definition of the first Lean principles[26] in Womack and Jones' (1996b) publication 'Lean Thinking'. Workload levelling, in short, is the idea of homogenously distributing workload thus moving away from the traditional batch-and-queue approach to developing products where marketing determines a 'need', engineers design and prototype a product to serve this particular need, the tooling department then develops and manufactures tools to mass-produce the product, and subsequently hands over these tools to the production engineers who determine how to set-up the machines most effectively and assemble the product. In the meantime, the purchasing department ordered the needed raw materials and required parts for productions after the design has been finalised and the marketing department developed a strategy as well as measures to successfully introduce the product to the market (Womack and Jones, 1996b). The batch-and-queue approach, which is often a direct result of employing a sequential process model such as Stage-Gate®, puts a heavy workload on the team currently engaged in the corresponding development activity while leaving those up- and downstream mostly idle. This approach to organising and structuring development creates a highly unlevelled workflow which, amongst others, significantly contributes to overburdening employees, increases development times and costs, as well as decreases the overall quality of development activities (Fiore, 2005; Hoppmann et al., 2011; Morgan and Liker, 2006; Reinertsen, 2009; Ward et al., 2007). For a more detailed account of the negative consequences associated with an unlevelled workload refer to Reinertsen's book on PD flow published in 2009 or see section 2.2.2 and 3.2.3 for the disadvantages of a sequentially structured development process.

[26] Workload levelling is a main enabler behind the third principle 'flow' (see section 2.1.3).

Next to the integration of cross-functional teams into a concurrent engineering environment, as discussed in section 3.2.2 and 3.2.3, workload levelling can be mainly achieved through well-balanced resource allocation and careful scheduling. According to Cusumano and Nobeoka (1998) who have dedicated themselves to the 'Lean movement', it is essential to start looking at resource allocation on a company-level. On this level most companies will have multiple development projects running in parallel with each of them competing for a limited amount of human, technical, and financial resources. Hence, maximising overall LPD performance asks for planning resources across development projects and considering further aspects such as project merits, immanent market needs, and strategic objectives (Cooper et al., 2004a, b; Hoppmann et al., 2011). Cusumano and Nobeoka (1998), Ward et al. (2007) and Morgan and Liker (2006) therefore recommend staggering development projects to avoid over- and underutilisation of resources where possible. However, since market forces often preclude this and sales and marketing have to determine ideal product launch times without much consideration for resource allocation, engineering is often left overburdened in a severely constraint resource environment (Morgan and Liker, 2006).

To optimise resource allocation across multiple, concurrent development projects and to assist companies in their effort to manage interrelationships between projects developing increasingly sophisticated and technologically complex products (Morgan and Liker, 2006), literature on LPD recommends employing multi-project management, an approach pioneered by Takeshi Uchiyamada, Toyota's chief engineer for the Prius which has been developed during the early 90s (Itazaki, 1999). Multi-project management reached a wide audience after Cusumano and Nobeoka's (1998) publication 'Thinking beyond Lean' and has since found its way into all LPD development frameworks that followed (cf. Morgan and Liker, 2006; cf. Brown, 2007; cf. Ward et al., 2007; cf. Hoppmann et al., 2011; cf. Schuh, 2013). While multi-project management recognises the autonomy and personal responsibility of a SPM, as discussed in section 3.2.1, it encourages multi-project thinking rather than focusing on single project optimisation. Although Cusumano and Nobeoka (1998) present compelling evidence in favour of Toyota's multi-project practices, the authors acknowledge that, amongst others, differences in the organisational structure, a company's product portfolio, and resource availability have a strong influence on how multi-project management can be best realised. In some cases internal and informal coordination among strong project managers and their project teams might suffice while other companies might achieve better results when installing a formal authority who coordinates and manages critical resources across all development projects (Cusumano and Nobeoka, 1998). Both authors, however, unequivocally agree that, independent of the company specific context, an important prerequisite to cross-project resource planning and coordination is the disciplined and accurate scheduling of development projects and its activities (Morgan and Liker, 2006).

The reliable planning and scheduling of development projects allow for appropriate resource allocation, especially with regard to functional experts who often find themselves burdened by having to work in multiple projects in parallel thus are exposed to inefficiencies caused by multitasking (Hoppmann et al., 2011; Smith and Reinertsen, 1991; Ward et al., 2007). Hoppmann et al. (2011), Morgan and Liker (2006) as well as Schuh (2013) suggest that a clear prioritisation, synchronisation, and uniform execution of tasks within all involved project teams is crucial when striving towards schedule discipline serving as the basis of cross-project resource management. Some authors suggest to replicate the in manufacturing well-established concept of cadence and takt time; introducing regular and rhythmic task cycles within individual projects to establish a uniform and predictable flow of activities (Haque and James-Moore, 2004; Hoppmann et al., 2011; Morgan and Liker, 2006; Oppenheim, 2004; Reinertsen, 2009; Schuh, 2013; Ward et al., 2007). For a detailed account of how a company can establish cadence in product development processes refer to Morgan and Liker (2006), Reinertsen (2009), and Schuh (2013). Due to unforeseeable events, the high probability of design iterations, as well as the inherently hard-to-predict nature of PD which can cause disruptions in the development schedule, a LPD system should provide extra capacity which can be flexibly used in case of any bottlenecks. Morgan and Liker (2006) report that Toyota, for example, combines flexible staffing with satellite companies which can provide additional resources.

A LPD process and its management is the product of a complex equation consisting of a myriad of variables which need to be carefully defined, integrated, and aligned to get the most out of a LPD system. While this section has merely discussed the importance of standardisation and workload levelling, which is mainly achieved through sensible resource allocation and rigorous scheduling, there are many more contributors to a successfully management LPD process. Without the infrastructure of a SPM who integrates cross-functional teams into a concurrent engineering environment in which all players communicate early and frequently with all involved parties including suppliers, and a culture of excellence in which people continuously improve all aspects of their work thus constantly increase the overall quality of a development process and its products, a LPD process cannot develop its full potential.

3.2.8 Product Variety Management

The days of Henry Ford when capturing large market shares meant producing standard products in large volumes are long gone (MacDuffie et al., 1996). Today's increasingly sophisticated customers demand products tailored to their needs and the globalised market has to react quickly to capture market shares in ever smaller niches. Ford's 'any colour, as long as it is black'-approach no longer represents a viable strategy to product diversity (Tanner, 2009). As a consequence, many companies have to deal with an ever growing product portfolio comprising of a large number of low volume niche products (Clark and Fujimoto, 1991b). The good intentions behind launching new products such as growing sales, maximising profits, and capturing market shares, however, often quickly erode under the pressure of the inability to use economies of scale as well as growing inefficiencies and increasing complexities throughout the company and the products' lifecycle (MacDuffie et al., 1996; Tanner, 2009). At the same time, offering customers an increasingly diverse product portfolio demands a more flexible workforce, manufacturing equipment and overall more responsive and adaptive processes (Suarez et al., 1991). In the LPD literature, authors who have researched techniques and strategies to cope with the disadvantages of a large product variety have summarised their efforts under 'product variety management' (Hopmmann et al., 2011).

Fiore (2005), Morgan and Liker (2006), Ward et al. (2007) as well as other authors generally recommend to buy-in readily available parts from suppliers if developing and manufacturing them in-house will not result in significant cost and technology advantages and if in-house production is not perceived to any other major upside. Buying catalogue parts of trusted suppliers not only frees up internal development and production capacities but also has the advantage of being able to draw on the suppliers' experience which have potentially already a far greater expertise in the relevant field and therefore could significantly reduce risks affiliated with the sourced part.

It is further suggested to make the most of already existing products and parts by reusing them in whole or in part. The reuse of existing 'off-the-shelf' parts further frees up development capacities, reduces risks affiliated with new parts, and significantly drives down costs since the company has already the tools and machinery to manufacture those parts and further saves on the development costs (Hoppmann et al., 2011). Schuh (2013) states regarding buying-in and reusing parts that companies should only develop and manufacture parts if they add value to the final product from a customer's point of view or if they add critical and significant differentiating factors which allows the product standing out from its competition. Ulrich (1995) further expands on Schuh's (2013) statement by suggesting that companies should only produce variants or new parts if they add value which can be perceived from the end customer and if there are no existing, reusable parts which could fulfil the demanded functions. Fiore (2005) supports Ulrich's (1995) findings arguing that his observations and interviews at Toyota have shown that the originator of the LPD system is very reluctant to develop new technology and generally tries to get the most out of their existing portfolio. A study by Schuh et al. published in 2007 has shown that Toyota and other development 'outperformers' carry over about two thirds of all parts from an existing product into its succeeding model. Although The Economist has denounced Toyota as 'the champion of putting old wine in new bottles' (The Economist, 2005, p.74) due to this high carry-over rate, researchers have recognised that this factor plays a vital role in the robustness of the final product and the processes it has to go through to its market launch as well as the ability to quickly react to market needs with a new model or product (Schuh et al., 2007).

Technologically complex and highly integrated products, however, often have a negative impact on the possibility of ordering catalogue parts or reusing existing off-the-shelf solutions. Therefore many companies facing the development and production of complex products make use of modules and smaller assembly groups with standardised interfaces (Baldwin and Clark, 2000; Hoppmann et al., 2011). The concept of modularity has proven successful in various industries which have recognised the advantages of working with units containing interdependent subassemblies and parts which are structurally independent of the larger system but work together if integrated into an architecture which 'allows for both independence of structure and integration of function' (Baldwin and Clark, 2000, p.75). Schuh (2013) who has studied a number of automobile companies has identified the Volkswagen Group as an impressive example how intelligently designed architectures and modules can yield significant competitive advantages. In their 2009 annual report, Volkswagen advertise an increase of 10% in carry-over parts and a decrease of 20% in development, production, and sourcing expenditure as well as 30% lowered engineering hours per vehicle (Volkswagen Group, 2009). Translated into a complex and development-intensive product such as an automobile and applied across the whole group in which technology is handed down from their premium brands including Audi to their medium-range brands such as Volkswagen to Skoda which is targeting more cost-conscious customers, this concept of intelligent modular construction can result in tremendous competitive advantages. The reported performance improvements are enabled, amongst others, by facilitating concurrent engineering, the redesign of subassemblies and individual parts, reducing the overall complexity of the product, as well as improving its maintainability due to their geometrical and technological well-defined nature and its standardised interface with neighbouring modules. Additionally, these enablers further improve the company's ability to drive continuous improvement and foster knowledge transfer (Fiore, 2005; Hoppmann et al., 2011; Morgan and Liker, 2006, Schuh, 2013).

Many companies which are facing different architectural and technological challenges or do not use an intelligent architecture as sophisticated as Volkswagen's modular construction design also resort to product platforms which, as the name suggests, serve as carriers for modules and subassemblies. These platforms allow proven modules to be integrated into other product lines hence are increasing a product's carry-over-rate and the reusability of existing solutions (Hoppmann et al., 2011). The combination of geometrically predefined modules with standardised interfaces on platforms enables a company to offer a diverse product portfolio while keeping part variety relatively low thus addressing as many customers as possible with the least of the previously mentioned negative consequences of high product variety (Markham and Lee, 2013; Morgan and Liker, 2006).

3.2.9 Continuous Improvement

The roots of continuous improvement (CI) can be traced far back into the 1800s, the days of industrial revolution and scientific management (Bhuiyan and Baghel, 2005). A big impetus for modern CI as we understand it today, however, was given when the U.S. government initiated the 'Training within Industry' service which aimed at increasing the national industrial output during war times in the 1940s. This programme was later introduced in Japan by today well-known quality gurus such as Deming, Juran, and Gilbreth as well as locally stationed U.S. military forces (Robinson, 1990; Schroeder and Robinson, 1991). Eventually, the Japanese adopted the practices taught in the 'Training within Industry' programmes and developed them further. In the beginning the concept of CI was largely confined to manufacturing processes but soon evolved into a broad management tool that found its application on all levels of an organisation (Imai, 1986). The Japanese CI guru Imai (1986, p.5) who strongly contributed to spreading the Eastern interpretation of CI, i.e. Kaizen, even goes as far as calling it 'a way of life' which is naturally and often unconsciously pursued by both managers and workers. For a detailed historical background and practice review of CI programmes see Bessant et al. (1993), Besant et al. (1994), Melcher et al. (1990) as well as Schroder and Robinson (1991).

Over time, a myriad of CI methodologies have developed through adopting it to different contexts and looking at it from different perspectives (Bhuiyan and Baghel, 2005). In manufacturing, for instance, CI can be pursued using a variety of initiatives including Reengineering, Total Quality Management, Six Sigma, Quick Response Manufacturing, Variance Reduction, Agility, and Lean (Kushrow, 2001). Continuous improvement has gained much attention with regards to improving production while little efforts have been made to improve PD performance (Nilsson-Witell et al., 2005). Similarly to the amount of approaches which can be taken to achieve CI, a multitude of definitions exists highlighting the different emphases the individual methodologies place. In this context, the author follows Bhuiyan and Baghel (2005, p.761) who define CI 'as a culture of sustained improvement targeting the elimination of waste in all systems and processes of an organization'. This definition is considered to include the most important characteristics of CI, i.e. *culture*, *sustained*, *waste elimination* as well as in *all systems and processes*, and sits well in the Lean context.

Morgan and Liker (2006) state that without a culture of CI, which is loosely defined as the intrinsic drive every employee shares to improve each aspect of every day work, there can be no LPD. A company as a whole, from top to bottom, needs to commit to improvement, recognise potential for improvement and create a culture where problems can be freely admitted (Cooper et al., 2004a; Markham and Lee, 2013; Imai, 1986). If leadership does not allow for things to go wrong there can be no trial and error and CI as well as the entrepreneurial and innovative culture it is seeking to foster, is severely hampered (Cooper et al., 2004a). Analogously, Cooper et al. (2004a) and Kahn et al.'s (2012) best practice studies suggest to introduce a company-wide product idea suggestion system which rewards and recognises not only new products ideas per se but also entrepreneurial employees who are championing new products.

Leadership and culture are intrinsically tied to each other (Morgan and Liker, 2006). In this context Morgan and Liker (2006) cite Toyota as an example: in times of unparalleled success in 2004 Toyota's President felt threatened and declared a crisis. The threat, however, was no economic downturn, change in the political climate or legal development; it was complacency, the arch enemy of CI and business reinvention. CI is, as the name states, an on-going process and not a one-off project (Karlsson and Åhlström, 1996; Faust, 2009; Nilsson-Witell et al., 2005:764). It cannot be implemented at once and be forgotten about it but needs to be a sustained effort to improve every day work or spoken in Lean terms, to eliminate waste and drive value creation. For a detailed discussion of the concept of value and waste in product development see 2.3.2 and 2.3.3. Improvement activities need to be enabled on all levels through providing the individual experts with the freedom to explore new approaches (Brown, 2007; Faust, 2009). In CI, the employee and his creative problem-solving potential are in the centre of attention (Schuh, 2013). Accordingly, experts on all levels should be empowered with competencies and encouraged by management to drive continuous improvement projects whenever a potential area for improvement is spotted and circumstances allow for trying out new ways (Faust, 2009; Kahn et al., 2012). Schuh et al.'s (2007) study has demonstrated that companies which systematically increase personal responsibilities in PD have more effective continuous improvement processes. This has also shown to have positive effects on employee motivation. To achieve this, most companies make use of 'black box' process modules which allow independent design of activities and components within few boundary conditions (Schuh et al., 2007). In this context, Karlsson and Åhlström (1996) highlight the importance of continuously developing and improving the LPD elements cross-functional teams and supplier relationships. Regarding the latter, Middel et al. (2006) raise the bar of CI by applying it to an inter-organisational setting seeking for ways to support the goals of the extended enterprise through improving shared processes to make best use of the opportunities within the network. This idea of 'co-improvement' is well aligned with the partnerial way of thinking about supplier relationships and integration detailed in section 3.2.4. On a different note, Imai (1986) stresses the importance of a process-oriented management system and mind-set which acknowledges improvement efforts. This stands in stark contrast to often employed Western practices which typically solely reward performance-based results and not the effort made to potentially improve it (Imai, 1986).

Schuh et al. (2013) recommend working with ideal situations to deduce targets situations a company wants to achieve to ensure the success of and a clear path for CI programmes. This approach not only provides guidance to employees (Schuh et al., 2013) but also assures that the improvement initiatives are in alignment with strategic goals defined by top management (Schuh, 2013). Schuh et al. (2013) also underline the importance of CI identifying improved aspects of a company as hard to emulate by the competition. Since they do not appear on the balance sheets and are barely observable from outside the company, they form a useful protection against competition prospering through emulation. The authors view CI as a means to building unique and hard-to-emulate company competencies that set themselves apart from competition (Schuh et al., 2013).

3.3 Internal Relationships

The previous part of this chapter has lead a detailed discussion about the individual LPD elements. Throughout this discussion, the single aspects of this framework have been investigated separately to provide a clear structure and thoroughly address the distinct parts of the proposed LPD framework. In this discourse, a number of distinct interrelationships and interdependencies have been identified such as in the case of 'concurrent engineering', 'set-based design', 'product variety management', and particularly 'process management'. The complexity of these relationships, however, did not allow for a detailed discussion so that strong links to other LPD elements have only been highlighted where their examination was necessary to help gaining a deeper understanding or was deemed appropriate.

The perception of LPD as a complex framework of interrelating elements emerged over time as the understanding of Toyota's PD practices was gradually increased and moved away from viewing Lean practices in PD as a conglomerate of loosely connected methods and tools. This perspective on LPD was notably advanced by Hoppmann (2009), Hoppmann et al. (2011), Morgan and Liker (2006), Schuh (2013), and further supported, amongst others, by Ballé and Ballé (2005) as well as León and Farris (2011).

After effectively answering the first research question by formulating a comprehensive LPD framework which further includes findings and insights from the wider PD research area, this section progresses towards addressing the second research question which enquires into the internal relationships of the LPD framework. During the collection of quotes for the content analysis employed to develop the LPD framework and the literature review which added further details to the individual elements, various authors have discussed interfaces, relationships, and dependencies between the different components. The statements discussing these relationships have been collected, consolidated, and compiled in Table 6 et seq. The 9x9 matrix describes the influence the element in the row exerts on the corresponding LPD item in the column. This large array of qualitative descriptions of the inner workings of the proposed LPD framework not only supports the perception of LPD as a system of tightly interwoven elements thus cautiously confirms previously mentioned authors but also serves as a means which will later inform the analysis of the questionnaire thus join the empirical findings with the theoretical insights from literature.

How does element in row influence element in column?	Stong Project Manager	Teams	Concurrent Engineering
Stong Project Manager	x	Creates stronger commitment and helps keeping the cross-functional teams focused [14]. Coordinates teams and fosters learning through mentoring and design reviews [21].	Front-loads the design process through early integration of all involved functions and makes major technology decisions early [21]. Assures collaboration between functions [15].
Teams	Functional experts in development teams facilitate making decisions, addressing trade-offs [21], and provide qualified employees for future strong project managers [31].	x	Better understanding of the involved up- and downstream activities [21, 31]. Specialised engineering tasks allow parallelisation [6].
Concurrent Engineering	Early integration of all involved functions front-loads the development project, adresses difficult trade-offs, and overall supports reliable project planning [21].	Facilitates interfunctional communication and collaboration [21]. Problem-solving capabilities are influenced by the degree of overlap [6].	x
Supplier Relationship and Integration	Close supplier relationships and early integration help making technological decisions [8]. Reliable collaboration partners support robust project scheduling [21].	Guest engineers' augment team capabilities in terms of design and problem solving capabilities [21].	Suppliers take major responsibilities for design, development, testing, and production [21]. Augment capabilities and increase development capacities [5, 8].
Set-based Design	Systematic and objective reduction of solution space results in more robust designs and fewer late changes which imrpoves adherence to project schedules [3, 30].	Systematic and objective choice of design hightens technological understanding, fosters learning, and increases knowledge base [25, 27].	Large number of design solutions demands front-loading of PD process thus intagrates all involved functions which facilitates problem-solving [21, 29, 30].
Communication and Knowledge Transfer	Growing knowledge base helps in all aspects of project planning and supports technology decisions [27]. Discussios and lessons learned lead to new standards derived from a *Hansei* (reflection) process [21].	Growing knowledge base increases technical expertise [21, 27]. Direct communication serves as a facilitator for functional integration [14]. Problem-solving capabilities are influenced by the quality and speed of communication [6].	Exchange of ideas, knowledge, and experiences improves and speeds-up the development process [6, 21, 27]. Frequent communication reduces uncertainty thus rework [16, 18].
Process Management	Appropriately allocated resources and standardised processes promote reliable project planning [7, 21]. Standardisation of routine tasks facilitates project planning and helps monitoring and controlling the project [3, 4, 21].	Standardised processes speed up problem-solving cycles thus free up time for inter- and intrafunctional learning opportunities and overall increase learning [21, 28, 30]. Continuous challenging of established standards increases knowledge base [21].	Standardised processes increase process robustness and reliability which facilitate their coordination across functional borders [21, 22, 27]. Staggered development projects and appropriately allocated resources increase reliability of simultaneously executed processes [7, 21].
Product Variety Management	Clear guidelines for reuse of existing parts and use of off-the-shelf products reduce uncertainty and improve schedule adherence [21]. Modules, platforms, and the use of proven technology reduces development time and support reliable project planning [19].	Higher specialisation and faster learning due to clearly separated modules [25]. Easier coordination of tasks [10].	Reduced complexity of parallel product and process development through standardised modules and interfaces [25].
Continuous Improvement	Improved project planning and overall smoother project execution due to improved processes and a strong tacit and explicit knowledge base [21].	On-the-job training and a mentoring scheme forces the employee to constantly question and learn thus build knowledge [21].	Improved processes and functional interfaces facilitate concurrency and reduce risk [21].

Table 6: Qualitative relationships between LPD elements (Part 1)

How does element in row influence element in column?	Supplier Relationship and Integration	Set-based Design	Communication and Knowledge Transfer
Stong Project Manager	Front-loads the design process through early integration of supliers and sets the rules for supplier involvement. Sets product specific part requirements. Evaluates suppliers' prototypes and makes go/no-go decisions [21].	Oversees and coordinates development of design solutions, makes major technological decision, and narrows down solution space [21, 22, 30].	Promotes inter-functional communication [14]. Ensures knowledge transfer through functional integration and coordination [21, 30].
Teams	Functional integration and close collaboration improves problem-solving capabilities and leads to knowledge transfer [21].	Cross-functional teams of technical experts address problems early in the design process, help finding design solutions and obejctively reduce the solution space [25, 30].	Close collaboration and collocation promote knowledge transfer and facilitate communication [21, 29]. Close-knit teams promote fragmented and unilateral sharing of information [5].
Concurrent Engineering	Clear requirement definition, supplier mentoring, and enhanced communication [2, 12, 30].	Systematic assessment of manufacturability due to frequent review meetings and formalised processes. Early integration of all involved functions speeds up finding possible design solutions and subsequently helps reducing the solution space [12, 21, 25, 27, 30].	Concurrent engineering requires and promotes the frequent sharing of preliminary information in a dialogue-mode [5]. Early integration of all involved functions into the development projects fosters communication and promotes knowledge transfer [21].
Supplier Relationship and Integration	x	Develop design solutions and facilitates reduction of design space [8, 21, 25].	Partnerial supplier provides customer (and vice versa) with insights and expertise [5, 21]. Early and intensive supplier involvement fosters communication and knowledge exchange [1, 21].
Set-based Design	Early integration of suppliers into the development of design alternatives. Close collaboration through early integration [21].	x	Inquiry into many different design solutions dramatically increases knowledge base [11, 30].
Communication and Knowledge Transfer	Good communication and knowledge transfer strengthen the relationship and increase effectiveness of development of outsourced (black-box) parts [1, 17]. Educational support helps suppliers to improve their capabilities and allow delivering the demanded products in a cost and time effective manner [1, 23, 24].	Active and intense communication is essential [29]. Technical knowledge is readily available, manufacturing capabilities are transparent, and best practices support decision-making [21, 30].	x
Process Management	Easier integration of suppliers through standardised procedures and processes [21]. Standardised routine tasks accelerate identification of potential problems and speeds up problem-solving cycles [30].	Rigorous process management frees up time to pursue multiple design solutions at once [30] while standardised processes further increase problem-solving capabilities which helps reducing the solution space systematically and objectively [21].	Constant challenging of existing standards increases knowledge base [21]. Standardised routine tasks faciliate communication [30]. Standardised processes improve problem-solving cycles and free-up time for documentation learning activities [21, 30].
Product Variety Management	Higher carry-over rate and use of off-the-shelf products simplifies product part sourcing. Clearly defined modules with standardised interfaces facilitate outsourcing [12, 21, 30].	Clearly defined modules and platforms with standardised interfaces facilitate parallel development and testing [30].	Easier documentation of lessons learned, best practice of structures, and designs due to lower part variability and clearly defined interfaces [25].
Continuous Improvement	Shared experiences and best practices help improving supplier's products and processes thus keep costs down and quality up, resulting in shared benefits [1, 21, 23, 24]. Daily wrap-up meetings clarify goals and assignments, capture lessons learned and help resolving problems quickly [21].	Improved problem-solving capabilites help reducing the solution space more quickly [21].	Constantly verifies and updates the explicit knowledge base and extends tacit knowledge [21].

Table 7: Qualitative relationships between LPD elements (Part 2)

How does element in row influence element in column?	Process Management	Product Variety Management	Continuous Improvement
Stong Project Manager	Sets project time frame and controls adherence to it [12, 21]. Great technical knowledge and major component decisions of strong project manager provide a clear concept and reduce variability [21, 25].	Sets guidelines for use of off-the-shelf products, reuse of parts, and modularisation by making major technoligical decisions and balancing the bussiness and engineering case [14, 22, 27].	Sets continuous improvement goals [25]. Exemplifies continuous improvement and establishes culture [21]. Systematically empowers and encourages employees to conduct continuous improvement initiatives [9, 25].
Teams	Integration of functional experts with deep reaching technical knowledge and their collaboration throughout the entire development project reduce design iterations, create more robust processes, and improve adherence to schedules [21, 30].	Team members draw on functional expertise and add their knowledge to the development of products, parts, modules, and platforms [21, 25].	Exercise continuous improvement on a daily basis [20, 21]. Strong knowledge base is the foundation for continuous improvement [12].
Concurrent Engineering	Early inegration of all involved functions reduces variability. Frequent review meetings and formalised design evaluation processes increase manufacturability, assembly compatibility, and make the development process more robust [21].	Necessary close departmental collaboration facilitates highly functional and manufacturable parts, modules, and platforms and overall supports holistic optimisation of products [21].	Close collaboration and intensive communication necessary for concurrent engineering reveals areas of potential improvement [21].
Supplier Relationship and Integration	Integration of high-capability suppliers into development project augments development capabilities thus frees up capacities and helps creating a more robust and reliable process by integrating supplier expertise [7, 21].	Suppliers challenge requirements and provide (innovative) input. In case of outsourced designs, the suppliers largely determine the product, its features, and performance and are only constraint by the customer's requirements [21].	Elevates continuous improvement to a collaborative level to drive optimisation in the value stream [20]. Suppliers and OEMs share knowledge, best practices, and experiences and coordinate common improvement activities [13, 20].
Set-based Design	Systematic and objective evaluation of multiple design alternatives and reduction of solution space to a single solution results in robust parts and products which promotes reliable project planning [25, 30].	Robust and objective choice of design solutions leads to better technological understanding and higher quality parts, modules, and platforms [25].	Exploration of a wide array of solutions strengthens the knowledge base and helps improving future products more quickly [21].
Communication and Knowledge Transfer	Up-to-date knowledge base including experiences from previous projects, facilitates appropriate resource allocation and helps the project staying on track by basing decisions on objective data [7]. Explicit knowledge base helps defining standards and promotes their continuous challenging [21].	Technical knowledge stored, developed, and shared within functional domains is largely made explicit. Previous technological experiences, best practices, and lessons learned inform parts, modules, and platforms [4, 12].	Effective and open-mode communication serves as a facilitator. Capturing and dessiminating knowledge [20].
Process Management	x	Appropppriate resource allocation and standardised processes facilitate development [7]. Standardised routine tasks help making decisions about carrying over parts [21]. Standardised processes result in more robust processes which facilitate the specification and design of parts, modules, and platforms [12, 21].	Standardisation is a prerequisite for continuous improvement [3, 21, 27]. Formal problem-solving cycle is required for continuous improvement [20].
Product Variety Management	Clear rules for reuse of existing parts and use of off-the-shelf products as well as standardised parts, modules, and platforms reduce variability and helps adhering to schedules and project targets [10, 12, 25, 30].	x	Modular design increases reuse, fosters learning, and continuous improvement [10, 11, 21, 26].
Continuous Improvement	Root-cause countermeasures prevent reoccuring problems [29]. Improved standards through shared *Hansei* (reflection) experiences. Reviewed and improved processes are more transparent, less risky, and speed up development time [21].	Continuous improvement drives part, module, and platform performance [30]. *Hansei* (reflection) events help keeping the product focused on the customer. Improved problem-solving capability helps arriving at an optimal solution quicker [21].	x

Table 8: Qualitative relationships between LPD elements (Part 3)

1	Aoki and Lennerfors, 2013	12	Hoppmann et al., 2011	22	Oppenheim, 2004
2	Asanuma, 1989	13	Kaltoft et al., 2007	23	Pérez Pérez and Martínez Sánchez, 2002
3	Ballé and Ballé, 2005	14	Karlsson and Åhlström, 1996	24	Sako, 2004
4	Brown, 2007	15	Kennedy, 2003	25	Schuh, 2013
5	Clark and Fujimoto, 1991b	16	Lin et al., 2010	26	Smith and Reinertsen, 1991
6	Clark et al., 1987	17	Lincoln and Shimotani, 2009	27	Sobek II et al., 1999
7	Cusumano and Nobeoka, 1998	18	Loch and Terwiesch, 1998	28	Thomke and Fujimoto, 2000
8	Cusumano and Takeishi, 1991	19	Mascitelli, 2011	29	Ward et al., 1995
9	Faust, 2009	20	Middel et al., 2006	30	Ward et al., 2007
10	Fiore, 2005	21	Morgan and Liker, 2006	31	Womack et al., 1990
11	Haque and James-Moore, 2004				

Table 9: Author legend for Table 6 - Table 8

3.4 Concluding Remarks

This chapter firstly introduced a number of existing LPD frameworks, discussed the chosen methodological approach to develop the subsequently detailed proposed framework, and lastly concluded with the qualitative description of the interrelationships between the single elements. On this endeavour, this third chapter of the thesis served a number of purposes which will be outlined in the following.

First and foremost, the development of a comprehensive LPD framework and its combination with findings from the wider PD research area effectively answered the first research question - what constitutes a coherent and comprehensive LPD framework? In an effort to thoroughly address this question, the individual LPD elements have been separately discussed in much detail to provide a clear and well-structured picture of this approach to managing and organising PD. The development of the proposed framework, however, not just answered the first research question but further constitutes a necessary requirement for addressing the other two major gaps identified in literature.

The second area of LPD research the work at hand is attempting to advance is the understanding of the inner workings of a LPD framework. Although the single components of this framework have been discussed individually for the sake of clarity, various authors convincingly argue to regard LPD as a framework of tightly and dynamically linked elements. Consequently, the third and last part of this chapter presented the qualitative descriptions, numerous authors brought forward, in a large 9x9 matrix. The mere fact that each of the 72 relationships is covered by literature and the amount of publications which have contributed to the description of these interrelationships strongly support the perspective on LPD as a framework of highly-interrelated elements. In addition to qualitatively describing the element relationships, this part of the chapter also serves as a starting point for the empirical inquiry into the inner workings of the proposed framework. Through their integration into the analysis of this study's primary data, the descriptions compiled in Table 6 et seq. provide a link between literature and the insights gained throughout this work.

In the course of developing and discussing the LPD framework as well as describing the relationships between its elements, this chapter conducted a detailed review of the existing frameworks and the numerous multifaceted research areas the individual LPD elements are placed in. The review of the various aspects of this chapter started at the centre of LPD research, covered topics such as continuous improvement which are closely connected to the material-based Lean philosophy, discussed concepts such as the SPM which are unique to the LPD approach, and delved into widely-discussed but relatively far-removed areas such as communication and knowledge transfer or supplier relationship and integration. Due to the heterogeneous character of this review, the limitations of this investigation, and in an effort to keep the focus firmly on the key ideas behind the individual LPD elements and their characterising concepts, the discussions needed to be limited to the core aspects most relevant to this work.

The necessity to be selective in the literature review for the development of the LPD framework was carried over to the integration of best practice studies since there are a number of best practices which, from a subjective point of view, seem to be aligned with LPD practices but do not fall within the scope of this framework. All three studies in which the current best practices in PD have been identified, for example, include a wide range of practices covering operational aspects of PD which lie beyond the scope of this work (see 2.2.3 or Appendix A for more details) (cf. Cooper et al., 2004a, b, c; cf. Kahn et al., 2012; cf. Markham and Lee, 2013). Analogously, other best practices which could not be associated with any of the LPD elements have not been considered.

In possession of a deep understanding of what constitutes a LPD framework and a firm grasp of what the individual elements represent, the succeeding chapter will detail the main methodological considerations of this study to pave the way for the subsequent presentation and discussion of the results.

4 Methodology

The chapter initially rationalises the chosen research design, then debates a number of philosophical aspects and firmly positions the author and this research in this discourse, before discussing the merits and shortfalls of mixed-methods research to contextualise the previously employed content analysis and shade light on the questionnaire which serves as the primary research instrument in this inquiry.

4.1 Research Design

The research questions posed in section 1.3 form the basis for the definition of a suitable research design. The primary concern is with the research gap and how it can be addressed most appropriately within the constraints of the research project (Creswell and Plano Clark, 2007; Gorard and Taylor, 2004; Johnson and Onwuegbuzie, 2004; Saunders et al., 2009; Teddlie and Tashakkori, 2009; White, 2009). A firm understanding of the research problem at hand informs the research design which is defined by de Vaus (2001, p.9) as ‘the logical structure of the inquiry’.

Presenting a research design bears difficulties since many typologies and a plethora of terms exist to classify and describe the logical framework of a research project (Robson, 2011; Teddlie and Tashakkori, 2009). In an attempt to offer a highly descriptive classification system Johnson (2001) advocates to characterise the variety of research designs in terms of the research purpose and time horizon. Following this call and referring back to the research questions in section 1.3, the chosen research design has a descriptive and explanatory character. With regard to the time horizon of the research project at hand, it is argued that the research questions reflect the literature's call for a cross-sectional design. Although the second research question which asks to investigate the relationships between the single components might just as well be answerable inquiring one or a few companies over a longer period in a more experimental scenario, time constraints and the strong demand for generalisable results with a strong empirical basis tip the case in favour of a cross-sectional approach.

Cross-sectional studies investigate a particular phenomenon or a multitude of phenomena on more than one case at a single point in time (Bryman and Bell, 2011; David and Sutton, 2011; Saunders et al., 2009). By its very definition, this characteristic rules out any design which relies on pre-test and post-test measures, such as experiments or action research. In contrast to the latter two design types where the independent variable is manipulated to determine how the dependent variable changes, a cross-sectional design requires an extensive literature review to determine all relevant variables and their type (David and Sutton, 2011).

Leaving now Johnson's (2001) way of describing research designs behind, the obvious choice at this point is to take a survey approach. The survey strategy is frequently used as a synonym for a cross-sectional design and typically associated with a questionnaire but by no means confined to (Bryman and Bell, 2011; David and Sutton, 2011). However, the exclusive employment of a survey would have not sufficed to appropriately address the research questions of this research. Since literature called for the development of a comprehensive LPD framework which combines the most established frameworks to overcome the current confusion about what constitutes a LPD system, a content analysis has been used to collect quotes from relevant LPD literature which characterise LPD elements. For the benefit of the structure of this thesis, the content analysis has been discussed in the previous section 3.1.2. Therefore, it is argued that a multi-strategy design, also referred to as mixed method design, appears most appropriate. Mixed method designs employ both qualitative and quantitative research methods within one research project and combine them in one overarching strategy (Bryman, 2006; Bryman and Bell, 2011; Johnson and Onwuegbuzie, 2004; Leech and Onwuegbuzie, 2009; Robson, 2011; Teddlie and Tashakkori, 2009). These designs address the specific demands posed by research questions which require employing qualitative and quantitative data collection methods.

The research questions demand developing the LPD framework before it can be studied in breadth and depth. The research methods are used in sequence with the results of the first method feeding into the second. This type of design is commonly referred to as sequential mixed design (cf. Creswell and Plano Clark, 2007; cf. Greene, 2007; cf. Leech and Onwuegbuzie, 2009; cf. Teddlie and Tashakkori, 2009). The first, exploratory and descriptive phase in this design was approached inductively employing the earlier described content analysis which led to the construction of the LPD framework discussed in detail in section 3.2. The proposed framework subsequently serves as the basis for the development of scales and items for the subsequent quantitative phase. In consideration of the identified gaps in literature, the principal method is the quantitative questionnaire. The smaller qualitative part of this study should be understood as a means to address the first research question and support the development of content for the questionnaire. This combination of research methods is, according to Bryman (2006), the most common choice among social scientists who employ both qualitative and quantitative methods in one study. A more detailed discussion on the methods and their interactions will be provided in the following section 4.3. Figure 20 illustrates the chosen research design based on Robson (2011).

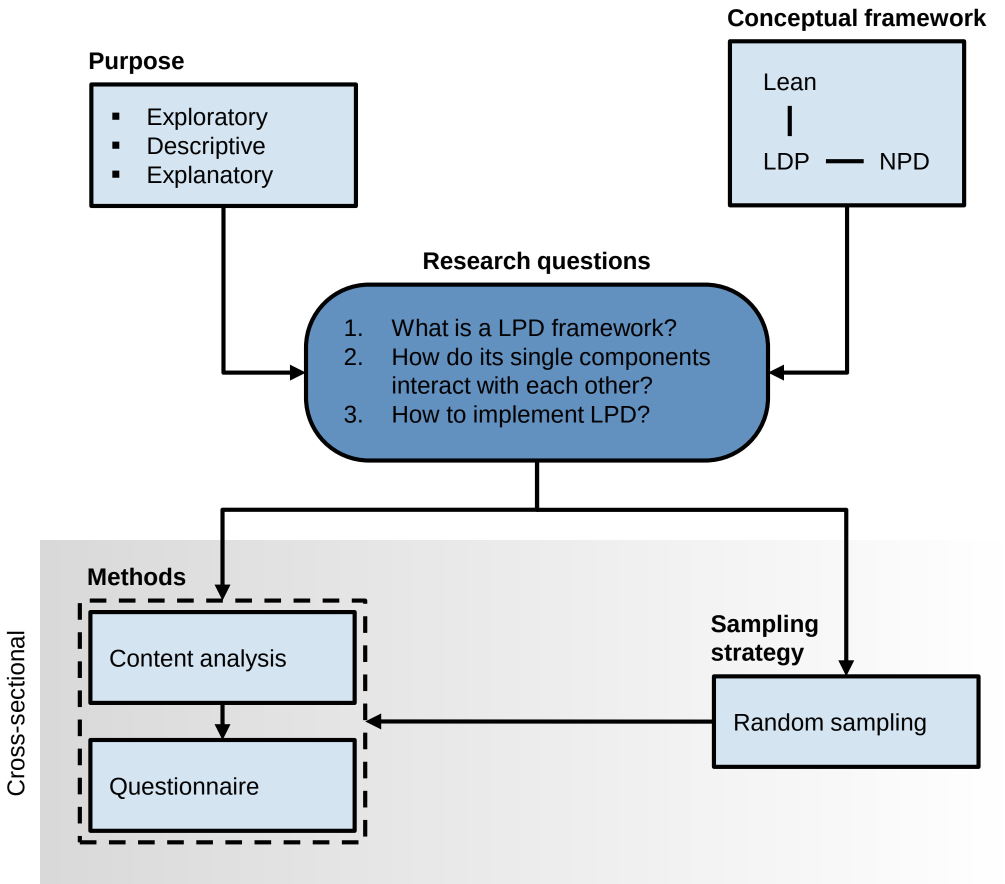


Figure 20: Research design framework

4.2 Philosophical Standpoint

The relationship between philosophy and the social sciences dates far back. The social sciences have in many regards emulated the natural sciences (Guba and Lincoln, 1994; Hughes and Sharrock, 1997) but, in contrast to the latter, never separated themselves from the realm of philosophy. In the social sciences, philosophical debates about the nature of reality, relationship to knowledge, role of values, use of language, and, more than anything, research methods have always been a breeding ground for fundamental questions beyond the academic inquiry itself (Hughes and Sharrock, 1997). The polarising discussions on these topics have brought forth a number of philosophical standpoints and have in various ways disunited the academic community (Blaikie, 2010; Hughes and Sharrock, 1997; Teddlie and Tashakkori, 2009). Each philosophical standpoint represents a different set of metaphysical assumptions on the nature of reality (ontology), the relationship to knowledge (epistemology), the role of values (axiology), the language used in research (rhetoric), and the process of inquiry (methodology) (Creswell, 2009). The determination of a researcher's own position within these philosophical branches is important to enable him to control for any influences from this direction, make the work easier accessible for the reader, and contextualise the choice of research methods. The following discussion focuses mainly on ontology and epistemology whereas axiology and rhetoric are only briefly addressed and methodology critically analysed in detail in the following section 4.3.

Ontology raises questions about the fundamental nature of reality (Bryman and Bell, 2011; Burrell and Morgan, 1979; Grix, 2002; Hughes and Sharrock, 1997; May, 2001; Saunders et al., 2009), is concerned with the nature of existence, and seeks to shed light on the structure of reality and how it works (Crotty, 2003; Saunders et al., 2009). Since there is no way to determine a single correct answer (Hughes and Sharrock, 1997), a multitude of possible solutions to this fundamental problem have been established over time (cf. Creswell and Plano Clark, 2007; cf. Lincoln and Guba, 2000). These ontological assumptions form a continuum between two extreme standpoints (Carson et al., 2001; Morgan and Smircich, 1980) within which the individual stances are categorised and described according to specific features they all share (Creswell and Plano Clark, 2007). On one end of the continuum, researchers regard reality as independent and external, whereas on the other end the social world is understood as a construct shaped by the individual perceptions and interactions of its social actors (Bryman and Bell, 2011; Saunders et al., 2009). The former is part of the positivist paradigm and the latter reflects an interpretivist's perception of reality. Both paradigms have an established position in academia and, according to Teddlie and Tashakkori (2009:4), their supporters appear to have ‘basic “cultural” differences between [them] in terms of the manner in which they are trained, the types of research programs they pursue, and the types of professional organizations and special interest groups to which they belong’. But despite their differences, these categories shall not be regarded as rigid but rather as a means to organise a multitude of attitudes and opinions (Creswell and Plano Clark, 2007) which can also change over time (cf. Grbich, 2004; cf. Hatch, 1997).

Between these most extreme and most established paradigms exists a number of other philosophical standpoints which can be adopted when determining a researcher’s relationship to social reality. Among them is the pragmatist paradigm which goes back to the work of the American philosophers Peirce, James, and Dewey (Cherryholmes, 1992; Howe, 1988; Johnson and Onwuegbuzie, 2004). The origin of pragmatism lies in the works of Peirce (Crotty, 2003; Dewey, 1931; Johnson and Duberley, 2000) in the early 20th century but has not gained much attention in recent decades until this philosophical branch was revived by neo-pragmatist Rorty (Robson, 2011). Neo-pragmatists, such as Davidson, Rescher, Rorty, and Putnam, draw on the ideas of the previously mentioned classical pragmatists and have refined their ideas and developed them in new directions (Johnson and Onwuegbuzie, 2004). This refinement and development process has led to a much differentiated understanding of this philosophical branch and resulted in many different ‘versions’ which emphasise different aspects or interpret some issues differently (Cherryholmes, 1992; Creswell, 2009; Crotty, 2003; de Waal, 2005). The following discussion, however, will focus on the central ideas of this philosophical approach since, in pragmatist’s terms, an overly deep metaphysical discussion would quickly exceed its usefulness and not produce any practical outcomes relevant to this research. Pragmatism is widely understood as a mediating philosophy which seeks to bridge the differences between controversial philosophical standpoints and therefore is often promoted as a more compatibilist and pluralistic approach. It rejects the prevalent traditional dualism, such as determinism versus free will or objectivism versus subjectivism, and presents itself as more moderate and rather focused on the practical consequences of philosophy (Johnson and Onwuegbuzie, 2004). Ontologically, pragmatism shares the positivist's view of an independently existing external reality but just as well recognises the existence and importance of a subjectively constructed psychological and social world reflecting the interpretivist's thoughts (Creswell, 2009; Creswell and Plano Clark, 2007; Johnson and Onwuegbuzie, 2004).

These ontological assumptions and the views on the world they reflect have a direct impact on a researcher's relationship to knowledge (Grix, 2002; Morgan and Smircich, 1980). Within philosophy, epistemology focuses its attention on 'the inquiry into the conditions of the possibility of knowledge' (Hughes and Sharrock, 1997, p.4) or, pragmatically spoken, is concerned with 'how we know what we know' (Crotty, 2003:8). Epistemological concerns are directed towards providing a philosophical ground for the nature and scope of possible knowledge as well as ensuring its adequacy and legitimacy (Hamlyn, 2005; Maynard, 1995). While numerous epistemological positions have been established over the years (cf. Lincoln and Guba, 2000; cf. Hughes and Sharrock, 1997; cf. Saunders et al., 2009), which are also subject to constant change (cf. Grbich, 2004; cf. Hatch, 1997), a central discussion in this discourse centres around the question whether social reality can be examined employing the ethos, principles, and methods of natural sciences (Bryman and Bell, 2011); Saunders et al., 2009). Positivists lean towards the natural sciences and perceive social reality as an observable and measurable phenomenon which is interlaced with its environment through causal relationships and, if analysed using objective structured quantitative methods, yields generalisable, law-like results (Bryman and Bell, 2011; Burrell and Morgan, 1979; Creswell, 2009; Saunders et al., 2009). In many regards taking an antagonistic approach to the perception of knowledge, interpretivists subjectively and emphatically interact with the intricate social reality formed by mankind rather than attempting to deduce rigid and generalisable laws (Bryman and Bell, 2011; Burrell and Morgan, 1979; Creswell, 2009; Crotty, 2003; May, 2001; Saunders et al., 2009). Pragmatism, in contrast to the former two, does not take an absolute epistemological position. Pragmatists accept that research is always conducted in a historical, political, and social context which is in a state of constant change and therefore endorses fallibilism, describing the philosophical principle which maintains that scientific claims may turn out to be false (Cherryholmes, 1992; Rescher, 2005). It acknowledges the complexity of reality and the low probability that truth is definitive and absolute (James, 1907; Johnson and Onwuegbuzie, 2004; Rescher, 2005). The pragmatist's relation to knowledge is much more practical: it accepts temporary truth in terms of 'what works' (Creswell, 2009; Creswell and Plano Clark, 2007; Howe, 1988; James, 1907).

Axiologically, pragmatists take a value-oriented approach to scientific inquiry (Cherryholmes, 1992; Johnson and Onwuegbuzie, 2004; Robson, 2011). This is not to say that pragmatists believe their research to be value-bound, as interpretivists do, but that values play a considerable role when choosing a research project and drawing conclusions from it (Teddlie and Tashakkori, 2009). Whereas an interpretivist regards himself as an inseparable part of his research, a pragmatist would not hesitate to change that position and exclude his own value-induced bias if that is the best way to address the research problem (Creswell and Plano Clark, 2007; Saunders et al., 2009). Classical positivism, on the other hand, strives to stay always as objective as possible by conducting research value-free in order to let data speak for itself (Carson et al., 2001; Lincoln and Guba, 2000; Saunders et al., 2009).

The language of the research, the rhetoric dimension of the paradigm the researcher adopts, behaves analogue to the way values are considered. Positivists detach themselves from their work by using a formal writing style, whereas interpretivists tend to use a more informal language (Creswell and Plano Clark, 2007; Lincoln and Guba, 2000). Pragmatists, again, find themselves between these extreme positions and allow themselves to choose their writing style depending on the need of the research project (Creswell and Plano Clark, 2007). The main points of the foregoing discussion on the positivist, pragmatist, and interpretivist paradigm and its elements is summarised in Table 10.

	Positivism	**Pragmatism**	**Interpretivism**
Ontology *Nature of reality*	Naïve realism - single, independent, external and objective reality	Diverse view points - views chosen to best address research problem (single or multiple realities)	Relativism - multiple, socially constructed and subjective realities
Epistemology *Relationship to knowledge*	Possible to obtain hard, objective knowledge and produce generalisable, law-like outcomes	Knowledge is obtained in a historical, political, and social context and research outcomes claim no absolute truth	Knowledge is 'perceived', subjective and outcomes are context-specific
Axiology *Role of values*	Research should be value-free, unbiased, the data should speak for itself	Values are important but can be excluded if research calls for it	Research is value-bound, biased, and conclusions are influenced by the researcher
Rhetoric *Used language*	Language is formal and agreed on definitions and variables are used	Language style is adaptable	Language is more informal and literary
Methodology *Research process*	Deductive, a priori theory is tested, chiefly quantitative methods	Combining deductive and inductive approaches, methods are typically mixed	Inductive, participants' views build up patterns and theory, chiefly qualitative methods

Table 10: Research philosophy overview (Bryman and Bell, 2011; Carson et al., 2001; Creswell and Plano clark, 2007; Lincoln and Guba, 2000; Saunders et al., 2009)

This research expressly adopts a pragmatist's standpoint and therefore ontologically recognises the complex nature of reality comprising of natural laws as well as socially constructed, subjective realities. Epistemologically, this work regards knowledge as obtainable in a historical, political, and social context and research outcomes as no absolute and indefinite truth. In this research context, the author has chosen to examine the research object value-free and in this regard as unbiased as possible. In the question of rhetoric, this investigation stays true to previous works of the author and largely detaches itself from informal and literary language. Methodologically, the author and this study remain a firm pragmatist standpoint thus employ whatever works best in the pursuit of addressing the research questions.

In summary, this research acknowledges the various levels of the research subject and attempts to put it in the broader context. This position promotes finding an appropriate balance between conceptual and empirical focus thus encourages results suitable for a real business setting which is advocated by León and Farris (2011).

4.3 Mixed Method Research

The discussions on the various philosophical fields are polarising and have in many regards divided academics who assert different metaphysical standpoints and often employ research methods which are being perceived as exclusively attached to their particular philosophical branch (Blaikie, 2010; Bryman and Bell, 2011; Hughes and Sharrock, 1997). However, the connection between metaphysical assumptions and research methods is by no means deterministic. A philosophical position merely reveals a predisposition towards a certain set of methods; accordingly, they should be understood as tendencies not as definitive connections (Bryman and Bell, 2011; Crotty, 2003). In addition to this often misinterpreted relationship, there has been, and to a certain extent still is, a heated debate about the superiority and incompatibility of certain sets of methods which have been crudely and overly-simplistically dichotomised into qualitative and quantitative instruments. Although this differentiation is a helpful way of organising the various methods, they should not be considered as polar opposites as what they are frequently treated as in many research textbooks (Crotty, 2003). Despite their differences, there is a growing body of literature which embraces a more compatibilist position and argues in favour of the combination of both qualitative and quantitative methods in a study if that is the best way to address the research problem (cf. Bryman and Bell, 2011; cf. Creswell and Plano Clark, 2007; cf. Gorard and Taylor, 2004; cf. Johnson and Onwuegbuzie, 2004; cf. Saunders et al., 2009; cf. Teddlie and Tashakkori, 2009).

Mixed-methods research is highly aligned with pragmatism which favours a practical approach to choosing research methods in terms of selecting the most appropriate instrument in a particular research setting (Creswell and Plano Clark, 2007; Howe, 1988; Johnson and Onwuegbuzie, 2004; Teddlie and Tashakkori, 2009). As stated in section 4.1, this research employs both qualitative and quantitative methods to gather primary data. Literature exhaustively covers the advantages and disadvantages of all widely-employed qualitative and quantitative research instruments (e.g. Bryman and Bell, 2011; e.g. Burns, 2000; e.g. Grix, 2001; e.g. Johnson and Onwuegbuzie, 2004; e.g. Kalof et al., 2008; e.g. Frankfort-Nachmias et al., 2016; e.g. Punch, 2005; e.g. Saunders et al., 2009; e.g. Shiu et al., 2009; e.g. White and McBurney, 2013). The remainder of this section will concern itself with a brief description of the qualitative and quantitative spheres and their limitations and then focus on the particularities of mixed-methods research relevant to this project. While the advantages and disadvantages of the previously employed content analysis have been discussed in section 3.1.2, the merits and shortfalls of the questionnaire will be discussed later in this chapter.

In general terms, quantitative research methods are typically concerned with the aggregation, analysis, and interpretation of numerical data (Bryman, 2015; Bryman and Bell, 2011;

Donmoyer, 2008). They are typically associated with the earlier discussed ontological stance of positivism and frequently employed in a deductive approach in which a theoretical position is defined prior to data collection (Bryman, 2015; Saunders et al., 2009). The numerical dataset is subsequently processed using analysis tools ranging from tables and charts to highly-complex statistics to confirm or reject the earlier defined hypotheses (Saunders et al., 2009; White and McBurney, 2013). While quantitative research methods deliver robust, reproducible, transparent, and generalisable results, this approach to collecting and analysing data also bears inherent disadvantages (Frankfort-Nachmias et al., 2016). Critical voices such as Guba and Lincoln (1994) reprove quantitative methods for their inability to sufficiently contextualise data which tends to strip away meaning and purpose, their incapability of exploring data as well as their inadequacy to deeply and meaningfully investigate individual cases.

Qualitative research, on the other hand, concerns itself with non-numerical data such as pictures, words, audio and video material (Bryman, 2015; Saunders et al., 2009; White and McBurney, 2013). The non-descript, inherently complex, and unstandardised nature has a direct impact on the data collection methods and analysis procedures. To allow for its meaningful processing, the data needs to be reduced, consolidated or restructured (Saunders et al., 2009). This approach tends to be adopted by researchers taking an interpretivist stance and is according to Curran and Blackburn (2001) a methodological choice dwindling interest in organisational research. Qualitative research doesn't necessarily rely on previously defined theoretical claims which allows the researcher the unobstructed and flexible immersion into a not well-comprehended subject (Bryman, 2015). Not having to develop hypotheses before data collection lends itself particularly well for exploring a research subject taking an inductive approach (Bryman, 2015; Clough and Nutbrown, 2002; Frankfort-Nachmias et al., 2016; Grix, 2001; Saunders et al., 2009). The empathic character of qualitative methods allow the researcher seeing through its subject's eyes thus provides rich and specific information. It is this high level of detail and specificity, however, which also render qualitative findings hard to generalise (Bryman and Bell, 2011).

A myriad of authors argue that using mixed-methods allows bringing together the strengths of qualitative and quantitative research instruments, while partially nullifying what Saunders et al. (2009) refer to as the negative 'method effect' (cf. Bryman and Bell, 2011; cf. Gill et al., 2010; cf. Grix, 2001; cf. Johnson and Onwuegbuzie, 2004; cf. Punch, 2005; cf. Saunders et al., 2009). The combination of both methodological strands, however, often requires the researcher to face the challenge of joining inherently different datasets (Saunders et al., 2009). In addition to the latter, another difficult situation in mixed-methods research arises from the extra demand for resources. Researchers frequently experience particular strain on the time component since they are required to develop and administer two inherently different methods as well as understand and execute their combination. Additionally, employing multiple modes of collecting and analysing data can quickly cause additional costs (Johnson and Onwuegbuzie, 2004). Another frequently mentioned challenge of mixed-methods research, which becomes particularly evident when several methods are carried out concurrently, is difficulty for a single researcher to administer them. This potential weakness, however, is completely eliminated by the sequential design. Last but not least, it should be highlighted that there are still areas in mixed-methods research which remain to be fully worked out. These areas include, but are not limited to, the interpretation of conflicting results, problems related to the mixing of paradigms and the qualitative analysis of quantitative data (Johnson and Onwuegbuzie, 2004). The aforementioned weaknesses of combining different methods have been carefully dealt with to minimise any negative consequences. Clearly, asides from thought-out and well-organised project phases, the most important measure is the employment of a tried and tested research design which helps to reduce uncertainties related to the combination of multiple methods. Simultaneously, the research design which has proven its effectiveness and reliability in the past, is the very same element which represents one of the biggest advantages of this methodological approach.

The employment of multiple methods in general allows utilising the individual instruments for different purposes in a research project (Saunders et al., 2009). In this instance, the previously employed content analysis was used to explore and describe the individual components of the proposed LPD framework. The collected data was coded, grouped, and abstracted to allow for the combination of numerous different frameworks. The additional integration of best practices and other insights from the wider PD field to extend the border of the nascent LPD research area effectively answered the first research question. Furthermore, the first qualitative part serves as a requirement for the subsequent quantitative phase. Without a previously proposed framework, it wouldn't be possible to qualitatively inquire into the interdependencies between the individual LPD elements (see section 3.3) and develop scales which allow the quantitative investigation of these relationships. While the qualitative content analysis for the development of the LPD framework can be considered to serve a descriptive purpose and the subsequent inquiry into the qualitative nature of the complex network of relationships classified as exploratory, the quantitative phase seeks to add a generalisable descriptive and explanatory character to this study. Amongst other aspects, the quantitative data will greatly complement the qualitative data as it adds numerical detail to the previously determined qualitatively described relationships (Johnson and Onwuegbuzie, 2004). The combination of the extensive content analysis with the questionnaire supports addressing the problem holistically instead of dividing it into several smaller studies. The whole data collection and analysis process as well as its individual phases and activities are illustrated in Figure 21.

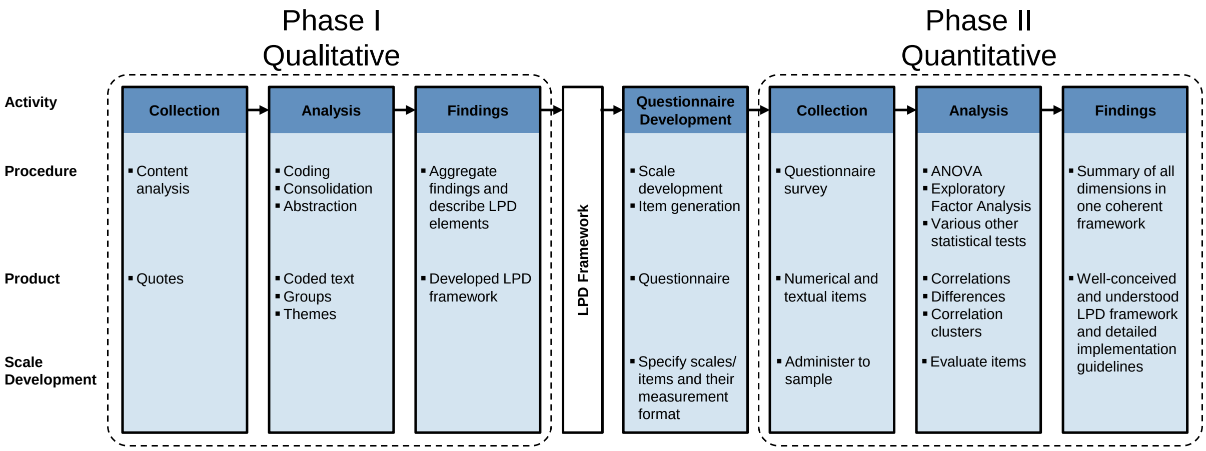


Figure 21: Sequential mixed-methods design (adapted from on Creswell and Plano Clark, 2007)

4.4 Questionnaire

The questionnaire is the most widely-employed research instrument for data collection in organisational research (Bryman, 2015) and primarily used for descriptive research (Saunders et al., 2009; Shiu et al., 2009; White and McBurney, 2013). A lot of its popularity is attributed to its ability to cover large samples and therefore provide vast amounts of data, give trend insights, and allow seeing beyond a detailed case and comprehending the bigger picture (Charmichael, 2012). Saunders et al., (2009, p.362) describe a questionnaire as a particularly well-suited choice if a researcher intents 'to identify and describe the variability in different phenomena' such as the relationships of different elements within the proposed LPD framework. Questionnaires are typically classified and labelled by the way they are administered, whether self or interviewer-administered as well as by the way in which they are delivered and returned (see Figure 22) (Bryman and Bell, 2011; Frankfort-Nachmias et al., 2016; Saunders et al., 2009).

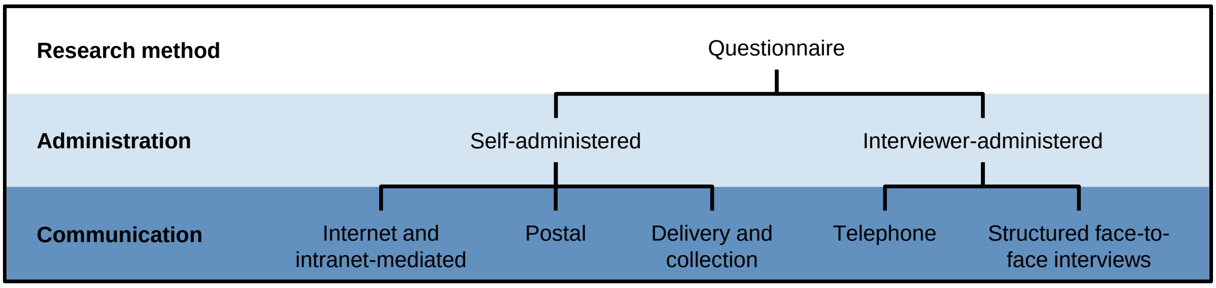


Figure 22: Types of questionnaires (Saunders et al., 2009)

Taking the resource constraints of this study as well as the size and geographical dispersion of the sample into account, which will be discussed in more detail in the following section, the only feasible options are self-administered internet and intranet-mediated or postal questionnaires. All other forms of questionnaires would be far too time-consuming and cost-intensive. Asides from the general advantages and disadvantages of quantitative methods, which have been briefly outlined in section 4.3, these types of questionnaires in particular have two noteworthy beneficial attributes: they are very cost-effective since there are no travel and administration expenditures as well as time-effective as they can be administered to the entire sample at once and filled in by the respondent at an agreeable time of their choosing (Bryman, 2015; Shiu et al., 2009). Furthermore, the self-administered internet and intranet as well as postal questionnaire strip away potential negative interviewer effects such as the bias induced through the subjective perception of language, facial expressions, gesture, and the general body language of the interviewer as well as interviewee (Bryman, 2015; Saunders et al., 2009; Shiu et al., 2009). In addition to these interpersonal interactions, the interview situation is influenced by large variety of characteristics including power, race, gender, class, and ethnicity (Denzin and Lincoln, 2000). This intricate scenario may give rise to various problems ranging from undeliberate recording errors to intentional falsification (Bryman, 2015; Saunders et al., 2009; Shiu et al., 2009).

According to Saunders et al. (2009) who comprehensively compared the different types of questionnaires, internet and intranet-mediated and postal questionnaires share the better part of characteristics but differ in the confidence that the right person has responded, the time taken to complete collection, the financial implications and the resources needed for data input. In all four categories the internet and intranet-mediated questionnaire is superior to the postal questionnaire. The time and financial dimensions in this study are of particular importance due to the chosen sequential mixed-methods research design and the natural constraints this project poses. In this regard, the time taken for completing data collection is stated to be on average two weeks less for internet and intranet-mediated questionnaires compared to postal questionnaires and the data input is fully automated which also reduces data entry errors. In financial terms, the main resource implications for internet and intranet-mediated questionnaires come from potential license costs for the questionnaire programme, which in this case have been obviated, whereas postal questionnaires cause costs for outward and return postage as well as printing which by far exceed the potential costs of the former in this research (Saunders et al., 2009).

Other shortcomings which are not confined to either of the previously two discussed types include, but are not limited to, a potentially low response rate and the general difficulty of asking any type of question other than structured, closed-ones (Bryman, 2015; Frankfort-Nachmias et al., 2016; Healey and Rawlinson, 1993; Saunders et al, 2009; Shiu et al., 2009). While the latter constitutes an inherent limitation of questionnaires which is not compensated through any measures in this research, the former will be addressed by the number of follow-ups as well as the employed recruiting strategy which includes making personal initial contact to identify potential participants. Establishing a personal relationship also partially compensates, according to Thompson and Surface (2007), one of the main adverse effects of web-based questionnaires, anonymity. The sending of a prenotification after the initial contact which raises the potential participant's awareness to the receipt of the survey in the near future further aims at deepening the relationship and building trust. The prenotification further bears the advantage of minimising the survey's risk of not being noticed since the email which delivers the survey link is less likely to be mistaken for junk mail thus automatically filtered out by the system (Thompson and Surface, 2007).

4.4.1 Sample

Following the literature's call for generalisable results, the questionnaire seeks to address the research questions using probability sampling.

In a first step, a suitable sampling frame needs to be created which ideally represents a complete list of all cases of the entire population from which the sample of this survey will be drawn (Bryman and Bell, 2011; Saunders et al., 2009; Shiu et al., 2009). This translates in this research's context to all automobile manufacturers as well as their tier one and tier two suppliers in the USA and Germany. Due to the absence of a freely available directory listing these companies in both countries and the resource limitations which do not permit to obtain one, the sample frame is manually compiled resorting to member lists of professional associations and a business database comprehensively covering the US automotive manufacturing supply chain. The combination of the German Association of the Automotive Industry (VDA) and the US

Original Equipment Supplier Association's (OESA)[27] membership lists with the US database Automotive Who's Who® , yielded a sample frame covering 641 German and 2046 US businesses. Although this might not constitute an ideal representation of the entire population and therefore somewhat limits the generalisability of the obtained results, it is considered a very good approximation of the industry's population this research seeks to project its findings on.

The initial sample size is determined following Shiu et al.'s (2009) proposed formula considering the expected reachable rate (ERR), expected incidence rate (EIR), and expected completion rate (ECR):

Initial sample size = Final sample size / (ERR) * (EIR) * (ECR)

The expected reachable rate which, as the name suggests, represents an estimate of contacts which can be reached, is surmised with 95% due to the up-to-date sample frame and recruitment strategy which requires making initial contact via telephone to obtain the contact details, ensure the respondents commitment, and increase the response rate. The expected incidence rate is estimated with 90% relatively high since this study uses no further qualifiers beyond the previously mentioned affiliation to the automotive industry. The expected completion rate is considered as fairly low with 25% largely due to the mode of data collection. Using these values for a minimum final sample size of 100 and an aspired amount of 150 usable responses provides an initial sample size of 468 and 702 respectively. Considering all three factors by dividing the final sample size with the corresponding initial sample size, calculates the estimated response

[27] The OESA is a division of Motor & Equipment Manufacturers Association (MEMA) covering the supply chain of the automotive industry in the USA.

rate as 21.4% which, according to Baruch and Holtom's (2008) study into response rates in organisational research, constitutes an achievable figure.

As the German part of the sample frame amounts to 641 companies, all potential respondents were approached which renders it a population survey. The US companies have been chosen using simple random sampling which was realised by assigning each potential respondent a unique number that was subsequently selected using a total amount of 702 randomly generated numbers between 1 and 2046 (the size of the sample frame). Numbers which have been generated more than once were ignored and the next number used to select a case. This bias-free selection method ensures that the selected cases represent the population accurately (Bryman, 2015; Saunders et al., 2009) and the considered sample size ensures that the random sampling error due to chance variations is negligibly small (Shiu et al., 2009).

The selected participating companies are initially contacted via telephone to identify the potential respondent, establish a personal relationship, and foster commitment. The respondents are chosen in small companies for their assumed role in PD projects and in larger companies for their position in a dedicated PD department. After the initial contact, each respondent is send an email which further deepens the relationship, mitigates anonymity and trust issues, and notifies the potential participant of receiving the survey in the near future (Rogelberg and Stanton, 2007; Thompson and Surface, 2007).

4.4.2 Questionnaire Development

The questionnaire is developed by following the flowerpot approach advocated by Shiu et al. (2009) and resorting to a number of measurement items developed by Hoppmann (2009). Hoppmann's (2009) study is currently the only published investigation into a systematic implementation of LPD which is based on quantitative data (see section 2.3.1). Consequently, the nascent LPD research area is lacking established measurement constructs, items, and scales which allow the valid, rigorous, and comparable measurement of various aspects of LPD and its implementation. Therefore, this investigation falls back on using a number of aspects of the author's questionnaire which have been tried and tested in this first exploratory study in this particular area. The variable sheet in Appendix B 17 et seq. provides an accurate account of which items have been developed in the following process and which have been lent due to their appropriateness and suitability from Hoppmann (2009).

The flowerpot approach considers the theoretical principles of questionnaire design and 'integrates established rules of logic, objectivity, and systematic procedures' (Shiu et al., 2009, p.329). It recognises the importance of systematically and scientifically developing a questionnaire and follows the frequently encountered general-to-specific sequence (cf. Frankfort-Nachmias et al., 2016; cf. Saunders et al., 2009; Shiu et al., 2009).

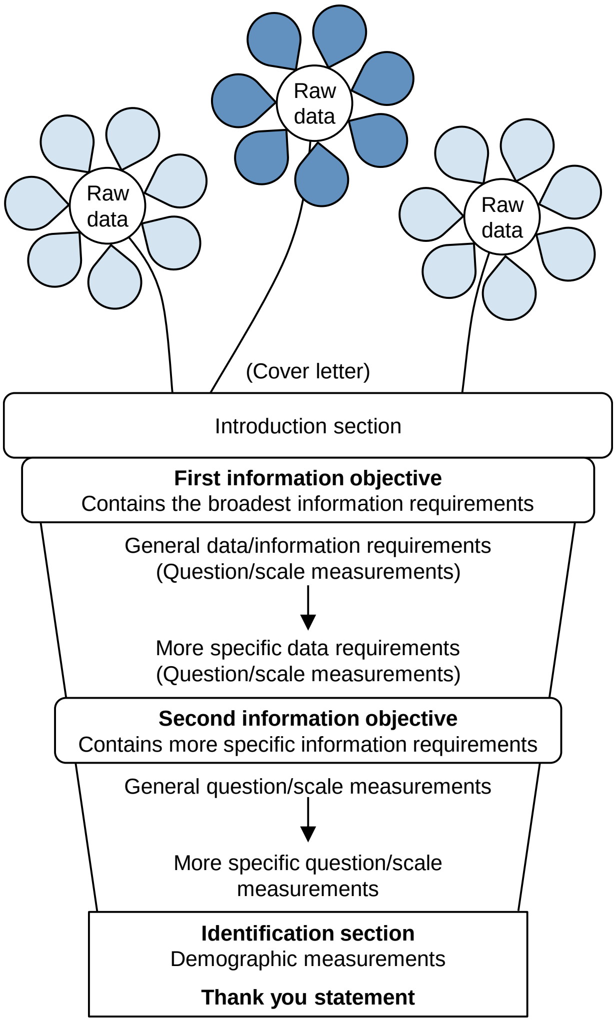


Figure 23: Flowerpot approach (Shiu et al., 2009)

The above illustrated notion of the flowerpot is derived from the typical clay pot shape which is wide at its brim and narrowing towards the bottom, symbolising the flow of the data from general to specific[28] (Shiu et al., 2009).

[28] The rationale for and importance of the general-to-specific approach is discussed in Shiu et al. (2009).

In a first step, the flowerpot approach asks to transform the research objectives, the employed data collection method seeks to address, into information objectives which seek to provide an overall structure (Shiu et al., 2009). The translation of the second and third research objective, defined in section 1.2, yielded two distinguishable information objectives representing two separate information flowerpots.

(1) Collect data on the current use and implementation status of the individual LPD elements which can be used to assess their relationships and determine the current state of LPD
(2) Collect data on the introduction of LPD elements which allows the development of an effective implementation plan

Consequently, both information objectives are addressed consecutively moving from general to specific. The data collection method has been previously determined as internet-mediated questionnaire which is distributed among product development engineers and, in smaller companies without a dedicated development division, otherwise in product development involved employees in the automobile industry.

In a next step, the information requirements for the previously defined information objectives are determined and ordered according to their place in the general-to-specific sequence. The hierarchically arranged information requirements, presented in the following, determine the specific data needs necessary to effectively address the information objectives and establish the overall structural flow (Shiu et al., 2009).

(1) Information objective 1:
    a. General considerations regarding the current implementation status of LPD
    b. Element-specific implementation information

c. Assessing the use of key characteristics of the individual LPD elements

d. Causal considerations regarding the relationships between LPD elements

(2) Information objective 2:

a. Implementation order of LPD elements

b. Implementation problems encountered during the introduction of the individual LPD elements

After having established the data requirements and introduced a hierarchical order, the flowerpot approach advocates to develop the questions itself and their measurement formats. Throughout this step, Shiu et al. (2009) highlight the importance of considering the kind of data (e.g. intention, behaviour, or state of being), question format (open or closed questions), data type (nominal, ordinal, interval, or ratio), and exact wording of both questions and scales. Subsequently, the individual measurement items are evaluated regarding their appropriateness using the authors' guidelines presented in the following Table 11.

	Guidelines
1	Questions should be as easy to understand as possible
2	The question setups, attribute statements, and data response categories should be unidimensional
3	Data response categories should be mutually exclusive
4	Arrangement of response categories should be made to minimise the opportunity of bias in the respondent's answ er
5	Unless necessary, undue stress of particular w ords should be avoided
6	Double negatives should be avoided
7	Unless necessary, technical and sophisticated language should be avoided
8	Wherever possible, questions and scale measurements should be phrased in a realistic setting
9	Questions and scale measurements should alw ays avoid the use of double-barreled items

Table 11: Guidelines for evaluating the appropriateness of questions (Shiu et al., 2009)

The previously developed and assessed questions now need to be put in a logical order aligned with the information objectives and corresponding to the information requirements. Further, the individual questions and sections are introduced to provide the respondent with the necessary information and establish a common ground when assessing the LPD elements. The additional development and inclusion of a cover letter, which simultaneously serves as a consent form and follows the strict ethical guidelines of the University of Birmingham, provides some introductory explanations and addresses ethical considerations. A number of demographic questions in the final identification section, a concluding thank you statement, and a final evaluation of the overall instrument complete the design stage.

The resulting questionnaire is now ready to be piloted, revised, and finalised according to the procedures and techniques laid out in the next two sections (Appendix B 1 et seq. presents the final version of the questionnaire).

4.4.3 Piloting

Pilot studies play an essential role in evaluating the effectiveness of a research method, anticipating potential problems, and checking the feasibility of the inquiry (Bryman and Bell, 2011; Leon et al., 2011; Saunders et al., 2009; Thabane et al., 2010). In this sense, they prepare and assess the employed data collection as well as analysis techniques thus help to uncover any practical issues which may impede the main round of the survey (Doody and Doody, 2015; Sampson, 2004). Bryman and Bell (2011) further emphasise the importance of pilot studies when employing a self-completion questionnaire since there is no interviewer present to clarify any confusion. In the light of its role, Kim (2011) summarises the main advantage of pilot studies to provide the research with the opportunity to adjust and revise the data collection method before embarking on the full-scale study.

Protocol analysis was employed in two cases to maximise the effectiveness of the pilot study, ensure that respondents correctly understood the questions, and establish face validity (Saunders et al., 2009). Protocol analysis entails the systematic evaluation of verbal accounts and is often used in combination with the think-aloud technique (Lundgrén-Laine and Salanterä, 2010). In this context, the think-aloud technique required the respondents to verbalise their thoughts while taking the questionnaire. The utterances were manually recorded and subsequently analysed to identify any problems in the survey (Owen et al. 2006). While this process generates a high-quality record of conscious, verbalisable thoughts (Earle, 2004; Magliano et al., 1999), it hardly allows any clues into subconscious activities or difficult to express thoughts (Bargh and Ferguson, 2000). The unearthed insights predominantly addressed language and phraseology and in two instances led to the complete rephrasing of a question thus considerably helped improving the questionnaire.

In additional three cases, in which the above techniques and methods could not be applied, the respondents have been called immediately after taking the survey to discuss the subjects' responses to the questionnaire. This technique is referred to as debriefing analysis and has a firm place in the evaluation of focus groups. The basic idea behind this approach is capturing insights and perceptions regarding thoughts, ideas, and suggestions and use the findings to improve the employed data collection method (Shiu et al. 2009). In this instance a particular focus was set on ensuring that all questions have been understood correctly and identifying any conceptual problems.

The pilot study in combination with the prior described methods and techniques have proven to be an essential input in terms of clarifying the description of LPD element measurement constructs detailed at the top of the corresponding pages (see Appendix B 3 et seq.), improving terminology and language in general, and overall greatly helped in developing the questionnaire and ensuring its effectiveness.

4.4.4 Response Rate Enhancement Techniques

Low survey response rates might lead to smaller datasets which reduce statistical power, potentially undermine generalisability, and possibly limit the choice of applicable statistical techniques. In some cases a low response rate might also negatively affect the survey's perceived credibility in the stakeholders' eyes (Luong and Rogelberg, 1998). In an effort to mitigate the aforementioned and other problems associated with a low response rate, Rogelberg and Stanton (2007) conducted an extensive literature review and identified a number of established facilitation techniques which are listed in Table 12 below.

Enhancement technique	Summary
Prenotify participants	Personally notify potential participants for the receipt of the survey in the near future.
Publicise survey	Actively announce the survey using posters, emails, etc., inform potential participants about the study's purpose and the use of its results.
Design prudently	Carefully consider the physical appearance of the survey by making it easy to comprehend, structurally accessible, and generally aesthetically pleasing.
Provide incentives	Provide small incentives such as key rings, coasters, pens, when appropriate.
Control survey length	Use theory to determine vital areas in the survey design and avoid including too much content.
Conduct follow-ups	Remind potential participants three to seven days after distributing the survey.
Provide response opportunities	Guarantee opportunity to respond by providing alternative means of participating, considering the respondents' schedules, and generally accommodating any special requirements.
Monitor response rate	Keep an eye on response rates and take further measures when identifying areas of low response.
Convey importance	Communicate the importance of the respondents' participation.
Foster commitment	Where applicable, involve a number of potential participants across various levels in the survey development.
Provide feedback	After data collection, provide survey feedback to positively influence future inquiries.

Table 12: Summary of response rate enhancement techniques (Rogelberg and Stanton, 2007)

These response rate enhancement techniques are carefully considered throughout the development of the questionnaire and its administration. As previously indicated, potential participants are prenotified to establish a relationship, mitigate trust and anonymity issues, foster commitment, and inform about the study’s purpose and the use of its results. The overall design of the survey is kept clear and the colour scheme friendly yet professional by using only this study’s light blue, dark blue, and grey (see Appendix B 1 et seq.). The design further considers Toepoel et al.’s (2009) study results and only placed four to ten items per screen to avoid unnecessary scrolling and respondent fatigue. The matrix measuring the influence between elements constitutes the only exception (see Appendix B 12). The survey length is carefully managed by focusing the inquiry on the measurement items which are needed to effectively and appropriately address the second and third research question. Following Rogelberg and Stanton’s (2007) as well as Saunders et al.’s (2009) suggestions, one week after emailing the questionnaire a first follow-up email including the covering letter and survey link goes out to thank early respondents and remind those who have yet to answer to partake in the study. Three weeks after distributing the survey, a second follow-up conveying the importance of participating in the study is send out to all non-respondents. A potential third follow-up email succeeds if the response rate is low (Saunders et al., 2009).

Despite potentially increasing the response rate, it is not deemed appropriate to provide potential participants upfront with incentives nor is it possible to foster commitment in the sense that Rogelberg and Stanton (2007) advocate. Furthermore, it is not expedient to offer feedback in the sense of a summarising report due to the sensible nature of the data and its implications for the author's professional prospects. The previously explained composition of the sample also made it not necessary to provide alternative response opportunities next to the web-based questionnaire which requires access to both a computer and internet.

4.5 Concluding Remarks

The foregoing chapter started out by discussing various aspects of this investigation's research design which has been chosen to most appropriately address the current gaps in LPD literature. The first research question has been inductively addressed in the previous chapter using an extensive content analysis to construct the comprehensive and coherent LPD framework demanded by literature. The results of this initial exploratory and descriptive qualitative phase serve as a basis for the subsequent investigation into the newly proposed framework's internal relationships as well as the development of an effective implementation plan. The latter mentioned second stage, which seeks to answer the remaining two research questions, is addressed using a questionnaire largely consisting of quantitative measurement items. Both main research instruments are embedded in a cross-sectional mixed methods research design and executed sequentially.

After discussing the most established philosophical standpoints positivism and interpretivism, this research positions itself on a pragmatic middle ground. Ontologically, pragmatism recognises both the objective and subjective view on reality and chooses the perspective which best addresses the research problem. In the discourse on epistemology, the pragmatist researcher appreciates that knowledge is obtained in a changing historical, political, and social context in which research claims may not hold absolute and eternal truth. Although recognising the importance of values, they have been as far as possible excluded to let the data speak for itself and free of bias from this direction. The axiological standpoint is therefore aligned with the positivist's value-free stance on the role of values which also translates into a formal and largely detached use of language.

Methodologically, the investigation at hand frees itself from the polarising debates on qualitative and quantitative research methods and employs instruments from both fields to appropriately address the research object. This practical approach of using the most suitable research method is well-aligned with the previously outlined pragmatist standpoint. After discussing the merits and shortfalls of both the qualitative and quantitative spheres as well as their combination, the focus shifts towards debating the administration and development of the questionnaire which is employed to collect primary data in the second, quantitative phase of this inquiry. The data is drawn from automobile manufacturers as well as their tier one and tier two suppliers in the USA and Germany. Both sub-samples are framed using membership lists of the largest and most established automotive associations in combination with a database of the US automobile manufacturing supply chain. Within this sample frame, product development engineers and, in the absence of a dedicated development department, otherwise in development involved employees are identified and initially contacted before being issued the previously piloted and refined web-based questionnaire. The survey approach is chosen to collect generalisable data and complement previous case-study-based research with a self-administered questionnaire addressing a representative sample. The analysis of the largely quantitative data aims at describing and explaining the interrelationships between the single LPD elements and formulating an implementation plan to support companies currently struggling with introducing LPD.

The results of the questionnaire survey which seek to answer the second and third research question are presented, described, and discussed in the next chapter.

5 Results and Discussion

The forthcoming chapter is divided into descriptive and advanced analysis. The first chapter limits itself to presenting a number of variables which initially describe this sample of the study, then outline some indicators for implementation status and supporting factors, and finish by reporting miscellaneous variables measuring different aspects of the nine LPD elements. The second chapter takes all the previously presented variables and further introduces numerous new measurement items, critically evaluates those using advanced statistical methods, and directly discusses the results by cross-referencing them with other findings and embedding them in literature.

5.1 Descriptive Analysis

In the course of this section, the numerous variables which elaborate various sample characteristics are firstly reported and briefly discussed before reporting three measurement items which give a general impression of the current implementation status and supporting factors a company seeking to embrace LPD might employ. Lastly, this first part of the chapter outlines the average use of the characteristics which describe the individual LPD elements and further elaborates on the single components of the LPD framework by presenting variables which measured their perceived ease and benefit of implementation as well as the order in which participating companies have chosen to introduce them.

5.1.1 Sample Characteristics

The sample of this study is characterised by four variables which inquired about some general information about the company with regards to the location of their PD division, the industrial sector in which the company mainly operates, the amount of employees currently working for the company, as well as the position held by the respondent.

The first variable aimed at geographically locating the PD division in which the respondent is currently employed. This not only lays the foundation for a geographically-based investigation into the characteristics and aspects which are inquired about in the remainder of the survey but also allows for a geographic comparison later in the analysis. All 208 respondents have answered the question 'In which country is your product development division located?' and provided a string variable which was firstly harmonised and later recoded into a nominal variable. The harmonisation was necessary since a number of respondents have chosen different ways of spelling their country, e.g. 'US', 'USA', 'U.S.','U.S.A.', or 'United States', or simply made a spelling mistake which needed correction. After the harmonisation process of the string variable, it was recoded into a nominal variable consisting of three different categories - USA, Germany, and others – to allow for its statistical analysis.

As depicted in Figure 24, of the 208 respondents, 47% are located in the USA, 44% in Germany, and 9% have been found to be located in others countries, such as Italy, France, China, Czech Republic, Spain, Sweden, UK, and Austria, representing 97, 92, and 19 of the respondents respectively.

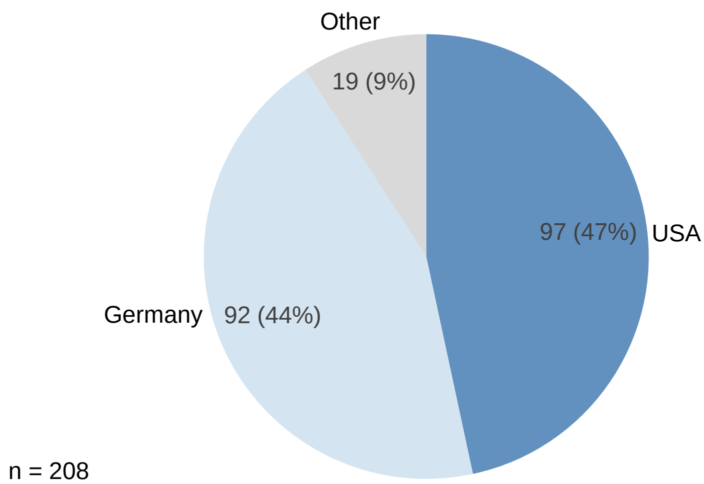


Figure 24: Product development division locations

With 117, representing over 56%, the majority of participants of the 208 companies which have participated in this study mainly operate in the automobile industry. 23% of the companies are represented by the machinery, electrical, and transport equipment industry. This fairly broadly defined industry largely covers what sometimes is referred to as industrial equipment and is followed with almost 5% by the aerospace industry, with 4% by the chemical industry, and with just over 2% by the mining and quarrying industry. The remaining participating companies, represented with just under 10%, have been allocated to other industries including audio equipment, defence, electronics, medical devices, (metal) processing, oil and gas, information technology, as well as shipbuilding. While Figure 25 provides a graphical overview of the industrial sectors in which the participating companies mainly operate, Figure 26 breaks down the ‘other’ industries in their individual industrial sectors.

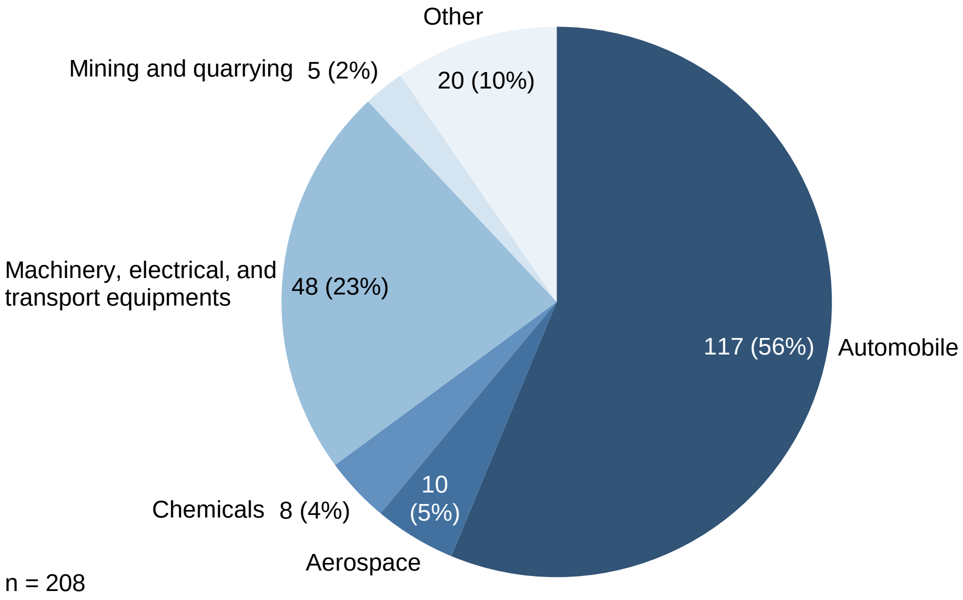


Figure 25: Companies by industrial sector

The majority of companies within the 'other' industry category are allocated to industrial sectors represented by only one or two companies of the sample with the only exception of the 7 companies from the electronics industry.

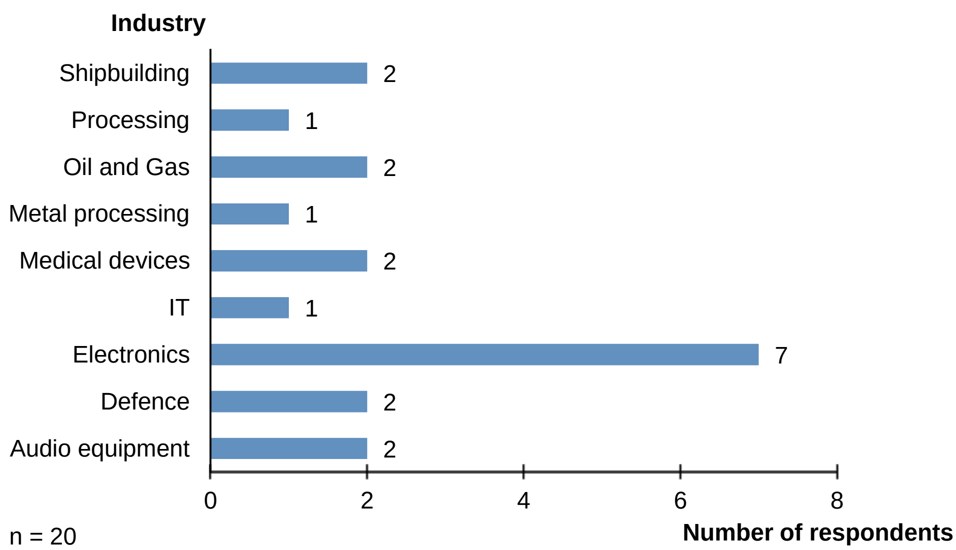


Figure 26: Breakdown of industrial sectors summarised in 'other' industries

After having determined the location of the PD division and the industry the participating companies mainly operate in, the following Figure 27 illustrates the number of employees currently working for the companies responding to this survey. The question invited the respondent to enter the exact amount of employees, represented in SPSS by a scale variable, which has been recoded into an ordinal variable and grouped as depicted in Figure 27. Only 14 of the participating companies, equating to 6.7%, do not exceed 99 employees. The majority of companies (42.8%) have more than 100 but less than 1000 employees. This largest group is followed by the 25.5% which fall into the 1,000 to 9,999 employee range and the 41 companies (19.7%) which have more than 10,000 but less than 99,999 employees. Of the 208 respondents only 11 companies, representing 5.3% of the entire sample, have more than 100,000 people currently in employment.

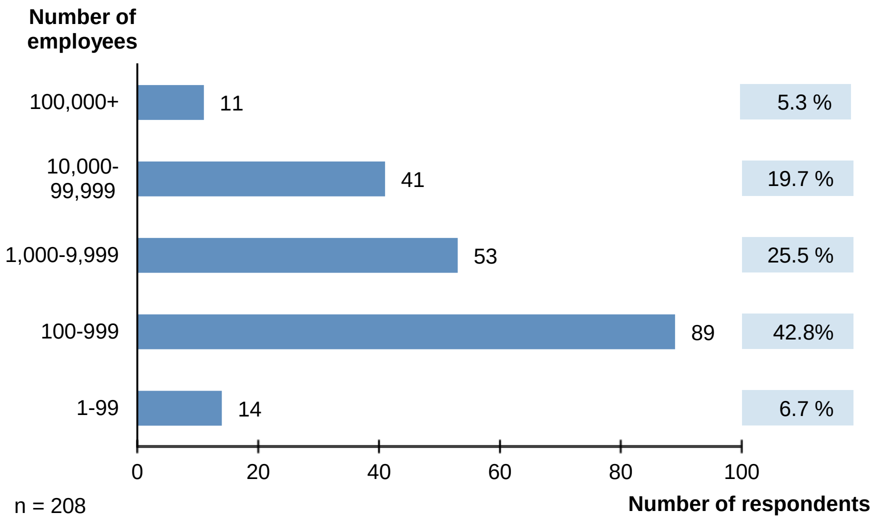


Figure 27: Participating companies grouped by number of employees

13 respondents of the 208 participating companies have chosen not to disclose their position in the company. The majority of participants (42.8%) who have answered to this question hold

the position of Product Development Engineer, followed by 25.5% who are employed as Chief Engineers on a departmental level. Another 6.3% act as Chief Engineers on a company level, while 4.3% have a job as Chief Product Development Officer and another 8.2% work as Chief Innovation Manager. These five groups are complemented by 6.7% who hold other positions which have not been made available as a choice in the survey. Respondents who have chosen 'other' position and have disclosed the title[29] they are currently holding include Engineers, Project Managers, Managers, and one Chief Executive Officer. Figure 28 graphically illustrates the respondents' position in the participating companies and further provides the exact amount of people holding the individual job titles.

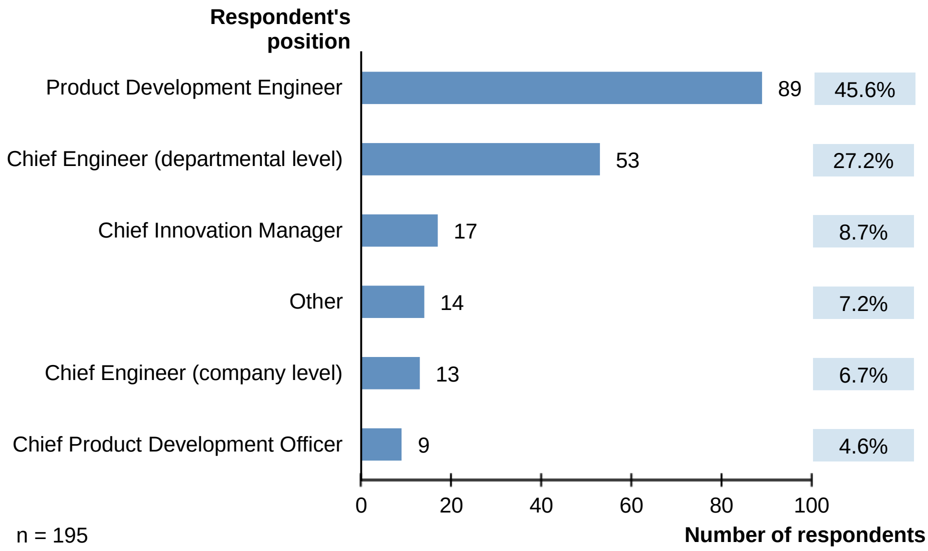


Figure 28: Respondents' position in the participating companies

[29] Of the 14 respondents who have chosen 'other' as their job position, 7 have disclosed their current position while the other 7 have refrained from providing this information.

5.1.2 Implementation Status and Support

After the participating companies have been characterised with regards to the location of their PD division, the industrial sector they mainly operate in, their current amount of employees, as well as the position the respondents hold in the companies, the focus now shifts towards LPD. Initially, this section will describe the responses to the question delving into the LPD status of the participating companies, whether they have a LPD strategy in place, defined any lower-level goals, and have appropriate performance measurements in place or none of the above. The remainder of the section will then shade some light on two human resource aspects of LPD implementation.

As depicted in Figure 29, 26% of the entire sample do not have lower-level goals nor are they planning to develop any. An additional 11% have yet to define goals but plan to do so in the future. The three remaining groups of the participating companies (top three entries on the vertical axis in Figure 29) equating to 62.9% have already developed an overall LPD strategy. With 31.7%, the majority of these companies have yet to identify lower-level goals and define suitable performance measurements to assess their efforts. Another 14.9% have, in addition to an overall LPD strategy, measurable goals in place but lack corresponding performance measurements. 16.3% of the companies which have responded to this survey reported to have all three, developed a LPD strategy, defined appropriate lower-level goals, and identified performance measurements congenial to these goals.

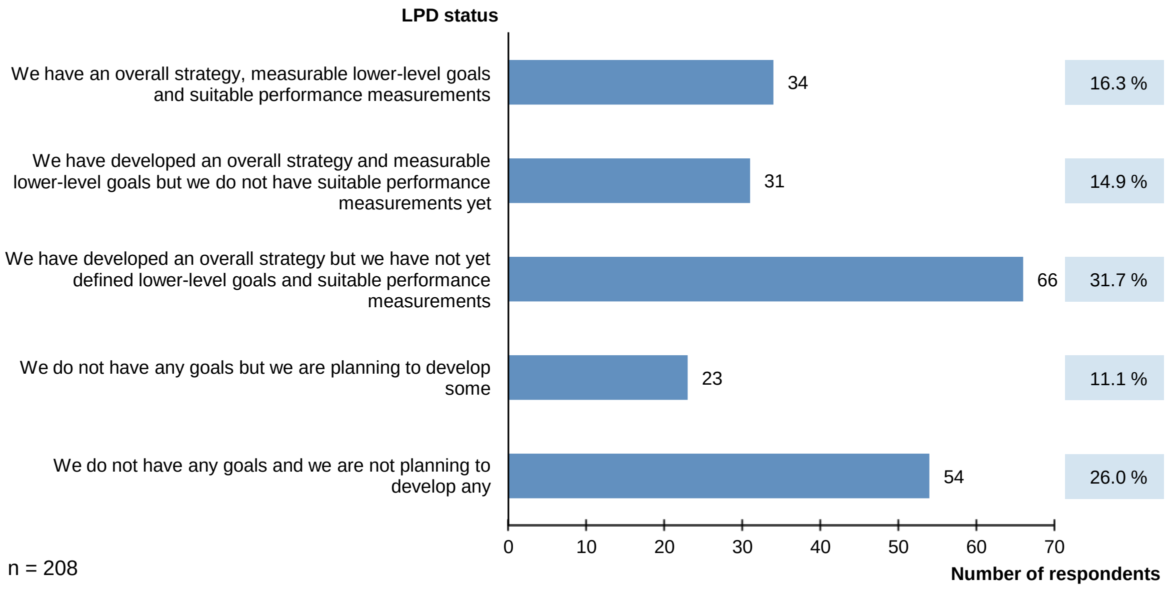


Figure 29: LPD implementation status

With 5 missing responses, 117 of the participating companies, representing 58% of the 203 responding participants, stated that their company has not chosen a person responsible for implementing the guiding Lean principles into PD. As graphically illustrated at the bottom left in Figure 30 and corresponding to this majority, there are 86 companies, equating to 42%, which have reported to have assigned a person responsible for the implementation of LPD. In response to the question whether the participating company is using or plans to use external help to implement LPD, the majority (73%) have declined any such actions or intentions. Only 55 (27%) of the responding 201 companies are supporting their LPD implementation efforts by making use of external help or planning to do so in the future.

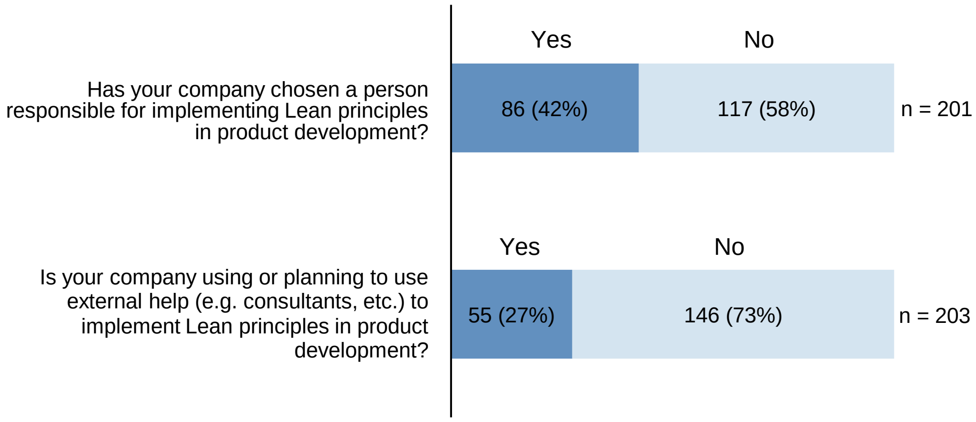
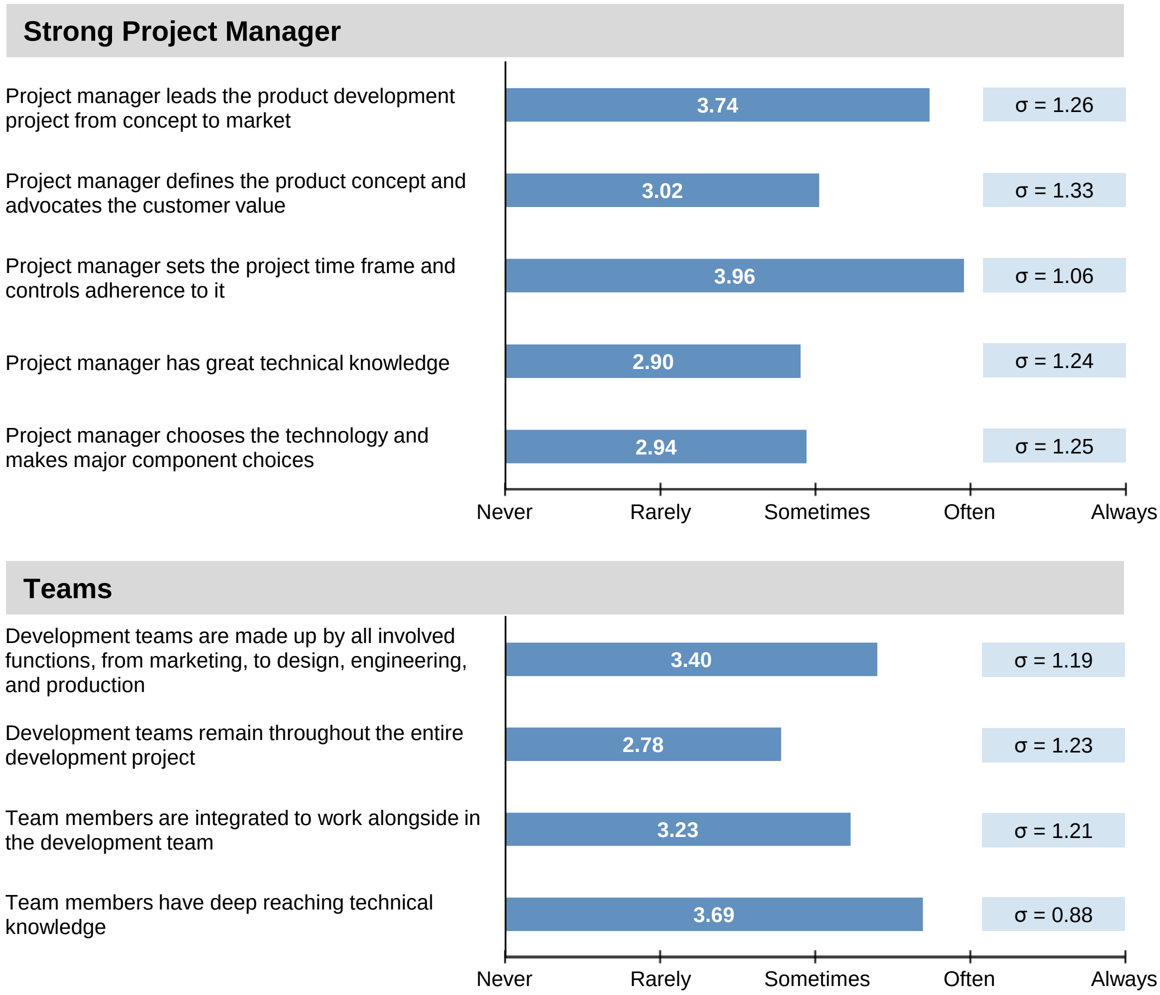


Figure 30: Human resource aspects of LPD implementation

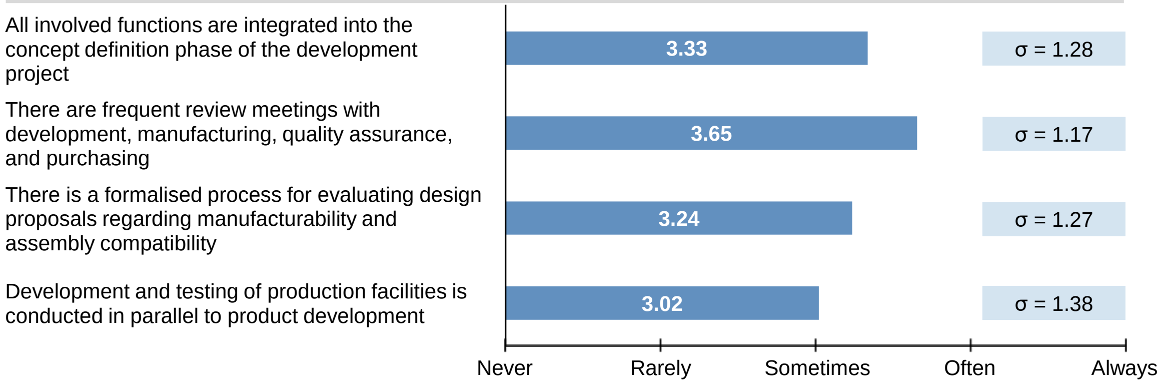
5.1.3 LPD Elements

After the demographic data has been reported and the general implementation status of LPD described, this section presents the data collected about the individual LPD elements. The question to acquire this data form the main body of the questionnaire and is divided into multiple parts. This section will initially graphically illustrate to which extent the participating companies are making use of certain characteristics which describe a LPD element. Subsequently, the section will discuss the perceived ease as well as the perceived benefits of implementing the individual elements and finally present the order in which the participants have reported the single LPD components have been introduced in their company.

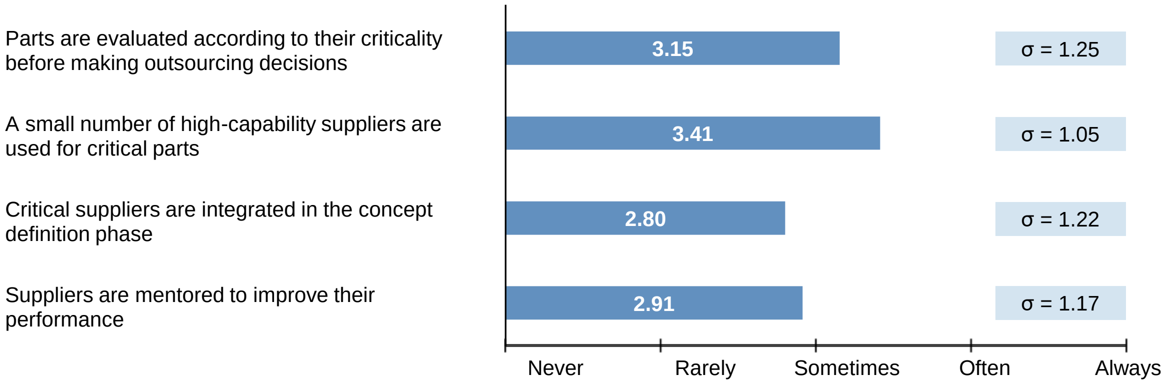
The extent to which the responding companies are employing the individual LPD elements is depicted in Figure 31. Each element is broken down into its distinct characteristics and represented by its own chart. The respondents have rated their usage of the individual attributes on a 1-to-5 ‘never’-to-‘always’ response scale. The following charts report the average usage of each describing characteristic with its mean and the standard deviation to indicate the spread of the data around the mean. The average extent to which an attribute of a LPD element has been used ranges from 2.44 for ‘alternative solutions for a design problem are developed and tested simultaneously’ all the way to 3.96 for ‘strong project manager: sets the project time frame and controls adherence to it’. On the chosen Likert scale, these values represent averages from ‘rarely’ (2) through ‘sometimes’ (3) to ‘often’ (4). The amount of characterising attributes varies from 4 to 6, depending on the number of distinct features identified in the course of developing this survey. As graphically illustrated in the following figure, some average values of the individual characteristics vary widely as in the case of the ‘strong project manager’ while others are quite stable such as those describing ‘product variety management’ (PVM).



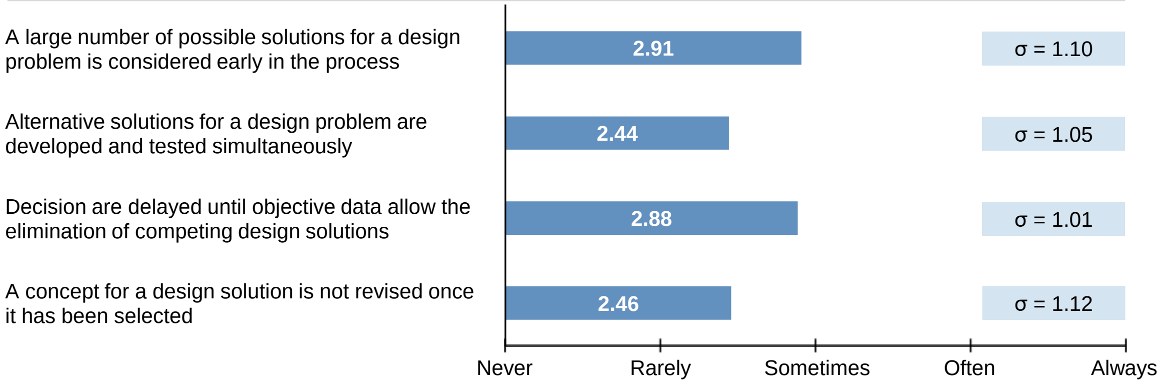
Concurrent Engineering



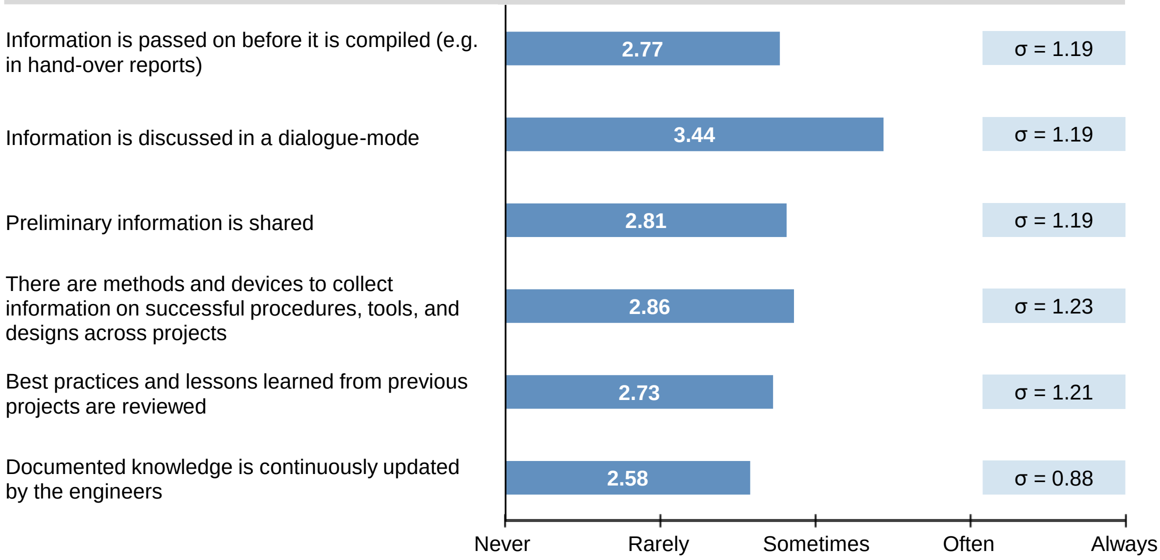
Supplier Relationship and Integration



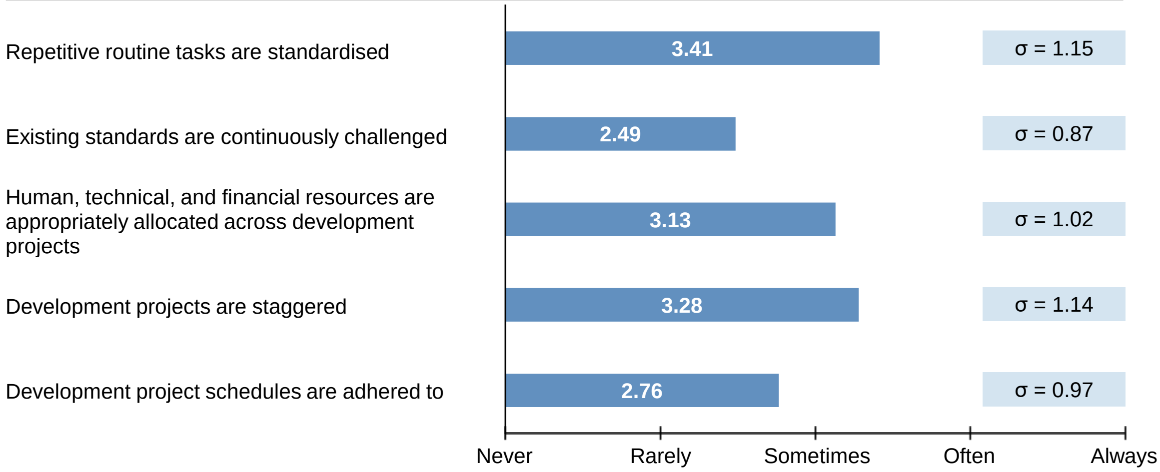
Set-based Design



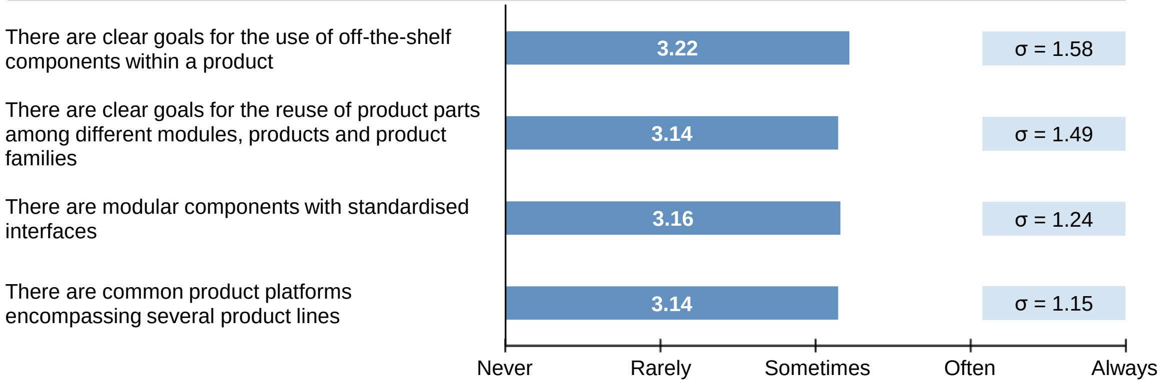
Communication and Knowledge Transfer



Process Management



Product Variety Management



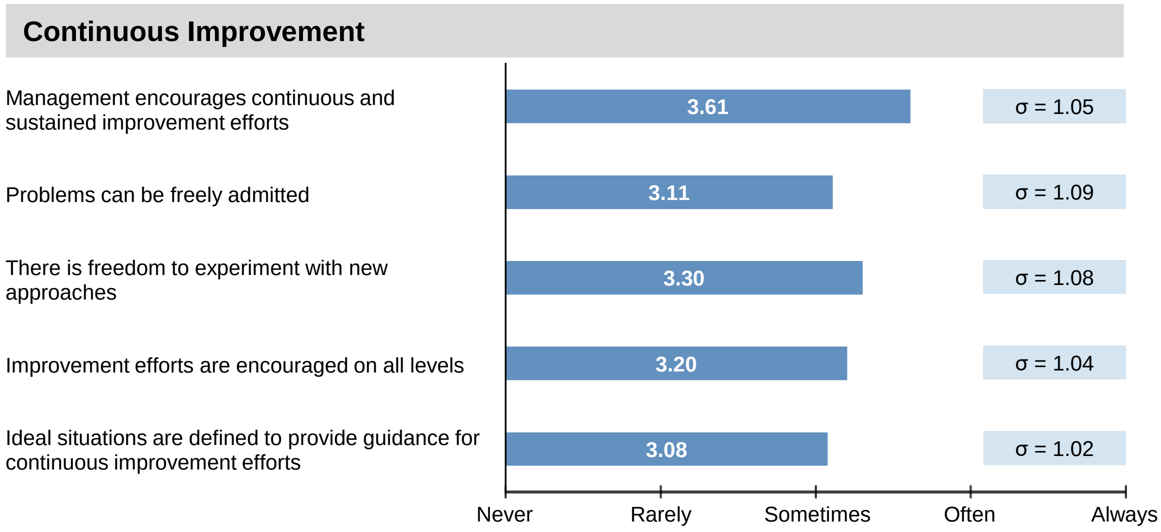


Figure 31: Usage of individual characteristics of the LPD elements

The above presented data offers a rich insight into the individual LPD elements and the extent to which its most distinct features are employed in the participating companies. In an effort to provide a first means to compare the LPD elements, the single characteristics have been drawn together in an average mean. This mean of the average usage of LPD elements is compiled in the following Figure 32. Before further discussing and analysing these results, a reliability test needs to be conducted to establish a statistical rigorous base for the variables representing the average use of LPD element characteristics. The Cronbach α values which numerically express how well a measure is reflecting the construct it is supposedly measuring are provided for each LPD element in Figure 32 (see Appendix C 1 for detailed results). The α-values for the average usage of LPD elements are all above the, by statistics literature recommended, minimum value of 0.7 which leads to conclude that the newly introduced variables reliably represent the characteristics they are composed of. However, with an average Cronbach α value of 0.87, ‘communication and knowledge transfer’ (CKT) scoring 0.743 falls significantly behind. While this result causes no concern at this point, it seems advisable to consider it when discussing findings of further analyses.

LPD Element	Cronbach α
Strong Project Manager	0.798
Teams	0.870
Concurrent Engineering	0.931
Supplier Relationship and Integration	0.853
Set-based Design	0.843
Communication and Knowledge Transfer	0.743
Process Management	0.920
Product Variety Management	0.953
Continuous Improvement	0.948

Figure 32: Cronbach α values per scale

As depicted in Figure 33, the elements SPM as well as ‘teams’ (T) share the first places in the ranking with an average usage of 3.31 and are closely followed by ‘concurrent engineering’ (3.27) (CE) and ‘supplier relationship and integration’ (SRI) (3.26). The aforementioned four elements represent the most widely employed aspects of LPD. On the other end of the spectrum, the by far least used LPD elements are PVM with 2.86 and ‘continuous improvement’ (CI) with 2.67. In order to be able to make a statement about the significance in difference between consecutive ranks an independent t-test is performed. Before conducting the t-test, the average use variables have been inspected whether they meet the statistical assumptions underlying parametric tests. The independence of the observations was assumed, no outliers had to be accounted for, and the test for linearity was passed. The nine variables tested significant in the Kolmogorov-Smirnoff test and therefore exhibit a not normal distribution. Hence, the data was bootstrapped using a sample size of 2000 and bias corrected accelerated confidence intervals to retrieve most accurate results. The bootstrapping allows for the computation of significance tests through robustly and elegantly circumventing the limitations posed by non-normally distributed data. Six of the nine variables tested significant in Levene’s test for equal variances thus violated the assumptions for heteroscedasticity and heterogeneity. The independent t-test revealed only one significant difference on a 5% level between the last two ranks, CKT and 'set-based design' (SBD) (see Appendix C 2).

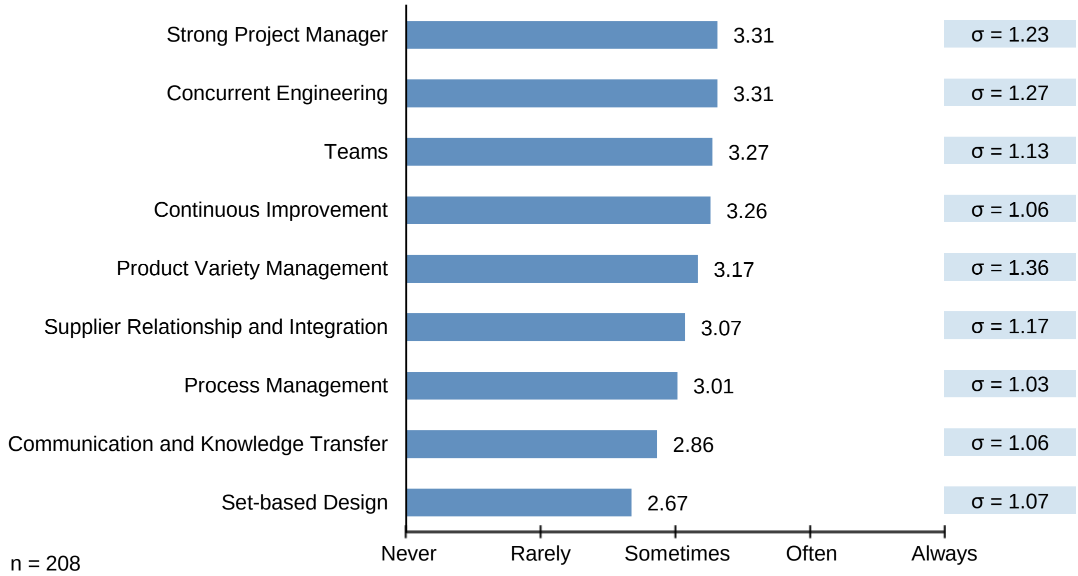


Figure 33: Average usage of LPD elements

After describing the usage of the individual LPD elements, the participating companies have been asked to rate the perceived ease of introducing these elements, as characterised by the statements in Figure 31, on a 1-to-7 'very difficult'-to-'very easy' Likert scale. The results, summarised in Figure 34, show a wide variety ranging from 2.80 for PVM to 4.39 for T. The introduction of cross-functional teams is perceived by far to be the easiest LPD element to implement. PVM as well as CKT, on the other hand, are seen as the most difficult among the LPD components to be introduced. An independent t-test between neighbouring ranks has revealed only one significant difference on 1% level between CI and SRI (see Appendix C 3). The corresponding values for the standard variation are relatively stable between 1.17 and 1.39 with the notable exception of 1.53 for CI.

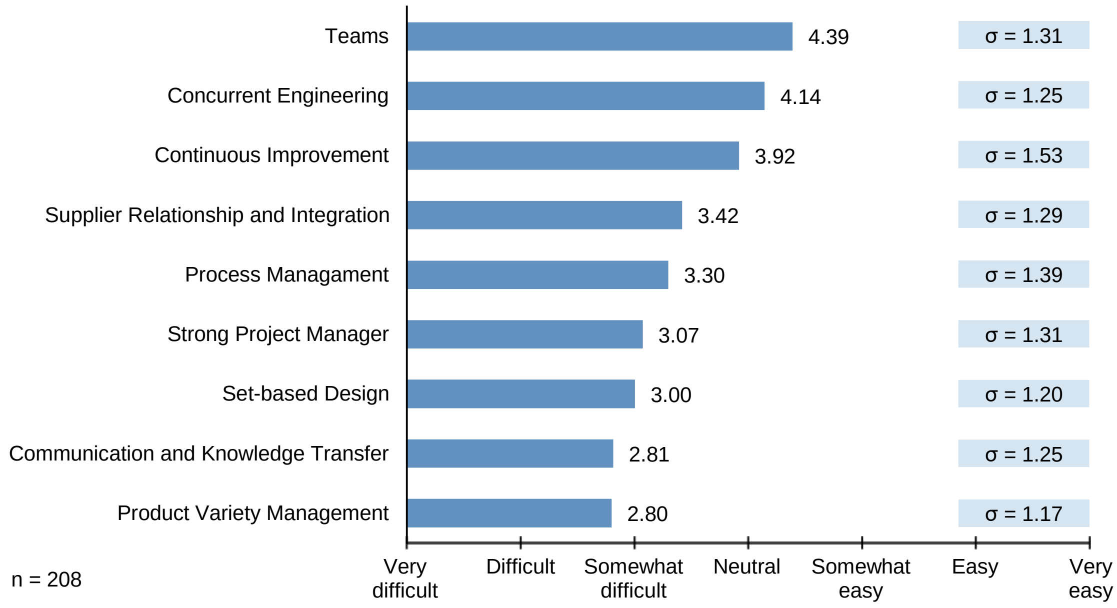


Figure 34: Perceived average ease of implementing LPD elements

After the previously reported wide-spread results, Figure 35 summarises the collected data on the perceived benefit of introducing the individual LPD elements as characterised in Figure 31. The participating companies where asked to rate their response on a 1-to-7 'very low'-to-'very high' Likert scale. With 5.96 it is again the T element which leads the ranking closely followed by CE with 5.92. The two elements perceived to yield the least benefits are CKT with 5.16 and SBD with 5.20. Between the top and bottom two, the five middle-ranking elements show fairly little variation in their average values. An independent t-test between neighbouring ranks statistically substantiates the impression of relatively homogeneously distributed values by identifying no significant differences (see Appendix C 4). Overall, the σ-value indicates that the data points are relatively close to the mean reported in Figure 34, while the standard variation for PVM (1.37) and CKT (1.40) testify to a wider spread around the mean.

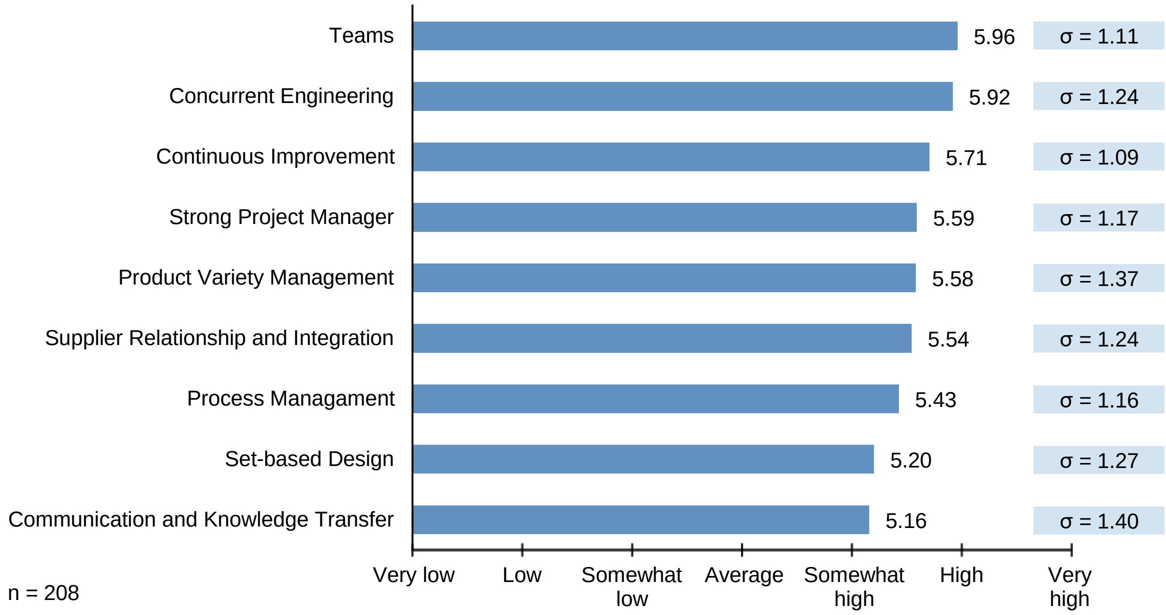


Figure 35: Perceived average benefit of implementing LPD elements

Following the main body of the survey in which the responding companies have reported the extent to which they employ the individual LPD elements, the perceived difficulty as well as the perceived benefit of implementing the single LPD components, the participating companies were then asked to rank the LPD elements in the sequence in which they have been implemented. Corresponding to the amount of elements in the proposed LPD framework, respondents were asked to rank those elements from 1 (1^{st}) to 9 (9^{th}). The LPD elements T with an average rank of 2.79 as well as the SPM with 2.83 notably set themselves apart on ranks one and two. Showing a significant difference between neighbouring ranks (see Appendix C 5), a clear third place goes to CE with 3.37 while CI, PVM, ‘process management’ (PM), SBD, and SRI set themselves significantly apart from the third place and make up the middle ranks with fairly little variation. The independent t-test, however, shows a significant difference between PVM and PM. CKT has been reported to be implemented lastly with a significant difference of

0.69 to the second last place. The standard variation values are relatively constant across all nine LPD elements with the only exception of σ = 2.21 for SBD.

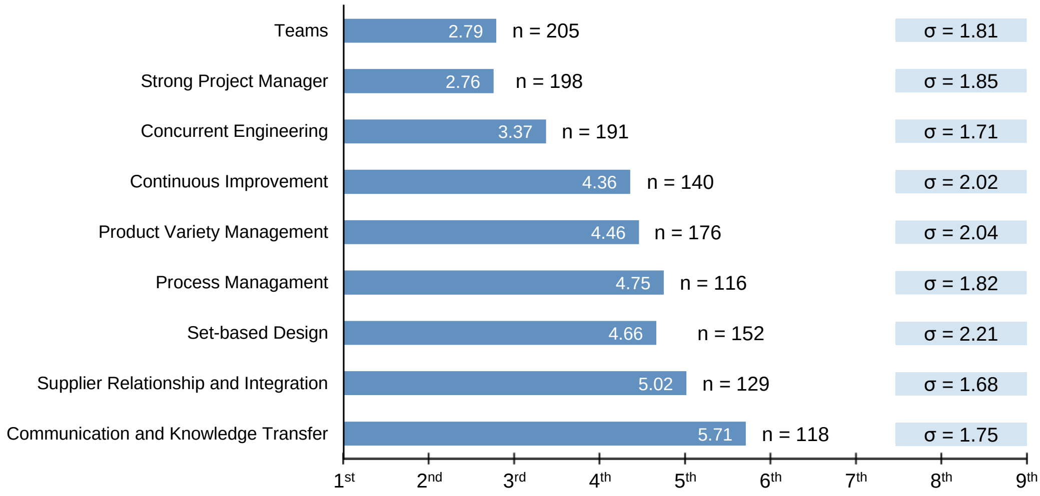


Figure 36: Implementation order of LPD elements

As reported next to the average ranking value in Figure 36, the number of respondents who have chosen to rank the individual elements has varied strongly across the field. With a total number of responses of n = 205, T has been ranked most often, followed by SPM (n = 193) and CE (n = 191). The number of respondents who have chosen to assign a rank to the five middle ranking LPD elements varies between n = 116 and n = 176 with no apparent order to it. CKT, the on average last introduced LPD component, is with n = 118 the second least ranked item among the nine LPD elements.

Figure 37 sheds some more light on another dimension of the number of responses to this question. The graph depicts the number of responses on the vertical axis over the ranks assigned to the LPD elements which describe their implementation order. It shall be noted, that the participating companies have been forced to answer this question without a limitation to which extent the question needed to be answered. Figure 37 shows that the complete sample assigned the places one and two but then the amount of respondents slowly dropped to n = 197 for the sixth place. After that, the number of responses steeply fell to n = 134 for the 7th, n = 59 for the 8th, and only n = 10 for the 9th place.

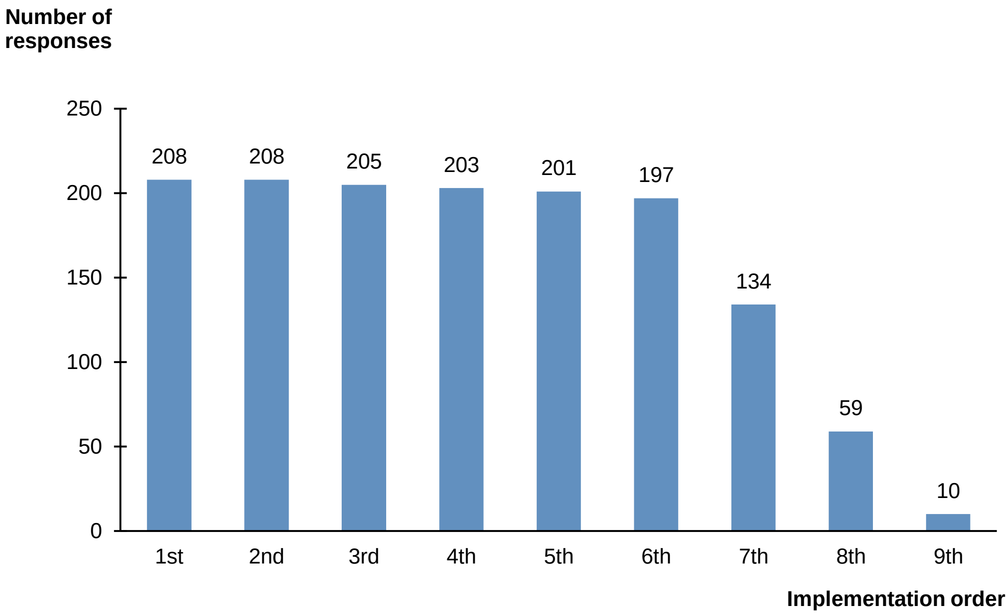


Figure 37: Number of responses per rank

The previously presented data on the average use, perceived ease and benefit of implementation of the individual LPD elements, as well as the sequence in which the respondents have reported the individual elements have been introduced in their company, have been summarised in the following Table 13. The table, however, does not show the average score which has been reported in the previous charts but the rank the individual LPD elements have achieved with their corresponding average mean. The element T, for example, achieved an overall average use of 3.27 and with that ranked third behind SPM (3.31) and CE (3.31) (see Figure 33 and first column Table 13). While the table draws together the aforementioned results in a very simplistic way, it also ranks the LPD elements according to the overall score they have achieved. The overall score is no result of a weighed addition thus does not assign any particular importance to a category but is merely an addition of the ranks achieved in each category. T, for example, has been rated the 3rd most used LPD element and scored the 1st place in ease of implementation, benefit of implementation, and implementation order which equates to 3+1+1+1=6. In this very basic cross-categorical comparison, the first four places set themselves notably apart from the three elements forming the middle field with only one point variation. The last two places are clearly assigned to SBD and CKT with an overall score of 31 and 34 respectively.

LPD Element	Average use	Ease of implementation	Benefit of implementation	Implementation order	Overall score
Teams	3	1	1	1	6
Concurrent Engineering	1-2	2	2	3	8.5
Strong Project Manager	1-2	6	4	2	11.5
Continuous Improvement	4	3	3	4	14
Product Variety Management	5	9	5	5	24
Supplier Relationship and Integration	6	4	6	8	24
Process Management	7	5	7	6	25
Set-based Design	9	7	8	7	31
Communication and Knowledge Transfer	8	8	9	9	34

Table 13: Ranking of the LPD elements

The presented ranking with an overall score is quite unorthodox since it compares the results of four different concepts, illustrated in the corresponding columns in Table 13, which have been measured on different scales. Moreover, the difference in rank between one element and another is sometimes significant and sometimes not. Thus, the overall score, which has been used to rank the individual LPD elements, is out of the ordinary. Despite the uncommon approach to the ranking, however, it still has been included at the end of this section to provide the reader with a concise overview of the performance of the single LPD elements in the previously presented categories.

5.2 Advanced Analysis

This second part of the chapter is divided into three parts standing in close relationship to each other. Initially, the first section takes a close look at potential influence factors and investigates a number of previously presented variables with regards to their relationship to the use of LPD. The insight into external forces which might influence the use and performance of the proposed LPD framework not only deepens the understanding of this approach but also informs the remainder of the analysis. The second section effectively addresses the second research question inquiring into the inner relationships of the framework. Throughout this part of the analysis, the LPD framework is scrutinised to gain a deeper understanding about the inner workings of this approach. Once external influence factors have been identified in the first section and the inner relationships of the framework investigated, the third part sets out to formulate implementation recommendations which are aimed at companies seeking to embrace LPD. These recommendations address the third research question which asks about an effective way to introduce the proposed LPD framework. The implementation recommendations are developed by merging the findings of the first section with the insights into the inner relationships of the LPD framework and further including various variables which have so far not been closer investigated. The synthesis of the insights of the first two sections and their combination with new findings unearthed throughout this last section will effectively answer the third research question.

5.2.1 Influence Factors

The forthcoming section sets its focus on analysing the degree to which LPD has been implemented, henceforth Leanness, in the participating companies and which factors might influence the adoption of LPD. On this endeavour, the analysis combines measurement items from the previous sections which presented most of the survey items in the descriptive analysis. The investigation starts off comparing the Leanness of US and German companies to identify potential differences rooted in the geographical location. Subsequently, the analysis brings together the average use of LPD elements and the measurements on the industry the participating companies operate in as well as the company size to determine whether the industrial background or company size might influence the adoption of Lean practices in product development. Once the demographic influence factors have been considered, the companies' own implementation efforts in terms of choosing a person responsible for LPD, using or planning to use external help, and the development of a LPD strategy with corresponding goals and measurement items, will be investigated.

5.2.1.1 Geographic Location

Section 5.1.1 has reported the geographical composition of the sample under investigation. Although the companies have been solely recruited in the US and Germany, 19 respondents have stated their product development location to be in another country. These 'other' companies are geographically widely dispersed and have greatly varying cultural backgrounds (cf. Hofstede et al., 2010; cf. Trompenaars and Hampden-Turner, 1997). In addition, each of the other countries are only represented by a very low number of respondents with Italy being the strongest candidate with 4 participating companies. Therefore, only the 97 US and 92

German responses are considered to determine a potential geographical influence in this part of the analysis. The following Figure 38 illustrates the average use of LPD elements as well as their standard deviation in both the USA and Germany. As the graphic reveals, the USA is somewhat stronger in making use of CE, T, CI, and PVM. Germany only stands slightly out in the use of the SPM which participating companies employ on average 0.12 more than their competitors in the USA.

Figure 38: Use of LPD elements in the US and Germany

A subsequent independent t-test which compared the average means in the US and German sample, however, identified no significance in the previously mentioned differences. A summary of the t-test results is reported in the following Table 14 and the entire output of the t-test is provided in Appendix C 6. While the absence of significant differences in the adoption of managerial and organisational Lean practices might not be unexpected in the heavily consolidated and globalised automobile industry, the homogeneity with which LPD has spread from Japan constitutes an interesting finding. Considering that participating companies are OEMs, Tier 1, and Tier 2 suppliers in the automobile industry thus are somewhat differently removed from the early adopters, the OEMs, and significantly different in size and structure, it is remarkable how homogeneously LPD has been adopted throughout the USA and Germany. Apparently, the degree to which LPD elements are used on average is not significantly influenced by the geographic location but might be depending on the industry the companies mainly operate in or the companies' size thus the financial, human, and technical resources they have at their disposal.

LPD Element	USA		Difference		Germany	
	Mean	Std. deviation	Mean difference	Sig. (2-tailed)	Mean	Std. devitiation
Strong Project Manager	3.235	0.963	-0.121	0.359	3.357	0.851
Concurrent Engineering	3.472	1.106	0.290	0.119	3.182	1.185
Teams	3.371	0.950	0.222	0.084	3.149	0.994
Continuous Improvement	3.344	0.873	0.136	0.959	3.209	1.002
Product Variety Management	3.253	1.274	0.149	0.807	3.103	1.279
Supplier Relationship and Integration	3.088	0.963	-0.007	0.561	3.095	1.014
Process Management	3.049	0.916	0.052	0.691	2.998	0.868
Communication and Know ledge Transfer	2.921	0.641	0.059	0.422	2.862	0.737
Set-based Design	2.683	0.904	-0.032	0.324	2.715	0.873

* p < 0.05 ** p < 0.01

Table 14: T-test results for LPD element use in the US and Germany

5.2.1.2 Industry Sector

The next measurement item scrutinised for its potential influence on the average use of LPD is the economic affiliation to an industrial sector. Albeit all participating companies have been chosen due to their vertical integration into the automobile industry, many companies do not solely rely on a highly cyclical industry in which negotiating power is often unilaterally distributed and profit margins typically relatively low. Hence, companies often decide to diversify into other industries to spread the risk and increase their business. Consequently, 44% of the participating companies have reported to mainly operate outside the automobile industry (see section 5.1.1 for a detailed breakdown). Of those 44%, 20 companies, equating to 10% of the respondents, have stated to conduct the bulk of their business in ‘other’ industries. This ‘other’ category constitutes of nine different industries of which only the electronics industry was represented by more than just two companies. And since the electronics industry is stronger represented than the mining and quarrying as well as chemicals industry for which predefined categories existed in the survey, the electronics industry will be considered in the analysis while the remaining industrial sectors in the ‘other’ category are excluded from the following analysis. Figure 39 illustrates the average use of LPD elements broken down into industrial sectors.

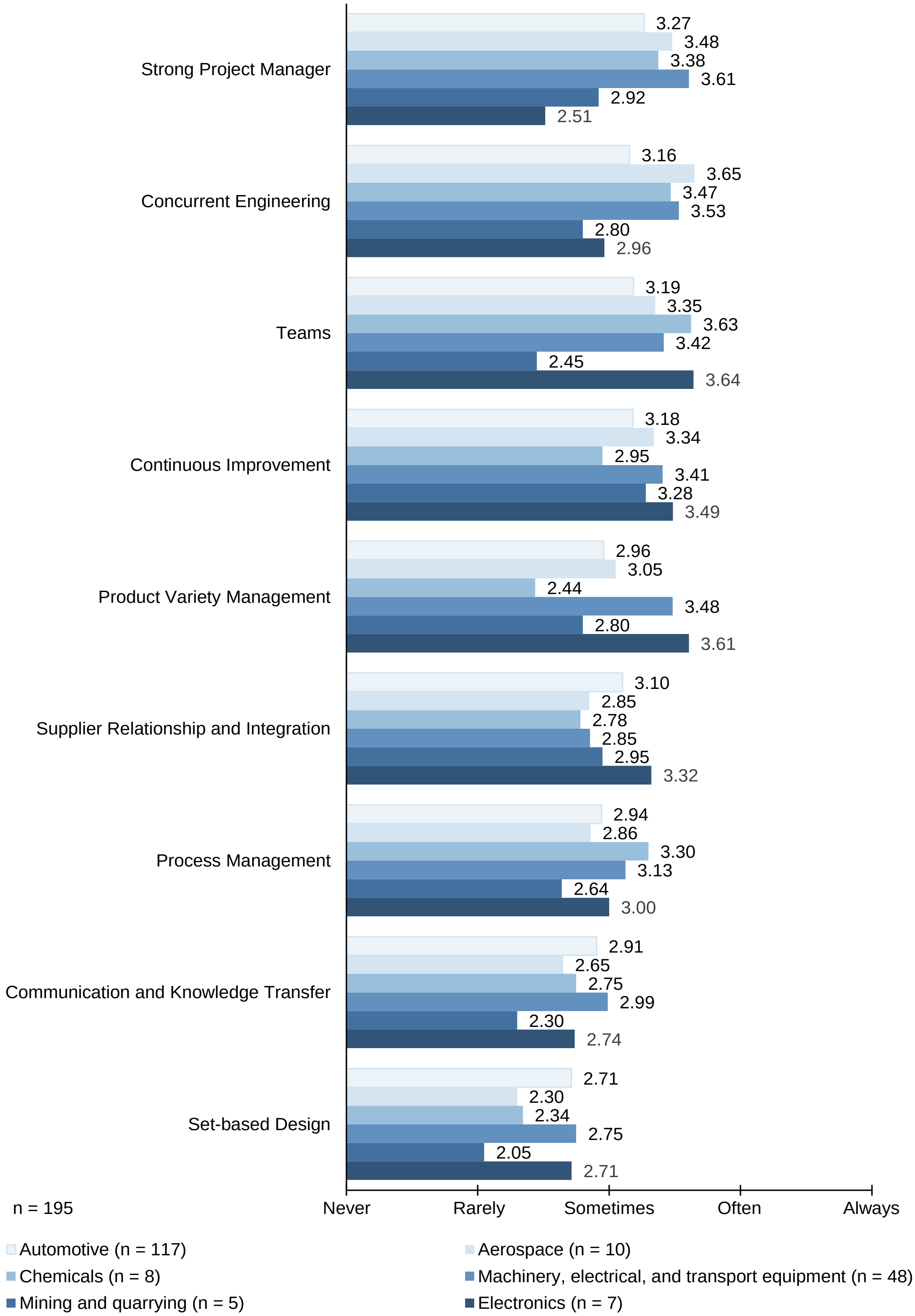


Figure 39: Use of LPD elements by industrial sectors

In order to be able to compare the nine different items measuring the average usage of LPD elements grouped into several categories, a one-way analysis of variance, often abbreviated with one-way ANOVA, has been chosen to carry out this statistical analysis. The one-way ANOVA, henceforth referred to as just ANOVA, is a statistical test which is in experimental research typically employed to compare a group of means and determine whether they significantly differ from each other (Backhaus et al., 2016; Field, 2013). Since ANOVA is using the *F*-ratio to test an overall fit of a linear model, all basic assumptions for linear models apply. While the independence of the measured observations is assumed, the data was checked for outliers and tested for linearity, normality, heteroscedasticity, and heterogeneity. The variables passed the test for linearity but were found to be non-normally distributed within the industries thus needed to be bootstrapped to be able to conduct the significance test in the analysis. The bootstrapping used 2000 samples and bias corrected accelerated confidence intervals to retrieve most accurate results. Heteroscedasticity and heterogeneity were tested using Levene's test. The results of the test are reported in Table 15 and the significant values have been highlighted in light blue. The variable measuring the average use of SBD tested significant in Levene's test thus the null-hypothesis of equal variances was rejected and the assumption of homogeneity of variances violated. Therefore, the in this regard more robust tests Welch's F and Brown-Forsythe F were used to determine a potential significance in difference between the individual means for this element.

LPD element	Levene statistic	df1	df2	Sig.
Strong Project Manager	.583	5	189	.713
Concurrent Engineering	.776	5	189	.568
Teams	.387	5	189	.857
Continuous Improvement	1.594	5	189	.164
Product Variety Management	1.608	5	189	.160
Supplier Relationship and Integration	.309	5	189	.907
Process Management	.720	5	189	.609
Communication and Know ledge Transfer	.648	5	189	.664
Set-based Design	2.534	5	189	.030

Table 15: Levene's test results for LPD element use within different industries

The analysis of variance revealed a significant difference on a 5% significance level within the ‘strong project manager’ group. The results of the ANOVA as well as of the Welch and Brown-Forsythe tests are listed in Table 16. The presented results, however, only allow stating the presence of a significant difference within the SPM group but it does permit inferring which industrial sectors show a significant difference in the use of this LPD element.

LPD element	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brow n-Forsythe F
Strong Project Manager	2.473	.034*	-	-
Concurrent Engineering	1.663	.301	-	-
Teams	1.568	.171	-	-
Continuous Improvement	.612	.691	-	-
Product Variety Management	1.892	.098	-	-
Supplier Relationship and Integration	.736	.597	-	-
Process Management	.644	.667	-	-
Communication and Know ledge Transfer	1.274	.277	-	-
Set-based Design	-	-	.058	.066

* p < 0.05 ** p < 0.01

Table 16: Significance test results for LPD element use within different industries

This differentiation can only be made by conducting post hoc tests. The relatively large difference in sample size among the groups ranging from n = 5 for ‘mining and quarrying’ to n = 117 for the ‘automobile’ industry as well as the lacking homogeneity of variances in one of the variables required running a number of post hoc tests which fit the parameter conditions. Following Field’s (2013) recommendations, Gabriel’s procedure was employed for the variables with equal variances but slightly different samples sizes, Hochberg’s GT2 for variables with homogeneity of variances but very different sample sizes, and Games-Howell’s procedure for variables such as SBD, which violate the homogeneity of variances assumptions. Tuckey’s HSD or Ryan, Einot, Gabriel, Welch q test, sometimes referred to as Ryan procedure or simply REGWQ test, have not been conducted due to the unsatisfactory performance in controlling for Type I errors[30] in situations with varying sample sizes (Field, 2013). The results of the post hoc tests, presented in the following Table 17, show a significant difference on a 5% level within the SPM group between the ‘electronics’ and the ‘machinery, electrical, and transport equipment’ industry. The value for Hochberg’s GT2 is slightly higher due to its more rigorous approach in dealing with strongly varying sample sizes.

[30] Type I errors arise from situations in which a true null hypothesis is falsely rejected, which is why it is also referred to as ‘false-positive’. In other words, a Type I error detects an effect in the population which is not present (Backhaus et al., 2016; Bortz and Schuster, 2010; Field, 2013).

	Strong Project Manager	1 (n = 117)	2 (n = 10)	3 (n = 8)	4 (n = 48)	5 (n = 5)	6 (n = 7)	
1	Automotive		1.000	1.000	.300	.996	.169	Gabriel
2	Aerospace	1.000		1.000	1.000	.985	.355	
3	Chemicals	1.000	1.000		1.000	.999	.626	
4	Machinery, electrical, and transport equipment	.335	1.000	1.000		.643	.017*	
5	Mining and quarrying	.999	.987	.999	.799		1.000	
6	Electronics	.383	.362	.627	.042*	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2						

Table 17: Post hoc test results for SPM

The interpretation of the significant difference in the average use of the SPM can only be speculated at this point since both industries fall outside the scope of this study thus the available theoretical background does not grant hypothesising a potential cause without overclaiming. However, calculating the effect size using

$$\omega^2 = \frac{SS_M - (df_M)MS_R}{SS_T + MS_R}$$

with

$$SS_M = Mean\ sum\ of\ squares\ between\ groups$$

$$df_M = Degrees\ of\ freedom\ between\ groups$$

$$MS_R = Mean\ square\ within\ groups$$

$$SS_T = Total\ sum\ of\ squares$$

provides $\omega^2 = 0.036$ for the identified significant difference. According to Kirk (1996), who provides practical guidelines for interpreting the effect size, this value amounts to a small effect[31].

5.2.1.3 Company Size

The previous independent t-test as well as the one-way analysis of variances have shown that neither the country's nor the industry's influence on the average use of LPD elements result in significant differences with the previously discussed single exception. The next demographic measurement item which has a potentially large effect on the use of LPD is the company size. The forthcoming ANOVA compares the average use of LPD elements across the company size groups which have been formed by recoding the scale variable measuring company size in terms of persons employed. The recoding of the latter mentioned variable resulted in the groups previously reported in section 5.1.1. Figure 40 reports the average usage of LPD elements broken down into the company size groups.

[31] Kirk (1996) reported that omega squared values for effect magnitude need to be larger than 0.010 for a small effect, 0.059 for a medium effect, and 0.138 for a large effect.

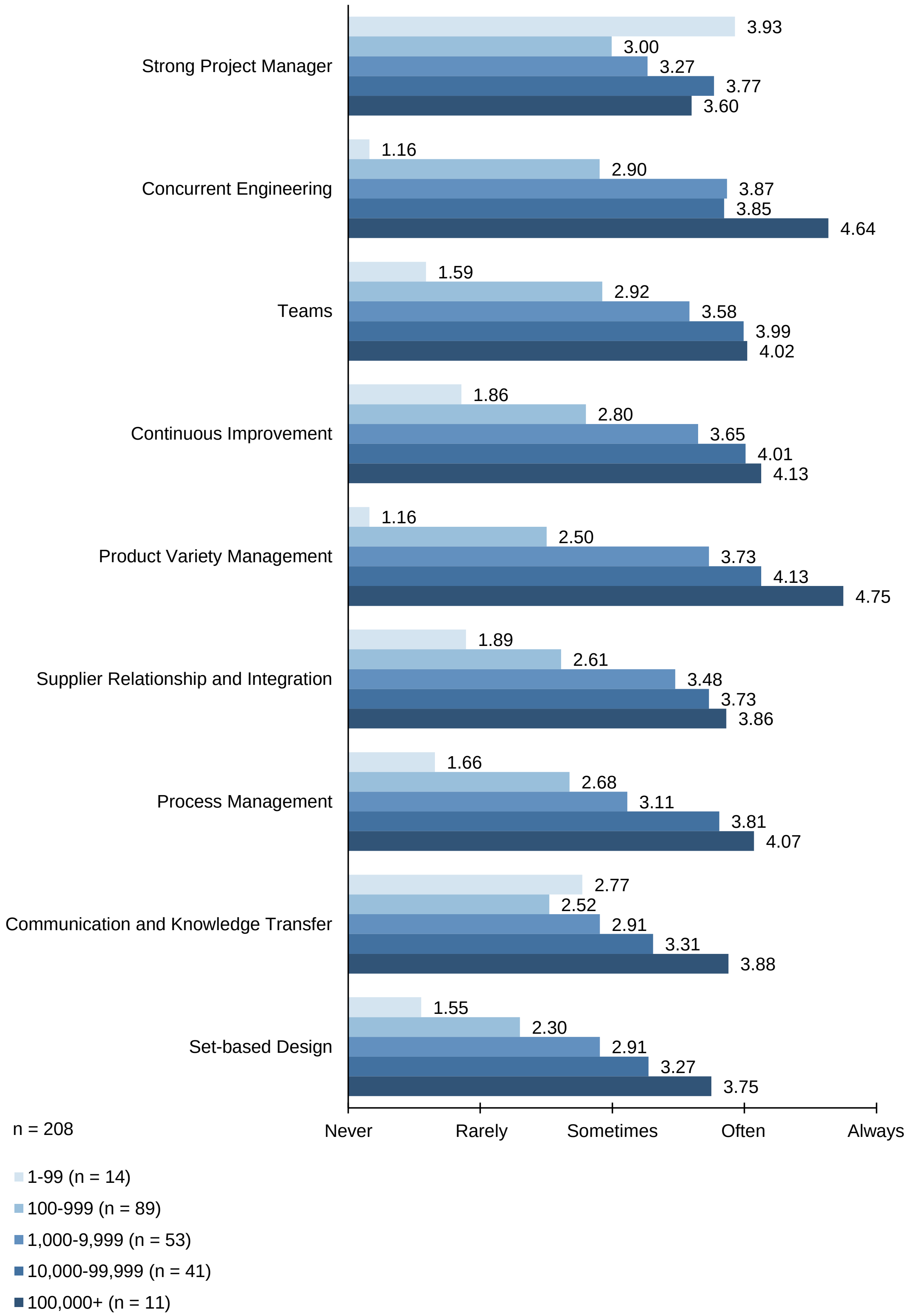


Figure 40: Average use of LPD elements by company size

The variables within the individual groups have been tested for the previously mentioned assumptions underlying an ANOVA. While independence was assumed, the variables were checked for outliers, tested for normality, linearity, heteroscedasticity, and heterogeneity. The test for linearity was passed while the Kolmogorov-Smirnov test for normality was failed by a number of variables. Hence, the average use of LPD element variables were again bootstrapped using a sample size of 2000 and bias corrected accelerated confidence intervals to retrieve most accurate results. Heteroscedasticity and heterogeneity were assessed using Levene's test of homogeneity of variances. The results reported in Table 18 show four of the nine variables tested significant in Levene's test thus violated the assumption of equal variances (highlighted in light blue). Consequently, Welch's F and Brown-Forsythe F were used to identify significant differences within these variable groups.

LPD element	Levene statistic	df1	df2	Sig.
Strong Project Manager	2.222	4	203	.068
Concurrent Engineering	11.589	4	203	.000
Teams	4.657	4	203	.001
Continuous Improvement	0.766	4	203	.549
Product Variety Management	11.781	4	203	.000
Supplier Relationship and Integration	0.899	4	203	.466
Process Management	1.620	4	203	.171
Communication and Know ledge Transfer	1.548	4	203	.190
Set-based Design	5.568	4	203	.000

Table 18: Levene's test results for LPD elements within different company sizes

The results of the significance tests summarised in Table 19 show a significant difference on a 1% level in all variables measuring the average use of LPD elements among different company sizes. These results align with literature reporting that the use of LPD is heavily depending on company size for a number of reasons. Firstly, a company might only reap the advantages of LPD once their product development efforts reach a certain resource intensity since potential efficiency and effectiveness improvements are proportional to the quantity of resources invested. Secondly, a company needs to carry out product development projects in a certain frequency to make investing in new approaches a worthwhile endeavour. Thirdly, the workforce needs the capacity and freedom to explore and test new approaches such as LPD. These arguments all point to the hypothesis that larger companies are generally more likely to employ LPD. The post hoc tests carried out in the following will enable a differentiation between the LPD element groups.

LPD element	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Strong Project Manager	8.310	.000**	-	-
Concurrent Engineering	-	-	.000**	.000**
Teams	-	-	.000**	.000**
Continuous Improvement	41.433	.000**	-	-
Product Variety Management	-	-	.000**	.000**
Supplier Relationship and Integration	28.705	.000**	-	-
Process Management	40.600	.000**	-	-
Communication and Knowledge Transfer	21.007	.000**	-	-
Set-based Design	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Table 19: Significance test results for LPD elements within different company sizes

Corresponding to the previously conducted ANOVA for the average use of LPD elements within the various industrial sectors, the choice of post hoc tests falls to Gabriel's procedure for variables with homogeneity of variances but slightly different sample sizes, Hochberg's GT2 if equal variances are present but sample sizes strongly differ, and Games-Howell's procedure if the homogeneity of variances assumption is violated. For variables with equal variances both Gabriel's and Hochberg's GT2 procedure have been carried out to allow for a cross comparison between categories which sample sizes only slightly differ such as the '1,000-9,999' (n = 53) and '10,000-99,000' (n = 41) categories and between those which show a significant difference in the number of responses such as the '100,000+' (n = 11) and '100-999' (n = 89) categories.

Table 20 reports the results for Hochberg's GT2 and Gabriel's procedure which allow the identification of significant differences between company sizes within the 'strong project manager' variable group. The test results reveal a significant difference on a 1% level between companies with 1-99 employees and those with a workforce of 100-999. These individual categories within the company size variable will henceforth be referred to with the corresponding category number, denoted in the first row and column of each table and highlighted with a light blue colour. Accordingly, the previously mentioned significant difference between companies with 1-99 and those with 100-999 employees is referred to as difference between categories one and two. Since this difference occurs between categories with strongly varying sample sizes, as reported in the second row of Table 20, Hochberg's GT2 is used to compare the two categories. Comparing the means of the average use of the SPM in each of the two categories, which have been previously illustrated in Figure 40 and are listed in the second column of Table 20, Hochberg's GT2 reveals a significant reduction in the usage of the characteristics represented by the SPM variable if a company outgrows the first category. This interesting finding might be explained by the growing organisational complexity once a company reaches a certain size. It appears that many of the SPM's responsibilities such as leading the PD project from idea to market launch, specifying the overall product concept and promoting customer values, and choosing technology as well as making major technological decision, which would in a small company typically fall to the senior engineer, are slowly redistributed in a growing company which in turn diminishes the mean value of the use of a SPM as defined in the proposed LPD framework. Consequently, it might be argued that participating companies on average choose not to elevate a senior engineer to a managerial position which would encompass the responsibilities of the SPM but rather keep the technical specialist in his traditional role while taking away managerial responsibilities such as setting the project time frame and controlling adherence to it. This impression is further strengthened when investigating the average use of the SPM's characteristics broken down into company size groups (see Appendix C 7). The aforementioned claim certainly goes beyond what the available dataset is able to explain but the results of the conducted analyses provide a good basis for further investigation.

On further comparison of the mean values in the second column of Table 20, it should be noted that the frequency in which the SPM attributes are used is highest for category one, starkly drops when reaching category two, subsequently slowly builds up again to peak in category four and then drops to 3.60 in category five. This trend results in another significant difference on a 5% level between the neighbouring categories three and four. It seems that companies growing beyond a workforce of 10,000 increasingly focus on empowering employees in the sense of the SPM potentially in an effort to consolidate PD responsibilities and restructure the development project. Next to the most interesting comparisons between neighbouring categories, which can be found left and right off the black highlighted diagonal, only the difference between categories two and four amounts to a significant difference on a 1% level.

	Strong Project Manager	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 3.93)		.000**	.068	.999	.982	Gabriel
2	100-999 (Ø = 3.00)	.002**		.475	.000**	.132	
3	1,000-9,999 (Ø = 3.27)	.097	.487		.046*	.900	
4	10,000-99,999 (Ø = 3.77)	1.000	.000**	.047*		.999	
5	100,000+ (Ø = 3.60)	.983	.235	.932	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 20: Post hoc test results of SPM for different company sizes

'Concurrent engineering' tested significant in Levene's test thus showed unequal variances which consequently called for the Games-Howell procedure in the post hoc test phase. The results of the Games-Howell procedure identified, next to the combined effects across multiple categories, differences on a 1% significance level between categories one and two, two and three, and four and five (see Table 21). Comparing the sigma values to the mean values in the second column, it can be observed that small, category one companies hardly employ any aspects of CE but as the companies grows, so does their average use of this LPD element. This finding is well aligned with literature which recognises small companies' difficulties of employing CE often due to their resource restrictions (Skalak et al., 1997). Consequently, the heightened use of CE indicates an increased resource capacity and the companies' ability to coordinate and integrate a growing number of specialists across different functions. This trend stagnates between categories three and four and sharply rises again reaching its maximum for companies with 100,000 and more employees. This trend might express the increasing need of growing companies to improve their time-to-market performance (Burt and Soukup, 1985; Smith and Reinertsen, 1991) and overall streamline their product development operation by integrating involved functions into the early phase of the development project as well as formalising interfaces and design evaluation processes. The plateau in mean value between companies with 1,000-99,999 employees (categories three and four) might be partially attributed to participating companies having reached a temporarily satisfactory level of CE thus shifted their focus on another aspect of PD or the absence of facilitating and enabling factors such as standardised routine tasks and fragmented sharing of preliminary information in a dialogue-mode (see Appendix C 15 et seq.).

	Concurrent Engineering	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.16)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.90)	-		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.87)	-	-		1.000	.004**	
4	10,000-99,999 (Ø = 3.85)	-	-	-		.003**	
5	100,000+ (Ø = 4.64)	-	-	-	-		

* p < 0.05   ** p < 0.01

Table 21: Post hoc test results of CE for different company sizes

The results of Hochberg's GT2 as well as Gabriel's procedure, presented in Table 22, identify, next to the combined effects across multiple categories, significant differences on a 1% level between categories one and two as well as two and three. The average use of the characteristics combined in the 'teams' element quickly rises from category one to three, somewhat slows down reaching category four, and then plateaus between categories four and five on a high average level around 4.00 which translates on the 1-to-5 'never'-to-'always' Likert scale to 'very often'. The characteristical aspects of integrating all involved functions into a development team, their colocation, and their continued collaboration throughout a development project seem to be almost never used by companies with 1-99 employees (Ø = 1.05) but increasingly focused on as companies grow to a certain size. When looking into the results of an ANOVA conducted among the different characteristics within the company size groups (see Appendix C 21 et seq.[32]), it becomes apparent that in small, category one companies only the characteristic describing the deep reaching technical knowledge of development team members seems to be at a relatively good level which also only slightly increases if companies grow in size. With the average use plateauing between categories four and five, this limit is located somewhere in the 10,000 and more employee range. Quite remarkable is the stark increase in the use of the T element between categories one and two. The focus on employing T, as defined in the proposed LPD framework, likely reflects a growing need to consolidate functional expertise or at least establish interfaces and practices which allow the effective use of functional knowledge in an increasingly large and complex company. The increasing use of the T element is largely attributed to the integration, colocation, and continued formation of development teams while the technical knowledge aspect only plays a marginal role (see Appendix C 21 et seq.). Once a company reaches a certain size and many of the characteristical aspects of T have been implemented, the need to further increase their use seems to stagnate. Quite interestingly, the overall use of T does not significantly correlate with the communication-focused CKT attributes (see Appendix C 15 et seq.).

[32] Appendix C provides the results of an ANOVA as well as the corresponding descriptive statistics, significance test results, and post hoc test results for every characteristic of each LPD element across the company size groups.

	Teams	1	2	3	4	5
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)
1	1-99 (Ø = 1.59)		.000**	.000**	.000**	.000**
2	100-999 (Ø = 2.92)	.000**		.000**	.000**	.000**
3	1,000-9,999 (Ø = 3.58)	.000**	.000**		.073	.427
4	10,000-99,999 (Ø = 3.99)	.000**	.000**	.074		1.000
5	100,000+ (Ø = 4.02)	.000**	.000**	.521	1.000	

Gabriel (above diagonal); Hochberg's GT2 (below diagonal)

* p < 0.05 ** p < 0.01

Table 22: Post hoc test results of T for different company sizes

The 'continuous improvement' group shows quite similar results in the post hoc test to the previous T element. Asides from the combined effect of multiple categories, Table 23 reports significant differences on a 1% level between categories one and two as well as two and three. Equally similar behaves the mean value of the CI variable across the different categories; starting off at a fairly low value of 1.86, the mean quickly rises, and plateaus just above the value of 4.00 which equates to 'very often' in the survey response scale. The stark increase in the use of CI and its fairly high plateau might be interpreted as a good indicator of how widely used CI practices such as kaizen or the in Germany often applied employee suggestion system are. With a mean value of 3.65 for companies with a workforce of 1,000-9,999 (category three) and a not significant difference between categories three and four, companies growing in size reach on average fairly quickly a high and quite stable level. The ANOVA on a characteristics level, provided in Appendix C 25 et seq., shows a very consistent and homogenous internal behaviour; all attributes show very similar significant differences with the exception of the ability to freely admit problems which starts at a relatively high level which does not differ significantly to category two companies. If looking at the correlations with other LPD element characteristics, it is interesting to note that this CI characteristic positively and significantly correlates with some of the SPM’s attributes which are largely independent within the proposed LPD framework (see Appendix C 15 et seq.).

	Continuous Improvement	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.86)		.001**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.80)	-		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.65)	-	-		.130	.039*	
4	10,000-99,999 (Ø = 4.01)	-	-	-		.959	
5	100,000+ (Ø = 4.13)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 23: Post hoc test results of CI for different company sizes

The results of the Games-Howell procedure for the ‘product variety management’ group exhibits, next to the significant differences across multiple categories, differences between all neighbouring categories on a 1% level with the exception of the comparison between categories three and four. The mean value of PVM for companies with 1-99 employees of only 1.16 close to the minimum value of 1.00, which equates on the 5-point Likert response scale to ‘never’, shows how little small companies employ the characteristics represented in the PVM variable. Only once companies grow beyond category one, they start paying attention to setting rules for using off-the-shelf products, reusing existing design solutions, and developing modular components as well as product platforms. This finding is well aligned with current LPD literature which seeks to counter problems affiliated to growing product portfolio of increasingly complex products by recommending the aforementioned practices. Especially Schuh (2013) attributes a relatively large amount of his publication to handling complexity. On inspection of the ANOVA results on the characteristics level, provided in Appendix C 28 et seq., it is interesting to note how modularisation as well as product platform developments stop increasing on any significance level while the increasing formalisation in terms of setting rules for using off-the-shelf products and reuse of existing parts are continually pushed on a significant level.

	Product Variety Management	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.16)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.50)	-		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.73)	-	-		.078	.000**	
4	10,000-99,999 (Ø = 4.13)	-	-	-		.001**	
5	100,000+ (Ø = 4.75)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 24: Post hoc test results of PVM for different company sizes

The results for the ‘supplier relationship and integration’ group, which tested not significant in Levene’s test thus exhibited equal variances, are listed in Table 25. Drawing on Hochberg’s GT2 for comparing categories one and two, the post hoc tests revealed a significant difference on a 5% level between these two neighbouring categories. While the difference between categories two and three also tested significant, the other two pairwise comparisons of neighbouring categories turned out not significant. Given the not significant difference between categories three and five, in addition to the missing significant differences between three and four as well as four and five, it can be concluded that once a company reaches the size of 1,000-9,999 employees (category three), companies no longer seem to significantly increase the frequency in which they employ the characteristics measured by the SRI variable. On a characteristics level, it is very interesting to see how the use of a small number of highly capable suppliers for critical parts does not significantly change with company size. Also noteworthy appears the low mean of the supplier integration attribute and the absence of a significant difference between categories one and two. Consequently, it can be concluded that it takes companies much longer to integrate critical suppliers into their concept definition phase. This might be a remnant of traditional Western arm-lengths supplier relationships in which suppliers were kept at distance and less treated like partners as promoted by the Japanese *keiretsu* system (see 3.2.4). The other two characteristics follow the pattern described by Table 25.

	Supplier Relationship and Integration	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.89)		.007**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.61)	.018*		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.48)	.000**	.000**		.719	.703	
4	10,000-99,999 (Ø = 3.73)	.000**	.000**	.722		1.000	
5	100,000+ (Ø = 3.86)	.000**	.000**	.775	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 25: Post hoc test results of SRI for different company sizes

Both post hoc tests for the ‘process management’ group, Hochberg’s GT2 as well as Gabriel’s procedure, identify significant differences in all comparisons but between categories four and five. On inspection of the mean values for each category, the PM variable shows a steady and rapid increase until reaching category four and subsequently only insignificantly increasing in category five. The relatively low starting point as well as the steady increase in the dataset reflect the propositions found in literature very well. Characteristics such as the standardisation of routine tasks, the continuous challenging of established standards as well as the appropriate resource allocation across multiple development projects are all prone to be found more frequently in larger companies. The other two characteristics represented in the PM variable, the staggered release of development projects and the adherence to development schedule, both start in category one at a somewhat higher mean value of 1.79 and 1.93 compared to the previously listed characteristics (see Appendix C 36). Both aspects of PM can be expected to be found more frequently used in small companies compared to the other three characteristics measured by PM. The plateauing between categories four and five might be partially explained by the overall relatively infrequent challenging of established standards as well as the stagnating mean values for appropriate resource allocation and schedule adherence. If considering the ANOVA results on the characteristics-level (see Appendix C 37 et seq.), it is interesting to note that while the standardisation of routine tasks as well as the staggered release of development projects is continuously driven across all company size categories, the challenging of existing standards does not show significant changes once a company outgrows category one. The latter also remains on a considerably lower level with a highest mean value of 3.27 compared to the other characteristics in large, category five companies. The detailed *R*-matrix provided in Appendix C 15 et seq. reveals relatively high, positive correlations with the knowledge-focused characteristics of CKT. It can therefore be concluded that companies seeking to increase the continuous challenging of existing standards would be well-advised to integrate tools and devices to collect best practices, review them in regular intervals, and update the documented knowledge continuously. These measures would mark an important step towards establishing a culture in which knowledge is not only preserved but continuously challenged in order to drive CI in all aspects of the company.

	Process Management	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.66)		.000**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.68)	.000**		.002*	.000**	.000**	
3	1,000-9,999 (Ø = 3.11)	.000**	.003**		.000**	.000**	
4	10,000-99,999 (Ø = 3.81)	.000**	.000**	.000**		.926	
5	100,000+ (Ø = 4.07)	.000**	.000**	.000**	.945		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 26: Post hoc test results of PM for different company sizes

Compared to all other LPD element groups, the post hoc test results for 'communication and knowledge transfer' are quite atypical (see Table 27). A first look at the mean values in the individual categories shows that category one starts at a remarkably high value (Ø = 2.77), the second highest after the SPM mean (3.93) for companies with 1-99 employees. The mean then insignificantly drops to category two, only to slowly rise again until reaching its maximum in category five. The rise in the use of CKT is significant on a 1% level between categories two and three and on a 5% level between categories three and four[33]. On inspection of the behaviour of the mean values for each characteristic (see Appendix C 41), the CKT exhibits a very unique pattern in the first three, communication-focused characteristics: the mean values for small, category one companies start at an ordinarily high level before suddenly dropping down to a much lower value in category two. The sudden drop of the characteristics 'information is passed on before it is compiled (e.g. in hand-over reports)', 'information is discussed in a dialogue-mode', and 'preliminary information is shared' might be reasonably explained by an

[33] For the comparison between categories four and five the results of Hochberg's GT2 were used due to the great difference in sample size. The difference between these two categories test non-significant for Hochberg's GT2 while testing significant on a 5% level for Gabriel's procedure.

increasingly formalised internal organisational context (see significant differences between categories one and two in CE, PVM, and PM). Further inquiries into the stark decrease of communication-focused characteristics and their relationship to other characteristics which relate to an increasingly formalised working environment such as CE’s frequent review meetings with all involved functions, PVM’s guidelines for using off-the-shelf parts, PVM’s goals for reusing parts among different products as well as PM’s standardisation of repetitive routine tasks show in 10 out of 12 relationships a significant negative correlation with the three communication-focused characteristics of CKT (see Appendix C 15 et seq.). These negative correlations further support the hypothesis that an increasingly formalised working environment severely diminishes the use of one half of the CKT characteristics. Further inquiries into the difference across company sizes on a characteristics level reveal that once the average use of communication-focused characteristics has dropped between categories one and two, they only recover in mostly insignificant increments unlike Table 27 might suggest. The other mean values for the three knowledge-focused characteristics start, like most other variables, on a fairly low level before rising and reaching their maximum for large, category five companies. This observation is also reflected in the ANOVA on the characteristics level (see Appendix C 42 et seq.). The discrepancy in the behaviour between the two characteristic groups combined in this variable indicate a divided nature which needs to be further investigated throughout the remainder of the analysis.

	Communication and Know ledge Transfer	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 2.77)		.692	.997	.031*	.000**	Gabriel
2	100-999 (Ø = 2.52)	.787		.003**	.000**	.000**	
3	1,000-9,999 (Ø = 2.91)	.998	.003**		.013*	.000**	
4	10,000-99,999 (Ø = 3.31)	.042*	.000**	.014*		.035*	
5	100,000+ (Ø = 3.88)	.000**	.000**	.000**	.053		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 27: Post hoc test results of CKT for different company sizes

The results of the Games-Howell procedure in the 'set-based design' group, presented in Table 28, strongly resemble the findings for T and SRI. Asides from the combined effect across multiple categories, the post hoc test exhibits differences on a 1% significance level between the neighbouring categories one and two as well as two and three. Analogously, the mean values strongly increase until reaching category three before they are no longer significantly increased in use. Although companies falling into category five reported a mean value of 3.75 in the use of the SBD variable, which is close to 'very often', and companies with 1,000-9,999 employees (category three) measured a mean value of 2.91, which would almost translate on the 1-to-5 'never-to-always' response scale to 'sometimes', the difference of 0.84 is not significant due to the relatively large difference in sample size (see second row of Table 28). The overall pattern described in the table below is translated into the ANOVA results of the characteristics across the company size variable with the notable exception of 'decisions are delayed until objective data allow the elimination of competing design solutions' (see Appendix C 46 et seq.). The mentioned attribute of SBD behaves quite differently as it does not significantly change from one neighbouring company size category to another and the average use mean value starts relatively high in category one (2.71) and remains at that level until starting to slowly increase beyond category three. Despite its positive correlation on a 1% significance level with company size (see Appendix C 50), this characteristic exhibits a quite different relationship to company size. Also noteworthy are the overall relatively low and few significant relationships with other LPD element characteristics with the notable exception of the high correlations with the knowledge-focused CKT attributes. The delaying of decisions characteristic is generally less depending on company size and other LPD element attributes.

	Set-based Design	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.55)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.30)	-		.000**	.000**	.002*	
3	1,000-9,999 (Ø = 2.91)	-	-		.209	.064	
4	10,000-99,999 (Ø = 3.27)	-	-	-		.525	
5	100,000+ (Ø = 3.75)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 28: Post hoc test results of SBD for different company sizes

The previously discussed results of the conducted post hoc tests comparing the average use of the nine LPD elements in differently sized companies revealed a number of interesting results such as the very strong use of the SPM's characteristics by small companies with a workforce of 1-99 employees which significantly drops to a much lower level when growing in size. Amongst others, also interesting were the results for CKT which gave rise to further doubts concerning the internal coherence of this element. After the close investigation of each element, Table 29 provides a summary of the category comparisons in an effort to identify clues which might be lost in a detailed analysis.

Reading Table 29 from left to right and focusing on the comparison of neighbouring categories first, the differences between categories one and two, reported as '1 / 2' in the second column, across all nine LPD elements is in seven cases significant on a 1% level and in one case on a 5% level. In other words, companies with a workforce of 100-999 employees make significantly more use of eight out of nine LPD elements compared to small companies with 1-99 employees. The only exception is CKT with its internally inhomogeneous behaviour. The next comparison between the neighbouring categories two and three identifies eight significant differences on a 1% level with the SPM being the only exception to this general trend. After these strong increases in the use of LPD elements, a comparison between categories three and four yields one significant difference on a 1% level and two on a 5% level and contrasting the mean values of categories four and five results in the identification of further two significant differences on a 1% level and one on a 5% level. Considering the large amount of significant differences between categories one and two as well as two and three, companies of growing size seem to adapt LPD practices across the whole range of elements. Given the relatively low overall average use of LPD[34] with a mean value of 1.55[35] of companies with 1-99 employees, the combined significant differences between categories one and three translate numerically into a more than twofold increase to a mean value of 3.39 for the overall use of LPD practices. On the employed 5-point Likert scale, a mean of 1 stands for 'never', 2 for 'rarely', 3 for 'sometimes', and 4 for 'often'.

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[34] The combination of the variables measuring the use of the individual LPD elements reliably represents the scale of overall LPD use (Cronbach's $\alpha = 0.865$). The detailed results of the reliability analysis are provided in Appendix C 51.

[35] The values for 'strong project manager' (3.93) and 'communication and knowledge transfer' (2.77) have been treated as outliers and taken out of the calculation for the overall use of LPD in companies with 1-99 employees. Including these two values would have resulted in an overall mean of 1.95.

In summary, small companies make on average very little use of LPD practices but if growing in size quickly adopt LPD characteristics across the entire spectrum likely in an effort to restructure and streamline their development efforts to cope with the growing pressure of the competition in an increasingly fierce market.

			Unequal variances	Equal variances	
Company size level	Difference	Significance level	Games-Howell	Gabriel / Hochberg	TOTAL
1	1 / 2	** p < 0.01	5	3 / 2*	7
		* p < 0.05	0	0 / 1	1
	1 / 3	** p < 0.01	4	3 / 3	7
		* p < 0.05	0	0 / 0	0
	1 / 4	** p < 0.01	4	3 / 3	7
		* p < 0.05	0	1 / 1	1
	1 / 5	** p < 0.01	4	4 / 4	8
		* p < 0.05	0	0 / 0	0
2	2 / 3	** p < 0.01	4	4 / 4	8
		* p < 0.05	0	0 / 0	0
	2 / 4	** p < 0.01	4	5 / 5	9
		* p < 0.05	0	0 / 0	0
	2 / 5	** p < 0.01	4	4 / 4	8
		* p < 0.05	0	0 / 0	0
3	3 / 4	** p < 0.01	0	1 / 1	1
		* p < 0.05	0	2 / 2	2
	3 / 5	** p < 0.01	2	2 / 2	4
		* p < 0.05	1	0 / 0	1
4	4 / 5	** p < 0.01	2	0 / 0	2
		* p < 0.05	0	1 / 0	1

1 = 1-99
4 = 10,000-99,999
2 = 100-999
5 = 100,000+
3 = 1,000-9,999

* The result of Hochberg's GT2 is counted towards the total amount

Table 29: Post hoc test results summary for LPD elements across different company sizes

5.2.1.4 Person Responsible

So far, the analysis in this section has assessed how the geographical position of the PD department, the industry the participating company mainly operates in, as well as the company size as expressed by the number of employees are influencing the use of LPD. The forthcoming analysis into Leanness concentrates on internal factors which might influence the extent to which LPD has been implemented into the participating companies such as the appointment of a person responsible for LPD, the employment of external help for introducing and facilitating LPD, and how the development of an overall strategy along with actionable goals and corresponding performance measurements effects the measured average use of LPD elements.

As previously presented in section 5.1.2, 86 (42.4%) of the 208 participating companies have stated to have a person responsible for implementing LPD, 117 (57.6%) have no such person, and 5 respondents have chosen not to provide any information in this regard. The average use of LPD elements has been broken down into two groups; companies which have a person responsible for LPD and companies which do not. The average means of the nine LPD element variables is compared using an independent t-test. As with the previous statistical tests, independence has been assumed while linearity was positively tested. The test for normality was failed by a number of variables which made bootstrapping of the variables necessary. The bootstrapping was performed using a sample size of 2000 and bias corrected accelerated confidence intervals in order to most accurately reflect the original variables. Levene's test for homogeneity of variances was significant for the average use of T and CE (see Appendix C 52). Figure 41 graphically illustrates the average use of LPD elements with and without a person responsible for implementing LPD. Whereas the use of the SPM as well as CKT appear to be very similar, the other variables show quite distinct differences. It should also be highlighted that the σ-values measuring the standard deviations are in all but two cases higher for companies not employing a person responsible for LPD. This higher variation suggests a wider spread of responses around the reported mean which in turn indicates that companies across the sample are less homogenous in their use of LPD if not employing a person responsible for LPD.

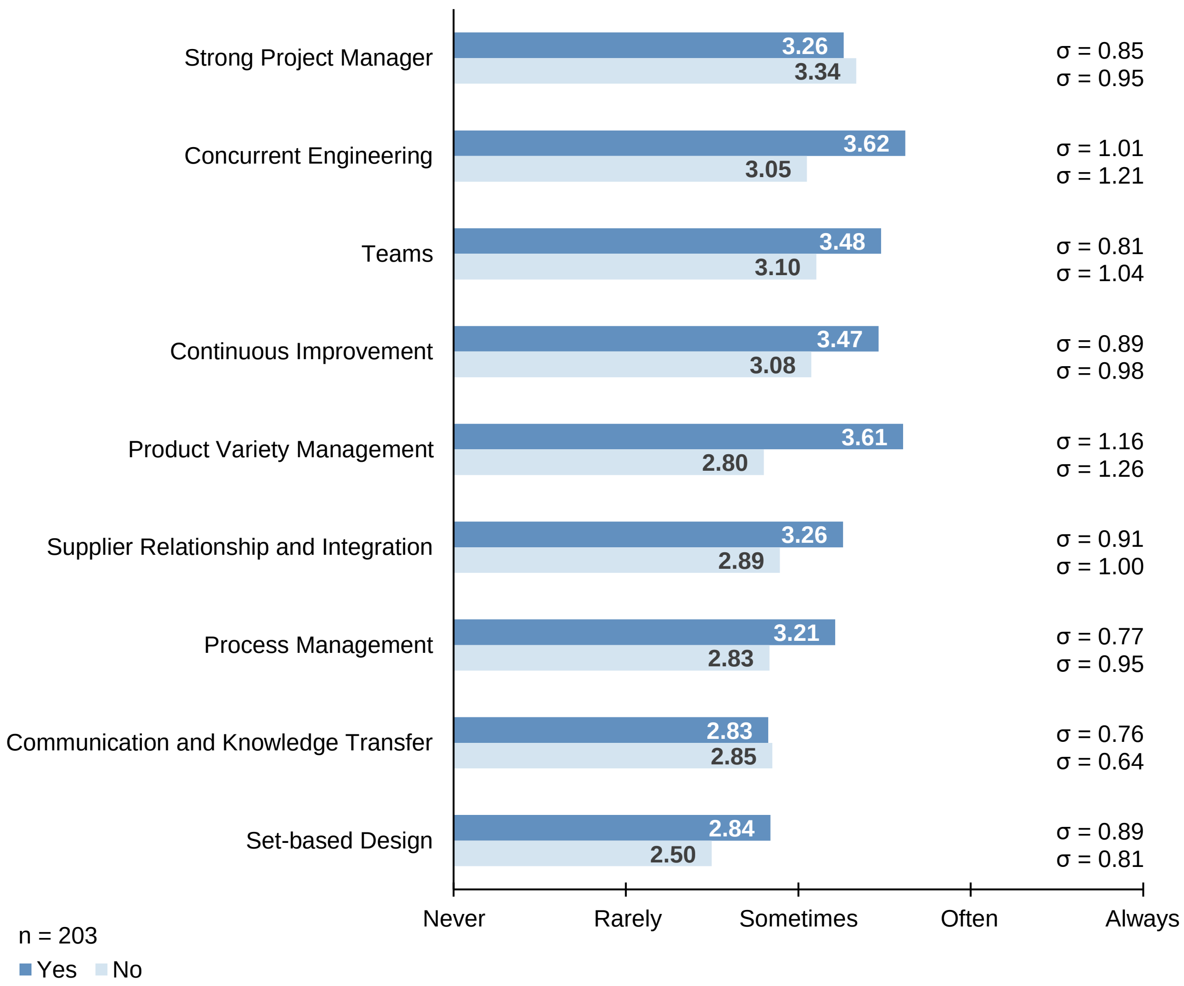

Figure 41: Average use of LPD elements with and without a person responsible for LPD

The results of the t-test, reported in Table 30, show a significant difference on 1% level in the average use of LPD elements for seven out of nine variables between companies which have a person responsible for LPD and those which do not. While most of these significant differences express a discrepancy in the mean use of LPD elements in the 0.3 range, CE (mean difference of 0.570) and PVM (mean difference of 0.808) appear to profit most from having an employee dedicated to implementing LPD. The average use of SPM as well as CKT do not seem to benefit from a person responsible for LPD or the gained advantage has been compensated by an unknown negative influencing factor. For CKT it might be that the on average low perceived ease and benefits of implementation as well as the reported last rank in the implementation order serve as deterrents for companies striving to embrace LPD practices. In combination with the overall low average use of this element of 2.86, which makes it the second least used LPD element, the previously mentioned factors might render it less attractive compared to other elements. Considering the high average use of the SPM in companies with less than 100 employees and assuming that a company needs to reach a certain size until it can reap the full range of LPD benefits and until it has the workforce capacity to fully or partially designate an employee to LPD, it could be hypothesised that the former partially cancels out the latter two aspects which results in a negative mean difference. Any causal claims, however, cannot be made on the grounds provided by the analysis of the dataset. The overall strong influence of having a person responsible for LPD on the average use of LPD elements constitutes an important finding.

LPD Element	Yes		Difference		No	
	Mean	Std. deviation	Mean difference	Sig. (2-tailed)	Mean	Std. devitiation
Strong Project Manager	3.263	.846	-.072	.571	3.335	.947
Concurrent Engineering	3.619	1.009	.570	.000**	3.049	1.214
Teams	3.480	.806	.375	.004**	3.105	1.045
Continuous Improvement	3.465	.890	.390	.004**	3.075	.978
Product Variety Management	3.608	1.164	.808	.000**	2.799	1.264
Supplier Relationship and Integration	3.259	.910	.366	.008**	2.893	.999
Process Management	3.214	.769	.381	.002**	2.832	.947
Communication and Know ledge Transfer	2.826	.756	-.023	.812	2.849	.643
Set-based Design	2.837	.889	.339	.005**	2.498	.808

* p < 0.05 ** p < 0.01

Table 30: T-test results for LPD element use with and without a person responsible

5.2.1.5 External Help

If a company does not have the workforce capacity to assign a person to LPD or does not wish to build its LPD knowledge base from naught, it might consider hiring a third party to facilitate their LPD efforts. With seven missing responses, 55 participating companies (27.4%) have reported to use or are planning to use external help such as consultants for the implementation of LPD while 146 companies, equating to 72.6% of the sample, do not and have no such intentions. The average use of LPD elements within the two groups of the nominal external help variable are illustrated in Figure 42. Overall, the figure shows only minor differences in the average use of the individual elements with only noteworthy differences in CE, CKT, and SBD. Whether these discrepancies amount to a statistically significant differences is assessed using an independent t-test.

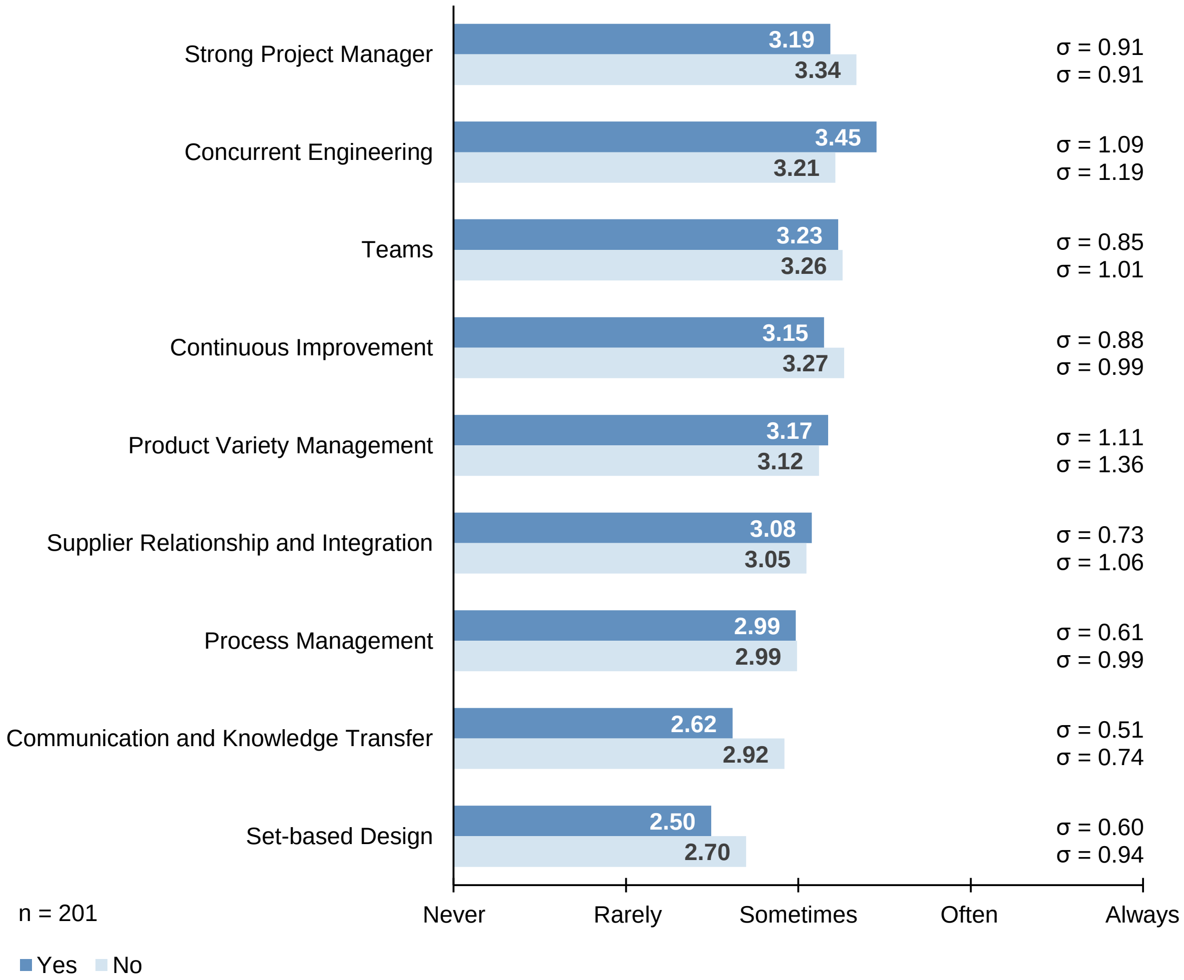

Figure 42: Average use of LPD elements with and without external help

Before conducting the t-test to compare the nine means within the two groups, the basic assumptions of linearity, independence, normality, heteroscedasticity as well as heterogeneity were checked. Analogue to the previous t-tests, independence was assumed, the test for linearity passed, and some variables showed a non-normal distribution. Therefore the nine variables representing the average use of LPD elements were bootstrapped using 2000 samples and bias corrected accelerated confidence intervals. Five of the nine variables tested significant in Levene's test thus violated the assumption of homogeneity of variances (see Appendix C 53). Only one of the three as noteworthy identified differences turned out significant in the independent t-test. CKT tested significant on a 1% level with a mean difference of -0.301. This suggests a general need for external help of companies struggling with introducing the characteristics which amount to the CKT element. On further inspection of the mean differences, Table 31 reveals in summary a negative mean difference leading to assume that companies with an overall lower use of LPD elements tend to employ external help to improve their LPD efforts. Consequently, this finding suggests that external help is more an implementation tool for companies which are new to LPD or have fallen behind in introducing LPD in their company. The finding that CE is on average 0.241 stronger in use by companies which use or intent to use external help constitutes a notable exception to the otherwise only small positive mean differences. It might be that CE with its previously detailed advantages of being generally an intensively used LPD element with strong perceived benefits while being perceived to be relatively easy to implement, and its distinct process character makes it a very interesting aspect of LPD for third parties. CE might be sold by externals as a ready-to-implement solution which needs only small amounts of tailoring thus makes it far more attractive than LPD elements such as SPM which typically needs some degree of organisational restructuring or SRI which, depending on the size and complexity of the supply chain, might require engaging in a lengthy and sensitive process very specific to the individual company.

LPD Element	Yes		Difference		No	
	Mean	Std. deviation	Mean difference	Sig. (2-tailed)	Mean	Std. devitiation
Strong Project Manager	3.185	.912	-.152	.294	3.337	.911
Concurrent Engineering	3.455	1.091	.241	.192	3.214	1.186
Teams	3.232	.852	-.025	.870	3.257	1.008
Continuous Improvement	3.149	.879	-.117	.443	3.266	.987
Product Variety Management	3.173	1.105	.053	.777	3.120	1.357
Supplier Relationship and Integration	3.077	.731	.031	.815	3.046	1.063
Process Management	2.985	.608	-.006	.957	2.992	.988
Communication and Knowledge Transfer	2.618	.509	-.301	.001**	2.919	.740
Set-based Design	2.495	.596	-.201	.073	2.697	.935

* p < 0.05 ** p < 0.01

Table 31: T-test results for average use of LPD elements with and without external help

5.2.1.6 LPD Goals

After the analysis of the previous five influence factors, the last variable which is investigated for its role in the average use of LPD elements is the development of an overall LPD strategy, as well as the formulation of goals and corresponding performance measurements. This variable is henceforth referred to as LPD goal variable. A first look at Figure 43 reveals a definite pattern described by an increasing frequency in which the characteristics are used, represented by the overall use of the individual LPD elements. This pattern is sometimes less distinct, for example for SPM or CKT, and at other times quite pronounced, for example in CI or SRI. The following ANOVA will identify significant differences, potentially determine patterns, and overall deepen the understanding of the influence of the LPD goal variable.

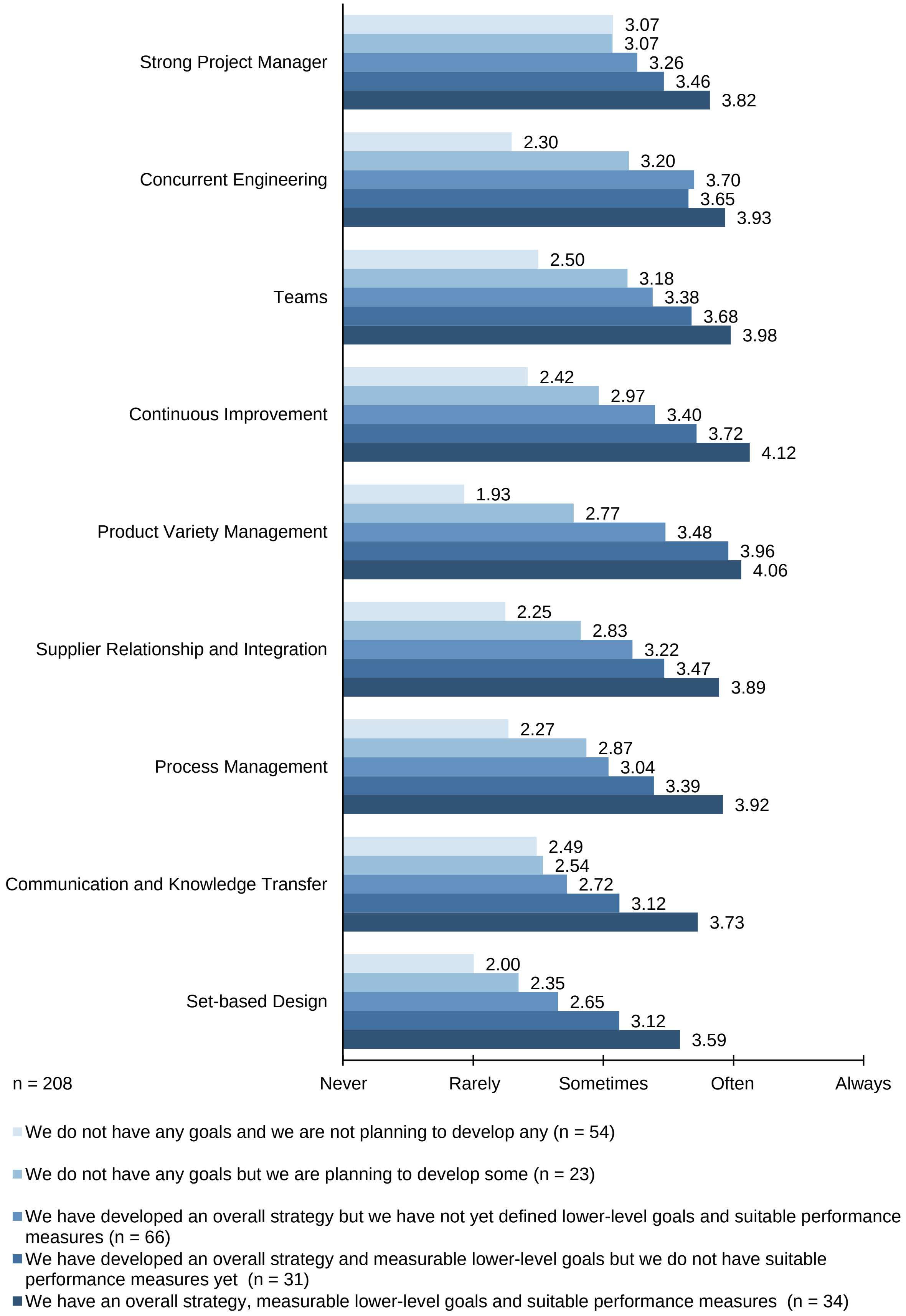

Figure 43: Average use of LPD elements according to LPD goals

Before conducting the one-way ANOVA, the various variables used in this statistical test have been subjected to statistical rigour to determine whether the assumptions for this analysis are met. After testing positive for linearity and assuming independence of the used observations, the nine LPD element variables within the ordinal LPD goal variables have been subjected to the Kolmogorov-Smirnov test for normality. A number of variables were found to violate the normality assumption and consequently the whole set of variables have been bootstrapped using a sample size of 2000 and bias corrected accelerated confidence intervals for most reliable results. Levene's test was used to assess heteroscedasticity and heterogeneity. Table 32 reports that all but 2 of the nine variables tested significant in Levene's test thus violated the assumption of equal variances.

LPD element	Levene statistic	df1	df2	Sig.
Strong Project Manager	2.808	4	203	.027
Concurrent Engineering	3.898	4	203	.005
Teams	2.820	4	203	.026
Continuous Improvement	1.737	4	203	.143
Product Variety Management	2.744	4	203	.030
Supplier Relationship and Integration	3.487	4	203	.009
Process Management	6.103	4	203	.000
Communication and Know ledge Transfer	.945	4	203	.439
Set-based Design	5.114	4	203	.001

Table 32: Results of Levene's test for different LPD goals

Consequently, the ANOVA is only run for CI and CKT which showed homogeneously distributed variances. All other variables are subjected to other, in this regard more robust, tests to compare their means. As before, Welch's F and Brown-Forsythe F are used to determine whether the previously in Figure 43 illustrated differences in the average use of LPD elements amount to a significant difference. Table 33 reports the results of these significance tests. Without an exception, all three tests revealed a significant difference on a 1% level within all nine groups. These results are investigated in more detail using a number of post hoc tests to determine where in these groups the significant differences lie. In an effort to paint a most accurate picture, each of the nine LPD element groups is evaluated individually to determine where exactly the significant differences occur. As with the previous two ANOVAs, the analysis uses Gabriel's procedure for variables with homogeneity of variances but slightly different sample sizes, Hochberg's GT2 for variables with equal variances but strongly varying sample sizes, and Games-Howell's procedure for the seven variables which violated the homogeneity of variances assumptions.

LPD element	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Strong Project Manager	-	-	.000**	.001**
Concurrent Engineering	-	-	.000**	.000**
Teams	-	-	.000**	.000**
Continuous Improvement	31.661	.000**	-	-
Product Variety Management	-	-	.000**	.000**
Supplier Relationship and Integration	-	-	.000**	.000**
Process Management	-	-	.000**	.000**
Communication and Knowledge Transfer	30.893	.000**	-	-
Set-based Design	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Table 33: Results of significance tests for different LPD goals

The following Table 34 reports the results of the Games-Howell procedure to determine any significant differences within the 'strong project manager' group which has violated the assumption of equal variances. As the table illustrates, there are no measurable significant differences between the lowest four levels of LPD goal definition. The average use of SPM appears to only start to significantly profit if the company develops an overall strategy, operational goals as well as the corresponding performance measures. Comparing categories one and three, it could be argued that the development of a strategy alone does not result in any significant improvements in the use of the SPM. Interestingly, there is no significant difference between groups four and five. And with the only difference between the last two categories (LPD goals categories 4 and 5) being the definition of performance measurements, it appears that implementing performance indicators alone does not result in a significant difference. Consequently, it might be concluded that the definition of lower-level goals which break down a strategy into achievable operational targets in combination with performance measurements which provide measurable feedback have a significant influence in the average use of the SPM. While this assertion holds true when looking at the LPD element, an ANOVA of the individual characteristics[36] within the SPM (see Appendix C 54 et seq.) reveals that the significant differences shown in Table 34 are for the most part not reflected in the single characteristics. Two of the five attributes do not even test significant in the ANOVA thus do not show significant changes across the LPD goal variable. The other three characteristics, similar to the overall LPD element, only show differences on a significant level if combining the effects of multiple categories. In conclusion, the SPM is only very little effected by the LPD goal variable, as reflected in the mean values presented in the second column of Table 34, and shows only any significant effects across multiple categories.

[36] For each of the following ANOVAs inquiring into the influence on the LPD goal variable on the use of LPD elements, there is a corresponding investigation into the characteristics of the same element. The results of these ANOVAs are presented in Appendix C 54 et seq.

	Strong Project Manager	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and w e are not planning to develop any (Ø = 3.07)		1.000	.826	.269	.000**	Games-Howell
2	We do not have any goals but w e are planning to develop some (Ø = 3.07)	-		.909	.461	.014*	
3	We have developed an overall strategy but w e have not yet defined low er-level goals and suitable performance measures (Ø = 3.26)	-	-		.780	.005**	
4	We have developed an overall strategy and measurable low er-level goals but w e do not have suitable performance measures yet (Ø = 3.46)	-	-	-		.276	
5	We have an overall strategy, measurable low er-level goals and suitable performance measures (Ø = 3.82)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 34: Post hoc test results of SPM for different LPD Goals

Table 35 summarises the results for the post hoc test applied to the ‘concurrent engineering’ group. The Games-Howell procedure reveals significant differences between categories one and all other levels of LPD goal definition. Since category one represents companies which do not have any goals for LPD and are not planning to develop any in the future thus represent the 54 of the participating companies (26%) which show no definable interest in LPD in this regard, the significant differences between categories one and all the other ones could be interpreted as putting no effort into the definition of LPD goals and the mere intention to do so (category two) and respectively the actual development of a LPD strategy, definition of lower-level goals as well as corresponding performance measurements make a statistically measurable significant difference. After a company has decided to invest in formulating LPD (category two) as defined by the LPD goal variable, the average use of CE does not seem to significantly profit from a strategy, goals, or performance measurements not considering the combined effects across multiple categories.

	Concurrent Engineering	1	2	3	4	5	
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.30)		.012*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.20)	-		.246	.421	.036*	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.70)	-	-		.999	.647	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.65)	-	-	-		.644	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.93)	-	-	-	-		

* p < 0.05   ** p < 0.01

Table 35: Post hoc test results of CE for different LPD Goals

As illustrated by the post hoc test results in Table 36, the average use of the ‘teams’ group shows a quite similar pattern to CE with regards to deciding to formulate a strategy and measurable goals alone (category two) makes a significant difference compared to not showing interest to define LPD goals on any level. In addition, the T variable seems to significantly profit from the combination of lower-level goals and suitable performance measurements as shown by the significant difference between categories three and five. The sole development of a strategy does not improve the average use of T on any significance level. Similar to CE, the missing significant differences between neighbouring ranks highlight the importance of fully formulating a LPD strategy with all its operational aspects. On a characteristics level, ‘the deep reaching knowledge of team members’ is far less influenced by the LPD goal variable compared to the other attributes of T which generally exhibit a quite similar behaviour to the one demonstrated by the consolidating T variable (see Appendix C 62 et seq.).

	Teams	1	2	3	4	5	
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.50)		.021*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.18)	-		.841	.176	.006**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.38)	-	-		.359	.004**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.68)	-	-	-		.536	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.98)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 36: Post hoc test results of T for different LPD Goals

The 'continuous improvement' group did not violate the homogeneity of variances assumption thus was tested with Gabriel's procedure as well as Hochberg's GT2. As Table 37 reports, the differences between the two post hoc tests do not amount to any noteworthy discrepancies. As with CE and T, the mere decision to define LPD on any level makes a significant difference in the use of CI. In addition to the significant differences between categories one and all other levels of LPD goal definition, both post hoc tests reveal a significant difference on a 1% level between two and four, two and five as well as three and five. In addition to these three differences, the missing significant differences between neighbouring ranks, with the exception of the difference on a 5% significance levels between categories one and two, indicate the importance of defining LPD goals down to an operational level. The mere development of a strategy or the partial definition of LPD goals on the operational level without defining suitable performance measurements did only have a limited impact on the frequency in which the characteristics measured by the CI variable are employed throughout the participating companies' development projects. This finding is confirmed by the ANOVAs on the characteristics level which paint a very similar picture without any noteworthy exceptions (see Appendix C 66 et seq.).

	Continuous Improvement	1	2	3	4	5	
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.42)		.035*	.000**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.97)	.042*		.151	.004**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.40)	.000**	.182		.406	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.72)	.000**	.004**	.430		.276	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 4.12)	.000**	.000**	.000**	.277		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 37: Post hoc test results of CI for different LPD Goals

The results of the post hoc test for 'product variety management' are fairly similar to the previously described results for CI with the notable exception of the missing significant difference between categories one and two. It appears that the mere intention to formulate LPD goals, and the limited commitment expressed in this intention, does not significantly impact the average use of PVM. The significant difference between category one and three, however, indicates that the formulation of a strategy alone has a significant influence on the employment of the characteristics represented by the PVM variable. As Table 38 reports, there is no significant difference between neighbouring ranks showing that the gradual formulation of LPD goals in the various degrees represented by the categories one through five does not significantly impact the use of PVM. In other words, the average use of PVM is only significantly increased if a company combines a strategy with actionable operational goals and its corresponding performance measurements. Considering the small mean difference, as depicted in the preceding Figure 43 and the second column of Table 38, and the result of the Games-Howell procedure of close to 1.000 between categories four and five, it could be argued that the introduction of performance measurements does not seem to play a major role in PVM; a clearly laid out strategy and workable goals appear to contribute more to the frequency in which the characteristics of this LPD element are employed. On closer inspection of the individual characteristics, this seems to be particularly important for the 'definition of guidelines for using off-the-shelf products' as well as the 'reuse of existing products parts' (see Appendix C 71 et seq.). If a company seeks to improve PVM beyond the definition of LPD goals, it might want to consider facilitating highly positively correlating characteristics of other LPD elements such as CE's formalised processes for assessing designs regarding manufacturability and assembly compatibility, PM's standardisation of repetitive routine tasks, or CKT's methods to collect best practice knowledge (see Appendix C 15 et seq.).

	Product Variety Management	1	2	3	4	5	
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.93)		.054	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.77)	-		.124	.002**	.001**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.48)	-	-		.065	.033*	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.96)	-	-	-		.988	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 4.06)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 38: Post hoc test results of PVM for different LPD Goals

The 'supplier relationship and integration' group shows overall very similar results to T in the post hoc test (Table 39). There is no significant difference between any neighbouring ranks and only the combined difference of multiple ranks amounts to any significance. This again highlights the importance of fully formulating a strategy including lower-level goals and suitable performance measurements. Looking closer at the characteristics level, the 'small number of highly capable suppliers for critical parts' attribute appears to be relatively little influenced by LPD goals (see Appendix C 74 et seq.). Another notable exception is 'the evaluation of parts regarding their criticality prior to making outsourcing decisions' characteristic which seems to profit from the development of a LPD strategy, unlike the other attributes.

	Supplier Relationship and Integration	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.25)		.140	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.83)	-		.419	.086	.001**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.22)	-	-		.508	.001**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.47)	-	-	-		.142	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.89)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 39: Post hoc test results of SRI for different LPD Goals

The results of the Games-Howell procedure for 'process management', as reported in Table 40, reveal that this LPD element is so far the first one to show a significant difference between categories four and five. In other words, PM is so far the only element to significantly benefit from performance measurements which facilitate the monitoring and controlling of the PM characteristics (difference between categories four and five). This is well aligned with best practices identified by Cooper et al. (2004a, b, c) as well as PD and LPD literature which stresses the importance of monitoring development processes to facilitate transparency and provide a basis for benchmarking and improvement (cf. Ahmed and Shepherd, 2010; cf. Morgan and Liker, 2006). If looking at the individual characteristics, the results reveal that the 'appropriate allocation of resources' as well as the 'adherence to schedules' attributes in particular benefit significantly from the introduction of suitable performance measurements (see Appendix C 78 et seq.). Asides from these findings, the use of PM is significantly increased if a company intends to formulate LPD goals as compared to not having any goals and not aim to develop any. This difference on a 5% significance level between categories one and two might be, similar to CE, T, and CI, partially if not fully explained by the fact that once a company shows intentions to formulate LPD goals, it has already committed itself to a certain extent to LPD, in all likelihood accumulated some knowledge about Lean practices in product development, and potentially already conducted some pilot projects. Asides from these two findings, only the combined effect of multiple categories amount to a significant difference.

	Process Management	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.27)		.013*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.87)	-		.746	.051	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 3.04)	-	-		.131	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.39)	-	-	-		.049*	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.92)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 40: Post hoc test results of PM for different LPD Goals

The results of Gabriel's procedure as well as those of Hochberg's GT2, presented in Table 41, show that the definition of lower-level goals as well as the implementation of corresponding performance measurements both individually make a significant difference to the frequency in which the characteristics of the 'communication and knowledge transfer' variable are employed (differences between categories three and four as well as four and five). With a significance value of 0.011 and 0.009, Hochberg's GT2 and Gabriel's procedure respectively disagree on whether the difference between categories three and four constitutes a significant difference on a 5% or 1% level. Considering Field's (2013) recommendation to use Hochberg's GT2 for variables with very different sample sizes and given that category three equates to 213% of category four's responses, Hochberg's GT2 is probably more suitable in the absence of clear cut definition of what constitutes 'very different' and 'slightly different' sample sizes. Regardless of the significance level, the definition of lower-level goals which provide operational targets make a significant difference in the frequency in which CKT is used. The inspection of the ANOVAs on the characteristics level further strengthen the impression of the inhomogeneity of the CKT variable (see Appendix C 82 et seq.); the knowledge-focused characteristics behave very similar to the overall element (see Table 41) while the communication-centred attributes almost show no significant differences with one of the three characteristics testing non-significant in both Welch's F and Brown Forsythe F. This finding shades further doubt on the composition of the CKT element. All other significant values represent combined effects across multiple LPD goal categories.

	Communication and Knowledge Transfer	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.49)		1.000	.221	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.54)	1.000		.829	.002**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 2.72)	.223	.855		.009**	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.12)	.000**	.002**	.011*		.000**	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.73)	.000**	.000**	.000**	.000**		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Table 41: Post hoc test results of CKT for different LPD Goals

Within the ‘set-based design’ group, Table 42 reports the previously frequently encountered significant differences between not neighbouring categories. Next to these combined effects, the Games-Howell procedure exhibits a significant difference on a 5% level between categories three and four which ascribes the definition of measurable and actionable lower-level goals significant importance in the use of SBD sign’. Further inquiries into the individual characteristics reveal that the attribute ‘decisions are delayed until objective data allow the elimination of competing design solutions’ does not follow the general trend described in Table 42 (see Appendix C 86 et seq.). While it is the only characteristic which, similar to the overall LPD element, shows a significant difference between categories three and four, it appears far less influenced by the development of a LPD strategy as well as the definition of operational goals. Only the addition of suitable performance measurements amount to significant differences across multiple categories.

	Set-based Design	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.00)		.249	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.35)	-		.340	.002**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures (Ø = 2.65)	-	-		.021*	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet (Ø = 3.12)	-	-	-		.168	
5	We have an overall strategy, measurable lower-level goals and suitable performance measures (Ø = 3.59)	-	-	-	-		

* p < 0.05 ** p < 0.01

Table 42: Post hoc test results of SBD for different LPD Goals

The previous detailed discussion of the results of the various post hoc tests performed on all nine LPD element groups and their characteristical attributes has revealed a number of interesting findings such as the significant difference the implementation of suitable performance measurements makes for the PM LPD element or the significant role the definition of lower-level goals plays in CKT. The findings of the individual post hoc tests have been summarised in Table 43 to provide an overview of what contributes the most to the use of LPD elements.

Reading the table from left to right and concentrating on neighbouring ranks first, the difference between categories one and two, denoted as '1 / 2' in the second column, is significant in four out of nine cases on a 5% level. As can be seen in the legend of Table 43, category one translates to the absence of LPD goals and the intentions to formulate any, while category two stands for missing goals with the intention to develop some. The difference between the two is reduced to the mere intent to formulate LPD goals and likely a certain degree of commitment to LPD by the participating company. While this intent translates to significant differences in four LPD element variables, the comparison between categories two and three yields no significant difference, while testing the difference between categories three and four as well as four and five results in two significant differences each. Consequently, it could be argued that the formulation of a strategy (category three) alone does not amount to a significant difference in the use of LPD elements but the additional definition of lower-level goals (category four) as well as implementation of measurable performance indicators (category five) both result on average to the increased use of two LPD elements if formulated consecutively and not in combination (moving across multiple categories).

It is also interesting to note when comparing the differences between categories one and five, two and five, and three and five, that the amount of significant differences, irrespective of their significance levels, is equal between categories one and five and two and five and only drops by one significant difference if contrasting them to the means of categories three and five. Therefore, it could be concluded that the presence of an overall strategy (difference between categories three and five) only amounts to such a small change in the average use of LPD elements that the total amount of significant differences is reduced by one in the case of CE. The impression of diminished importance for a strategy alone without formulating operational targets in combination with measurable performance indicators is further supported by the lacking significant differences between the neighbouring categories two and three. In reverse conclusion, the importance of lower-level goals and its corresponding performance measurements is heightened. This conclusion is further supported by the significant differences between categories three and four as well as four and five. The somewhat lacking influence of a strategy as a means to increase the use of LPD practices as well as the identified importance of actionable operational goals and suitable performance measurements constitutes an important finding. This finding is further supported by all three best practice studies which have been considered in the formulation of the proposed LPD framework (cf. Cooper et al., 2004a, b, c; cf. Kahn et al., 2012; cf. Markham and Lee, 2013) as well as noteworthy publications in the LPD research area such as Schuh (2013) and the wider PD field such as Ahmed and Shepherd (2010).

			Unequal variances	Equal variances	
LPD goal level	Difference	Significance level	Games-Howell	Gabriel / Hochberg	TOTAL
1	1 / 2	** p < 0.01	0	0 / 0	0
		* p < 0.05	3	1 / 1	4
	1 / 3	** p < 0.01	6	1 / 1	7
		* p < 0.05	0	0 / 0	0
	1 / 4	** p < 0.01	6	2 / 2	8
		* p < 0.05	0	0 / 0	0
	1 / 5	** p < 0.01	7	2 / 2	9
		* p < 0.05	0	0 / 0	0
2	2 / 3	** p < 0.01	0	0 / 0	0
		* p < 0.05	0	0 / 0	0
	2 / 4	** p < 0.01	2	2 / 2	4
		* p < 0.05	0	0 / 0	0
	2 / 5	** p < 0.01	5	2 / 2	7
		* p < 0.05	2	0 / 0	2
3	3 / 4	** p < 0.01	0	1* / 0	0
		* p < 0.05	1	0 / 1	2
	3 / 5	** p < 0.01	5	2 / 2	7
		* p < 0.05	1	0 / 0	1
4	4 / 5	** p < 0.01	1	1 / 1	2
		* p < 0.05	0	0 / 0	0

1 = We do not have any goals and we are not planning to develop any

2 = We do not have any goals but we are planning to develop some

3 = We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measures

4 = We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measures yet

5 = We have an overall strategy, measurable lower-level goals and suitable performance measures

* The result of Hochberg's GT2 is counted towards the total amount

Table 43: Post hoc test results summary of LPD element use for different LPD Goals

5.2.1.7 Summary

The detailed investigation into the potential influence of the previously tested variables has revealed numerous interesting findings. In an effort to complement these findings and summarise them in a concise manner, Table 44 brings together all six tested variables and presents the correlation coefficients of each of their categories with the single LPD elements. The inquiry into the relationship between each category within the single influencing variables made it necessary to introduce 22 dummy variables. Due to the categorical nature of the influencing variables listed on the left of the table, the individual relationships were determined using Spearman's correlation coefficient.

Analogously to the previously performed independent t-test, this non-parametric test identified no significant correlations between the geographical locations, whether it is the US or Germany, and the use of the single LPD elements.

A closer look at the relationship between the industrial sectors the participating companies mainly operate in and the use of LPD elements revealed a significant negative correlation of the automotive industry with CE and PVM. These findings are rather surprising since CE has been identified in the earliest publications of Lean practices in the PD environment (cf. Clark et al., 1987; cf. Womack et al., 1990). It could therefore be assumed that CE is well established in the automotive industry. A further inspection of the distribution of the different industrial sectors across the various company sizes reveals that 64.3% of companies with 1-99 employees and 65.2% of companies with a workforce of 100-999 people mainly operate in the automotive sector (see Appendix C 90). As the investigation into the use of LPD across differently sized companies has shown, these two categories have exhibited the lowest use of LPD elements. With 49.6% of the automotive subsample counted towards the previously two mentioned categories, the distribution in company size has a large impact on the overall performance of the automotive industry within the dataset. This might, at least partially, explain why PVM has also been identified to significantly negatively correlate with the automotive industry. The second largest industry category, machinery, electrical, and transport equipment, has been found to significantly positively correlate with SPM, CKT, and PVM. If combining the use of the individual LPD elements into an overall average use of LPD, as it has been previously done when investigating the influence of company size, the mean values reveal that the machinery, electrical, and transport equipment industry make among the various industrial sectors the most use of LPD practices (Ø = 3.24) as defined in the proposed framework. The frequent employment of LPD practices in development projects might be partially explained by the primarily large companies in this subsample. With 66.7% of the participating companies having more than 1,000 employees, this industrial sector is predominantly represented by large companies and overall stands out with its big proportion of 1,000+ employee companies. The negative correlation on a 5% level between the electronics industry and the SPM can only be hypothesised to be attributed to the general organisational structures in development projects in this industry. The strong focus of this research on the automobile industry, the corresponding limited scope as well as the available dataset do not permit making any reasonable claims beyond this general assumption.

The correlation coefficients between the five different company size categories and the individual LPD elements paint a very clear picture: companies with fewer than 999 employees predominantly strongly and significantly negatively correlate while companies with more than 1,000 employees overall significantly positively correlate with the LPD elements. The exception to the negative correlations is a single significant positive relationship between companies with a workforce of 1-99 employees and the SPM. The previous detailed investigation has presented grounds which lead to assume that the uncomplicated organisational structures and a lacking degree of specialisation in small companies erode the SPM’s sphere of influence thus have a strong negative influence. Companies with more than 1,000 employees have been found to strongly positively correlate with the use of LPD elements with the exception of a few relationships between certain company sizes and elements which have been found to be non-significant. In summary, it can be said that one of the biggest influencing factors on the use of LPD has been identified to be company size.

Corresponding to the previously presented findings, having a person responsible for implementing LPD in a company makes a significant difference for the use of many LPD elements. Analogously, not allocating an employee to the implementation of LPD significantly hampers companies seeking to embrace Lean practices in their product development projects. The SPM as well as CKT form the only exceptions to this general trend. The SPM is hypothesised not to significantly correlate with a person responsible for implementing LPD partially because it is assumed that a company needs to reach a certain size to be able to designate an employee to introducing LPD and to make LPD a worthwhile endeavour. As the previous discussion has shown, the SPM starts with a very high average mean and subsequently significantly drops in companies sizing 100-999 employees. It seems justifiable to assume that the initial high average use of the SPM in small companies with 1-99 employees at least partially cancels out the overall convincing benefits of a person responsible for the implementation of LPD. The CKT is hypothesised not to benefit from a person responsible for LPD due to the very low scores in ease of use, benefits of implementation, overall average use, and the generally low priority in implementing this LPD element. These aspects are likely to convince a company to set its focus on other, easier to implement and potentially more rewarding elements first.

The consultation of third parties such as consultants has been determined in the previous analysis to be a tool for companies which are either new to LPD or have fallen behind in implementing Lean practices into their product development environment. The previously identified significant difference and the in Table 44 reported significant negative correlation are hypothesised to be attributed to companies struggling to embrace the characteristics covered by the CKT variable. These companies are assumed to employ the help of external parties, especially when introducing information technological structures which support the three knowledge-based attributes of this LPD element.

The influence of the LPD goal variable is very complex and multifarious. In addition to the previously reported detailed analysis, Table 44 generally paints a very clear and easy to grasp picture. Companies which show no intention to define LPD goals on any level significantly negatively correlate with all LPD elements. Moreover, most of these relationships show fairly large negative correlation coefficients. On the other end of the LPD goal spectrum stand the significant positive correlations of companies which have developed a general LPD strategy, defined lower-level goals, and implemented suitable performance measurements. Between these two extremes are multiple significant relationships which have been previously analysed in detail. In summary, the importance of a strategy alone as a means to facilitate LPD practices has been severely diminished by the previous analysis. The operational aspects of the LPD goal variable, on the other side, have been found to play a vital role in the introduction of LPD; only if strategic targets are made actionable on an operational level using achievable goals and corresponding performance measurements, a company can expect to make the most use of LPD. The formulation of LPD goals on a strategic and operational level, company size as well as designating an employee to implementing LPD have been identified to have profound influence on the use of Lean practices in product development.

		Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Know ledge Transfer	Process Management	Product Variety Management	Continuous Improvement	
Location	USA	-.064	.099	.131	.036	.021	.074	.030	.057	.079	Spearman's rho
	GER	.031	-.111	-.105	.005	.030	-.022	-.019	-.039	-.047	
Industry	Automotive	-.048	-.106	-.154*	.023	.001	.041	-.103	-.186**	-.101	
	Aerospace	.030	.014	.065	-.071	-.100	-.066	-.042	-.020	.001	
	Chemicals	-.004	.077	.016	-.044	-.072	-.017	.061	-.119	-.078	
	Machinery, electrical, and transport equipment	.199**	.093	.115	-.106	.073	.137*	.074	.145*	.102	
	Mining and quarrying	-.084	-.123	-.058	-.006	-.113	-.119	-.055	-.046	-.010	
	Electronics (other)	-.156*	.076	-.061	.042	.034	-.070	-.011	.061	.033	
Company size	1-99	.189**	-.413**	-.423**	-.299**	-.380**	-.009	-.361**	-.401**	-.355**	
	100-999	-.310**	-.345**	-.316**	-.425**	-.407**	-.446**	-.362**	-.441**	-.469**	
	1,000-9,999	-.031	.186**	.263**	.250**	.241**	.053	.073	.237**	.253**	
	10,000-99,999	.261**	.383**	.209**	.336**	.334**	.338**	.450**	.368**	.399**	
	100,000+	.069	.181**	.288**	.192**	.263**	.290**	.264**	.310**	.230**	
Person responsible	Yes, person responsible	-.050	.161*	.208**	.154*	.174*	-.072	.185**	.290**	.168*	
	No, no person responsible	.030	-.176*	-.240**	-.201**	-.230**	.006	-.230**	-.324**	-.212**	
External help	Yes, external help	-.092	-.038	.063	-.024	-.080	-.227**	-.018	-.007	-.095	
	No, no external help	.047	-.012	-.118	-.008	.015	.132	-.047	-.042	.029	
LPD goals	No goals and w e are not planning to develop any	-.160*	-.443**	-.466**	-.470**	-.521**	-.314**	-.483**	-.547**	-.530**	
	No goals but w e are planning to develop some	-.103	-.045	-.052	-.086	-.143*	-.171*	-.063	-.109	-.135	
	We have a strategy but no goals and performance measures	-.037	.054	.226**	.078	.055	-.152*	.035	.150*	.104	
	We have a strategy and goals but no performance measures	.060	.173*	.103	.169*	.275**	.217**	.172*	.247**	.220**	
	We have a strategy, goals and performance measures	.267**	.328**	.213**	.370**	.404**	.500**	.416**	.314**	.399**	

* p < 0.05 ** p < 0.01

Table 44: Influence on LPD elements correlation matrix

5.2.2 Element Relationships

Equipped with a firm understanding of the external influence factors on LPD, this section sets its focus on understanding the inner workings of the proposed LPD framework. This task is addressed in three steps. Firstly, the individual LPD elements, as reliably represented by the characteristics measured in the survey (see section 5.1.3), will be analysed in a correlation matrix. The correlation matrix, also referred to as *R*-matrix, serves as a basis for the subsequent exploratory factor analysis which seeks to identify clusters of correlation in a systematic and statistically rigorous approach. The heightened understanding of the interrelationships between the single elements and the correlation clusters they have been placed in, is lastly strengthened by analysing the matrix in which respondents have been asked to convey the perceived influence of one LPD element on another. This tripartite approach to exploring and identifying potential interrelationships will establish a comprehensive understanding based on empirical data and form the foundation for the implementation recommendations developed in the next section 5.2.3.

5.2.2.1 Correlation Matrix

The usage of individual characteristics of the LPD elements have been drawn together in section 5.1.3 into a mean value to represent the average usage of LPD elements in scale variables. These variables have subsequently been subjected to the statistical assumptions underlying parametric tests to pave the way for the independent t-tests conducted in section 5.1.3. The variables passed the tests for linearity, heteroscedasticity, and heterogeneity, had no outliers to deal with and due to the nature of the data collection process, the assumption of independence has been assumed. The nine scale variables, however, did not meet the Kolmogorov-Smirnov test for normality and, consequently, the individual variables had to be bootstrapped using a sample size of 2000 and bias corrected accelerated confidence intervals for most accurate results. The bootstrapped scale variables have then been prepared for investigating the relationships using Pearson's product-moment correlation in a two-tailed test due to the non-directional character of the correlations. The results of this bivariate correlation are summarised in the *R*-matrix depicted in Table 45. In addition to the correlation coefficients, the table visually illustrates significant correlations on a 5% level with one asterisk and a light blue background colour and significant correlations on a 1% level with two asterisks and a dark blue background colour.

	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Knowledge Transfer	Process Management	Product Variety Management	Continuous Improvement
Strong Project Manager	1	.120	.024	.173*	.109	.296**	.186**	.150*	.108
Teams	.120	1	.657**	.463**	.399**	.316**	.591**	.511**	.529**
Concurrent Engineering	.024	.657**	1	.459**	.456**	.279**	.608**	.676**	.553**
Supplier Relationship and Integration	.173*	.463**	.459**	1	.478**	.331**	.531**	.580**	.484**
Set-based Design	.109	.399**	.456**	.478**	1	.484**	.506**	.567**	.482**
Communication and Knowledge Transfer	.296**	.316**	.279**	.331**	.484**	1	.439**	.293**	.405**
Process Management	.186**	.591**	.608**	.531**	.506**	.439**	1	.602**	.553**
Product Variety Management	.150*	.511**	.676**	.580**	.567**	.293**	.602**	1	.542**
Continuous Improvement	.108	.529**	.553**	.484**	.482**	.405**	.553**	.542**	1

* p < 0.05 ** p < 0.01

Table 45: Correlation matrix of the average usage of LPD elements

A first look at the *R*-matrix reveals the numerous significant interdependencies on a 1% significance level. This finding is in accordance with Hoppmann's (2009) results, supported by the numerous theoretical relationships identified in literature (see section 3.3), and indicates the extensive, simultaneous average use of elements of companies embracing LPD. Inversely, the strong correlations between the majority of LPD elements suggests that companies less invested in LPD seem not to employ only a number of practices but most of them simply on a lower level of intensity. Consequently, the findings revealed in the correlation matrix of the average use of LPD elements cautiously indicate that it appears common practice for companies to employ and advance a multitude of LPD elements simultaneously rather than introducing one element after another.

On second inspection it appears that all but the SPM heavily correlate with all other LPD elements. The SPM does, however, correlate with SRI and PVM on a 5% and with CKT as well as PM on a 1% significance level. On further examination using partial correlation to control for the influence of all other LPD elements, all significantly correlating elements but CKT (0.254**) diminish in their significance below the 5% level. This analysis has shown that CKT is on average used in combination with SPM which suggests the potential presence of a causal relationship. This aspect will be further investigated when including the respondents' answers to the perceived influence of LPD elements at the end of this section.

To allow a closer inspection of the relationships between the individual LPD elements, Appendix C 15 et seq. provides a correlation matrix, corresponding to Table 45, which shows the correlation coefficients between each characteristic. This *R*-matrix on a characteristics level provides a more detailed picture of the relationships between the LPD elements and the sub-scales they are composed of. It reveals, for example, that most characteristics of the SPM significantly correlate with the mode and frequency of communication as well as the best practice and lessons learned review practices represented by characteristics[37] measured in the CKT element. This relationship suggests that either the correlating characteristics of the SPM facilitate CKT or that CKT practices enable and empower the SPM. The findings provided in the correlation matrix, however, only quantify a degree of association and do not allow to infer causality.

5.2.2.2 Exploratory Factor Analysis

In a next step, the data on the average use of LPD elements is reduced to identify patterns in form of clusters of correlation which allows gaining further insights into the strongly interrelated LPD framework proposed in this work. While exploratory factor analysis lends itself well to constructing questionnaires evaluating latent variables which cannot be measured directly and reducing datasets without losing too much of the original data, it is also well-suited for understanding the structure behind a dataset (Field, 2013). Exploratory factor analysis is a multivariate statistical method which seeks to structure a set of variables into strongly correlating groups which separate themselves from groups with a lesser degree of association. In this context, groups of strongly correlating variables are referred to as factors which represent latent variables describing associations between measured variables (Backhaus et al., 2016). Within exploratory factor analysis, there are several methods for unearthing factors in a dataset. For this crucial step, Field (2013) distinguishes between methods which limit the findings to

[37] The fragmented mode of communication is represented by 'information is passed on before it is compiled (e.g. in hand-over reports)' while the review practices are measured by the item 'best practices and lessons learned from previous project are reviewed'.

the collected sample and those which allow generalising the results to the entire population. Due to the transferability of the findings, the author refers to the former as descriptive and the latter as inferential. Inferential methods such as maximum-likelihood method or alpha factoring, however, are based on the assumption that the measured variables make up the entire population of variables of interest (Field, 2013). Despite the comprehensive literature review, the examination of previous surveys, and the careful construction of the employed questionnaire, this assumption cannot be made. In addition, most scales measured in the questionnaire have been developed in the course of this work which precludes making this assumption in good consciences. Consequently, the choice for a specific exploratory factor analysis falls to a descriptive method such as principal component analysis, principal axis factoring, or image factoring. Without going into a detailed discussion about the advantages and disadvantages of the individual multivariate statistical methods, principal axis factoring has been chosen as the most suitable method for discovering factors. In literature, Backhaus et al. (2016), Eid et al. (2015), and Field (2013) recommend choosing principal axis factoring over the other methods if the main purpose of the analysis is identification of factors which explain the relationships between the measured variables.

Following the general procedure for conducting exploratory factor analysis, as outlined by Backhaus et al. (2016) and Field (2013), the data set is initially screened with regard to the suitability of sample size as well as the correlations between variables. While numerous differing recommendations in terms of sample size can be found in literature (cf. Comrey and Lee, 1992; cf. Nunnally, 1978; cf. Tabachnik and Fidell, 2014), there are established calculation methods which allow making assertions about a suitable sample size. Among the most established is the Kaiser-Meyer-Olkin measure of sampling adequacy which assesses samples on a scale of 0 (unsuitable) to 1 (ideal). The data set under investigation scored 0.88 in the

Kaiser-Meyer-Olkin test which strongly indicates that factor analysis should produce sound and reliable factors. Subsequently, the correlations between the variables is scrutinised to identify problems related to variables which do not sufficiently correlate with other variables thus would remain independent of any clusters of correlation and unnecessarily diminish the quality of the results as well as problems related to extremely highly correlating variables which would indicate multicollinearity and pose a problem to exploratory factor analysis since unique contributions to a specific factor would be impossible to identify. Scanning the *R*-matrix presented in the preceding Table 45, it is evident that all LPD elements sufficiently correlate with each other – even the SPM which significantly correlates with four variables in the correlation matrix and at least one variable when conducting a partial correlation analysis. Furthermore, the correlation matrix does not hold any coefficients greater than 0.9 which would be a strong indication for multicollinearity. Another heuristic suggesting no multicollinearity among the variables is the *R*-matrix determinant of 0.019 which is greater than the threshold of 0.00001 suggested in literature (cf. Field, 2013).

After meeting the aforementioned assumptions, the factor analysis was conducted and provided a correlation matrix (see Table 45), an inverse of the correlation matrix, and an anti-image matrix. The inverse correlation matrix, in literature typically denoted as R^{-1}-matrix, is used for various internal calculations such as factor scores which are of no further interest at this point. It does, however, also show the variance inflation factors (VIF) which can be found on the diagonal of Table 46 and are highlighted in a dark blue colour. These values are well below the threshold of 10, as defined by Myers (1990), which provides another strong indication that multicollinearity is not biasing the factor analysis. The anti-image correlation matrix, provided in Appendix C 91, shows on its diagonal the dark blue highlighted results of the previously mentioned Kaiser-Myer-Olkin (KMO) test for sampling adequacy for each individual variable.

Both Backhaus et al. (2016) and Field (2013) recommend examining the KMO values for the individual variables despite having an overall satisfactory score. The anti-image matrix yields KMO values well above 0.8 with the exception of 0.629 for the SPM element. But with the value being well above the advocated minimum of 0.5, the sampling adequacy can be reconfirmed.

	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Know ledge Transfer	Process Management	Product Variety Management	Continuous Improvement
Strong Project Manager	1.151	-.083	.278	-.086	.134	-.341	-.114	-.207	.055
Teams	-.083	2.062	-.898	-.214	.012	-.032	-.446	.119	-.293
Concurrent Engineering	.278	-.898	2.630	.103	-.013	.035	-.413	-1.019	-.285
Supplier Relationship and Integration	-.086	-.214	.103	1.749	-.218	-.045	-.273	-.546	-.210
Set-based Design	.134	.012	-.013	-.218	1.858	-.557	-.148	-.599	-.172
Communication and Know ledge Transfer	-.341	-.032	.035	-.045	-.557	1.563	-.335	.279	-.275
Process Management	-.114	-.446	-.413	-.273	-.148	-.335	2.250	-.366	-.229
Product Variety Management	-.207	.119	-1.019	-.546	-.599	.279	-.366	2.581	-.235
Continuous Improvement	.055	-.293	-.285	-.210	-.172	-.275	-.229	-.235	1.856

Table 46: Inverse of correlation matrix

An initial factor analysis was run to determine the eigenvalues for the individual factors. The eigenvalues of a factor assign a measure of importance in terms of explaining a certain percentage of variance or, put differently, the amount of data the factor represents. Two factors yielded eigenvalues over 1 thus meet the Kaiser criterion and combined explained 62.9% of variance (see Table 47). The scree plot, which shows the eigenvalue over the number of potential factors[38], exhibits an inflexion at three which would justify retaining three factors (see Appendix C 92).

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4.527	50.300	50.300	4.150	46.111	46.111	3.710
2	1.132	12.576	62.876	.660	7.337	53.448	3.611
3	.758	8.426	71.302	.291	3.236	56.683	2.292
4	.637	7.073	78.375				
5	.500	5.553	83.929				
6	.463	5.141	89.070				
7	.389	4.317	93.387				
8	.354	3.931	97.318				
9	.241	2.682	100.000				

Retained factors

Extraction Method: Principal Axis Factoring.

a. When factors are correlated, sums of squared loadings cannot be added to obtain a total variance.

Table 47: Factor extraction

[38] The number of potential factors equals the amount of variables – nine.

At closer inspection under which circumstances the Kaiser criterion provides accurate results, Stevens (2001) advises caution if retaining communality values (after extraction) of greater than 0.7 for less than 30 variables. As Table 48 illustrates the average communality value after extraction is 0.569 with only 3 factors above 0.7. Consequently, the Kaiser criterion may not be accurate. Following the scree plot, 3 factors were retained to best represent the correlation clusters in the dataset. This is in accordance with Jolliffe's (1972) recommendation who states that the Kaiser criterion is in many cases too strict and after conducting a series of tests suggests to retain all factors scoring eigenvalues greater than 0.7.

	Initial	Extraction
Strong Project Manager	.131	.112
Teams	.515	.665
Concurrent Engineering	.620	.705
Supplier Relationship and Integration	.428	.462
Set-based Design	.462	.499
Communication and Know ledge Transfer	.360	.749
Process Management	.556	.613
Product Variety Management	.613	.814
Continuous Improvement	.461	.503
Average	.461	.569

Table 48: Factor communalities before and after extraction

In accordance with these findings and recommendations in literature, the first 3 factors listed in the previous Table 47 have been retained to explain the clusters of correlation in the dataset. Following the identification of the number of factors, the fit of the model can be tested. The fit is assessed by comparing the correlation coefficients of the observed data, as presented in the *R*-matrix in Table 45, with the reproduced correlation coefficients by the model. The difference between the two is referred to as residuals and should be small and in case of a perfect match

0. Field (2013) recommends most values to be smaller than 0.05. In the employed model all residual values but the one between SBD and the SPM are below the defined threshold. Out of the 36 bidirectional relations, this one residual equates to 2.8% of the model which does not fit well. Although there are no strict rules for the percentage of residuals greater than 0.05, it is safe to assume a good fit with all but one relationship represented well by the model.

	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Know ledge Transfer	Process Management	Product Variety Management	Continuous Improvement
Strong Project Manager		.029	-.044	.035	-.070	.014	.029	.036	-.032
Teams	.029		.001	.019	-.013	-.011	.003	-.006	-.003
Concurrent Engineering	-.044	.001		-.041	.001	.028	-.001	.026	-.002
Supplier Relationship and Integration	.035	.019	-.041		.009	-.034	.019	-.005	.018
Set-based Design	-.070	-.013	.001	.009		.027	-.009	-.003	.015
Communication and Know ledge Transfer	.014	-.011	.028	-.034	.027		-.012	-.004	.004
Process Management	.029	.003	-.001	.019	-.009	-.012		-.006	-.003
Product Variety Management	.036	-.006	.026	-.005	-.003	-.004	-.006		-.015
Continuous Improvement	-.032	-.003	-.002	.018	.015	.004	-.003	-.015	

Residuals are computed between observed and reproduced correlations. There is 1(2.8%) nonredundant residual with absolute value greater than 0.05.

Table 49: Residual matrix

After a sensible number of factors has been extracted and the fit of the model assessed, the factor loadings need to be rotated to improve their interpretability. The factor loadings represent the degree to which the individual variables (LPD elements) load on each factor. A factor rotation is performed by using either orthogonal rotation, which assumes that factors are unrelated, or oblique rotation should there be theoretical grounds to infer a relationship between the factors. Informed by León and Farris, (2011), Hoppmann et al. (2011), Morgan and Liker (2006) and other contemporary LPD publications, which unanimously advocate LPD as a system of closely interrelated elements and supported by the numerous identified relationships compiled in Table 6 et seq., there is a sufficient theoretical base for assuming closely associated clusters of correlation. Following the recommendations of Costello and Osborn (2005), Eid et al. (2015), and Field (2013), this analysis uses the most widely employed oblique rotation method called oblimin. The second most established oblique rotation method promax would only be preferred if dealing with larger and more complex datasets. The oblimin rotation allows choosing a δ-value which influences the degree of correlation between individual factors. Eid et al. (2015) as well as Field (2013) recommend choosing δ-values between -0.8 (less correlated factors) and 0.8 (stronger correlated factors). If, however, there are no specific grounds to manipulate the δ-value, both publications recommend keeping it at 0. This special case of an oblimin rotation is sometimes also referred to as a direct quartimin rotation (Eid et al., 2015). The rotated factor loadings are summarised in the pattern matrix in the following Table 50.

		Rotated factor loadings		
		1	2	3
1	Teams	.866		
	Concurrent Engineering	.674		
	Process Management	.476		
	Continuous Improvement	.422		
2	Communication and Know ledge Transfer		.848	
	Strong Project Manager		.333	
3	Product Variety Management			.904
	Supplier Relationship and Integration			.482
	Set-based Design			.480
	Eigenvalues	4.53	1.13	0.76
	% of variance	50.30	12.58	8.43
	Cronbach α	0.85	0.45	0.77

Table 50: Summary of exploratory factor analysis results

The summary of the exploratory factor analysis results conducted for the average use of LPD elements is presented in Table 50. The factors are arranged from left to right according to their substantive importance described by the eigenvalues and the corresponding percentage of variance the individual factors represent. In combination, the identified three factors explain 71.3% of the total variance. In other words, the results of the exploratory factor analysis reduced the information in the dataset to 71.3% in the effort of revealing so far unknown underlying structures which inform the understanding of the interrelationships within the proposed LPD framework.

A close examination of the characteristics which make up the individual LPD elements combined in the presented three factors yielded that the first correlation cluster almost exclusively combines attributes which describe procedural chracteristics, while the second factor concentrates on administration and the last, third factor largely focuses on various aspects of the product. Accordingly, factor one will henceforth be referred to as ‘process’ cluster, factor two as ‘administration’ cluster, and factor three as ‘product’ cluster

The Cronbach α-values for the factors reveal that ‘process’ and ‘product’ are reliably represented by their corresponding variables while the ‘administration’ correlation cluster has a relatively low reliability with a Cronbach α-value of 0.45 which is well below the minimum value of 0.7 postulated in literature. This finding is in accordance with the results of the reliability test conducted in the course of drawing the use of LPD elements characteristics together into the overall average use of LPD elements (see section 5.1.3). Although the average use of the ‘communication and knowledge transfer’ element reliably represented its describing characteristics with a Cronbach α-value of 0.743, the result still raised doubts due to its relative low score compared to the other LPD elements. These doubts were further supported when the investigation of the influence of the company size and LPD goal variable on the average use of CKT revealed internal discrepancies which indicated a somewhat divided nature. Additional doubts arose when taking a closer look at the correlation matrix on the characteristic level (see Appendix C 15 et seq.). The detailed *R*-matrix revealed a fairly inhomogeneous correlation with the SPM as well as other elements. On second inspection of the association of the characteristics of CKT, it appears that the three communication characteristics do not correlate well with the other three knowledge transfer characteristics within this element. This internal inhomogeneity might be partly the reason for the unreliable representation of the ‘administration’ factor by SPM and CKT.

In addition, the communality values after extraction presented in Table 48 reveal the relatively poor representation of the SPM by the ‘administration’ factor. The value of 0.112 translates into the ‘administration’ factor only representing 11.2% of the common variance found in the SPM. With the second lowest communality value being 0.462 for SRI and an overall mean communality of 0.569, this finding identifies another contributor to the low reliability of the 'administration' correlation cluster.

After the importance and reliability of the single factors have been discussed by interpreting the eigenvalues and percentage of variance as well as the Cronbach α-values, the focus now shifts to the individual variables which make up the factors. The rotated factor loadings reported in Table 50 allow drawing conclusions to the significance as well as the substantive importance of the individual variables within their corresponding factors. In a first step in gauging importance, it is essential to provide evidence of the significance of a variable within its correlation cluster. The significance of a variable, however, is depending on sample size (Bortz and Schuster, 2010; Field, 2013; Stevens, 2001). Therefore, the authors argue that the frequently advocated threshold factor loading values of 0.3 or the stricter 0.4 are problematic. Consequently, in order to be able to make a statement about significance of factor loadings, researchers have to resort to critical value tables against which factor loadings can be compared. Stevens (2001) advises factor loadings to be greater than 0.364 for a sample size of 200 to assume significance on a 1% level. Accordingly, all factor loadings presented in Table 50 but the one for SPM are significant. The SPM factor loading value of 0.333 is just below Stevens' (2001) critical value for 1% significance but above the often employed 0.3 threshold value. Unfortunately, Stevens (2001) does not present significance values on a 5% level so that factor loadings falling between the aforementioned threshold values of 0.3 and 0.364 are open to debate whether they significantly contribute to the factor. In consideration of the previously identified weak communality value for SPM, the somewhat intricate relationship of CKT and SPM on a characteristic level, and the unreliability of the 'administration' factor, caution is advised when going forward with this part of the results. Once the individual variables have been assessed for significance, Field (2013) advocates to square the rotated factor loadings to get an estimate of the importance of the single variables within the correlation cluster. The square of the factor loadings, as presented in Table 51, provide the percentage of variance the variables have contributed to the factors. For example, after the direct oblimin rotation of the factors, T contribute 74.9% of its variance to the 'process' factor. Similar to the communality values, the closer the squared rotated factor loading value is to 1, the more the individual variable contributes of its variance to the factor, the more important a variable is to the correlation cluster. The SPM or CI, for example, only contribute 11.1% and 17.8% respectively thus are of relatively little importance to their corresponding factor. The variables in Table 50 and Table 51 have been arranged in descending rotated factor loading values to convey not only its numeric importance but also its relative importance within their factors.

		Rotated factor loadings	Squared loadings
Process	Teams	.866	.749
	Concurrent Engineering	.674	.455
	Process Management	.476	.227
	Continuous Improvement	.422	.178
Administration	Communication and Knowledge Transfer	.848	.719
	Strong Project Manager	.333	.111
Product	Product Variety Management	-.904	.818
	Supplier Relationship and Integration	-.482	.232
	Set-based Design	-.480	.231

Table 51: Squared rotated factor loadings

In conclusion, the previously frequently encountered findings which provide reasonable grounds to suspect 'communication and knowledge transfer' to be internally incoherent and inhomogeneous, the low communality value for SPM manager', the inconsistent relationship between the two previously mentioned elements, the unconvincingly low factor loadings and corresponding small squared loadings for SPM as well as the low Cronbach α-value for the ‘administration’ factor, make in summary a convincible argument for not retaining this second factor. Although dropping a factor representing a greater eigenvalue, thus percentage of variance, might not be considered a usual practice, the numerously encountered problems with the CKT scale, the very low and almost insignificant loading scores for SPM, and the Cronbach α-value of 0.45 in particular make this factor highly problematic. The additional prospect of processing this factor further in the forthcoming analyses, especially its integration into an implementation plan in section 5.2.3.3, further strengthen the case for dropping the ‘administration’ factor. Consequently, the remainder of this section as well as the following section 5.2.3 will treat both elements as individual components not belonging to any correlation cluster.

Beyond that, the exploratory factor analysis has yielded some important insights into the inner workings of the LPD framework brought forward in the work at hand. It has shown that within the overall strong correlations between the LPD elements, there are clusters of tightly interwoven elements which form an underlying structure. A sole evaluation of a correlation matrix would have made it hard to unearth these ‘hidden’ structures. The factor analysis has identified the second and third most widely used LPD elements, T and CE, not only to stand in close relationship to each other but also to be an integral part of a correlation cluster which further includes PM and CI. In consideration of the overall good results the variables have achieved in average use, perceived ease and benefit of implementation, and the order in which they have been introduced in the participating companies, this ‘process’ cluster might form a good starting point for companies seeking to implement Lean practices in their PD department.

The second wave of LPD implementation might include PVM, SRI, and SBD which form the ‘product’ correlation cluster identified in the exploratory factor analysis. The fairly low correlations between the SPM and the other LPD elements indicate a largely independent role within the LPD framework. Given its good values in average use, perceived benefit of implementation, and implementation order, it appears that many participating companies choose to introduce this element fairly early on and in combination with the LPD elements forming the 'process' cluster. The findings indicate that companies seeking to concentrate their implementation efforts might want to either introduce the SPM first or after the four elements forming the 'process' correlation cluster.

Considering the overall unimpressive results of CKT in terms of average use, perceived ease and benefits of implementation as well as implementation rank (see section 5.1.3) and the additional identified internal inconsistencies, a company might be well advised to either gradually introduce the individual characteristics of CKT as and when required or wait with the introduction of this LPD element until after the 'product' correlation cluster has firmly established its position.

5.2.2.3 Influence Matrix

The briefly presented findings will be complemented by the following analysis of the influence matrix which will add causality to the previously identified and quantified, yet undirected relationships. In an effort to determine causal effects in the LPD framework, participating companies have been asked to indicate the influence of one element on another by checking a box in a 9x9 matrix. Hence, the presence of a perceived influence is represented by a '1' while its absence is described by a '0' in the dataset. The analysis of this matrix of zeros and ones is conducted using an approach originally pioneered by German biochemist Frederic Vester who, in dependence on the cross-impact analysis, developed a simple yet effective method known as paper computer or influence matrix (Gomez and Probst, 1999). For this method, the individual elements are plotted against each other in a matrix and the effect the element in the row has on the corresponding element in the column is indicated using the responses from the questionnaire. Ideally, these causal relationships would have been indicated using a 4-point scale from 0 ‘no influence’ to 3 ‘strong influence’. However, since the diligent filling in of a 9x9 matrix needs a considerable amount of thought and accordingly a substantial amount of time, and that at the end of a questionnaire which by then already required around 20 minutes of the respondent’s time, the matrix has been simplified to a binary character. Hence, the figures in Table 52 represent the total amount of responses which have indicated the presence of a causal relationship. Analogue to the original influence matrix, the frequency with which the presence of a causal effect has been indicated might be interpreted as intensity, ‘the magnitude of a quantity […] per unit’ (Merriam-Webster, 2016). However, due to the lacking statistical basis of this approach and the somewhat qualitative nature, no claims will be made regarding significance within this network of bidirectional relationships.

Effect of item in row on item in column	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Know ledge Transfer	Process Management	Product Variety Management	Continuous Improvement	Cumulative Effect Size
Strong Project Manager	-	29	21	6	23	7	16	18	12	132
Teams	6	-	33	2	13	16	6	11	25	112
Concurrent Engineering	0	1	-	7	26	14	5	7	4	64
Supplier Relationship and Integration	2	6	11	-	12	4	14	9	6	64
Set-based Design	4	0	17	3	-	23	5	16	12	80
Communication and Know ledge Transfer	15	21	24	9	13	-	6	3	26	117
Process Management	10	7	22	12	14	6	-	19	14	104
Product Variety Management	8	3	21	17	18	2	14	-	7	90
Continuous Improvement	5	6	14	4	17	23	26	12	-	107
Cumulative Influenceability	50	73	163	60	136	95	92	95	106	-

n = 208

Table 52: Influence matrix

Table 52 yields important and unprecedented insights into the causal relationships between elements within a LPD framework. The empirical evidence collected from the 208 participating companies complements existing qualitative relationships (see section 3.3) with generalisable data which extends previously discussed correlations by adding causality. As indicated earlier, Table 52 yields information in three dimensions – vertically it reports the effect another LPD element has on the element in the column, horizontally the table presents the effect the element in the row has on a corresponding element in the column, and the figures in the individual boxes indicate the effect size of the former two dimensions. The summaries in the last column and last row provide the overall effect size and cumulative influenceability which are also sometimes referred to as active and passive sum. While the discussion of Table 52 focusses on the causal relationships between the individual LPD elements, the following Figure 44 will discuss the cumulative effects in detail. Due to the sheer volume of information this table holds, the discussion will limit itself to the most prominent and most interesting causal relationships.

If reading the second 'strong project manager' column from bottom to top, the influence analysis identifies PM and CKT as the biggest influencing factors on the SPM' which is in accordance with the findings made through analysing the correlation matrix (see Table 45). Synthesising the previous results with the qualitative relationships in literature (see Table 6 et seq. in section 3.3), these interdependencies are hypothesised to be at least partially caused by appropriately allocated resources as well as standardised routine tasks of LPD PM which promote reliable project schedules and overall help monitoring and controlling the development project (Ballé and Ballé, 2005; Brown, 2007; Cusumano and Nobeoka, 1998; Morgan and Liker, 2006). CKT was identified to support and empower the SPM with a growing knowledge base which aides all aspects of project planning and helps making objective technological decisions (Sobek II et al., 1999). If shifting the focus now on the effect, the SPM exerts on other LPD elements, the second row of Table 52 identifies the strongest causal relationships between the SPM and T, SBD, and CE. Interestingly, while PM as well as 'CKT have been earlier recognised to strongly and significantly correlate with the SPM (see Table 45), these newly identified elements have not been found to significantly correlate in average use. The causal relationships with all three elements emphasise the importance of the SPM in integrating all involved functions, coordinating their efforts, and narrowing down the solution space by making major technological decisions (Kennedy, 2003; Morgan and Liker, 2006; Oppenheim, 2004; Ward et al., 2007).

The LPD element T has also been identified to be strongly influenced by CKT potentially because of the earlier described enabling and facilitating qualities of a growing explicit knowledge base as well as the mode of communication this LPD element promotes (Clark et al., 1987; Karlsson and Åhlström, 1996; Morgan and Liker, 2006; Sobek II et al., 1999). In its active role of exerting influence on other elements, T has been found to strongly influence CE as well as CI. Judging by the literature and comparing these findings to the *R*-matrix, both causal relationships do not come surprisingly since cross-functional teams, their early integration into the development project and their continued collaboration throughout the process, constitute a significant enabling factor for CE (Clark et al., 1987; Morgan and Liker, 2006; Womack et al., 1990). At the same time, the development team members exercise CI on a daily basis and backed by the SPM promote CI efforts throughout their spheres of responsibilities within the development project (Middel et al., 2006; Morgan and Liker, 2006).

Table 52 further uncovers the overall strong influenceability of CE. All other elements exert a more or less strong influence on this aspect of the LPD framework while it only directly effects SBD as well as CKT. The latter two causal relationships have been reported in literature to primarily originate in the early integration of all involved functions, the communication mode simultaneous engineering requires, and the frequent review meetings which not only promote the development of feasible and manufacturable design solutions but also help in the time-effective reduction of design alternatives in the solution space (Clark and Fujimoto, 1991b; Hoppmann et al., 2011; Morgan and Liker, 2006; Schuh, 2013; Sobek II et al., 1999; Ward et al., 2007).

SRI appears to be fairly independent of other LPD elements with the notable exception of PM and PVM. Literature explains these causal effects on the supplier component mainly through the easier integration of suppliers because of standardised processes and procedures and the clear rules for the use of off-the-shelf products and the reuse of existing parts which notably simplifies the sourcing of external parts (Hoppmann et al., 2011; Morgan and Liker, 2006; Ward et al., 2007).

Quite similar to CE, SBD is reported to be overall relatively susceptible to the influence of other elements while only causing notable effects on CE, CKT, and PVM. Plausibly, SBD exerts a considerable direct influence on CE as the evaluation of a large number of design alternatives in the beginning of a development project puts enormous pressure on development teams which have to integrate all involved functions and increase their problem-solving capabilities in an effort to deal with the additional work-load (Morgan and Liker, 2006; Ward et al., 1995; Ward et al., 2007). At the same time, the objective assessment of many different design solutions dramatically increases a company's knowledge base and leads to more robust and potentially technologically superior parts, modules, platforms, and overall products (Haque and James-Moore, 2004; Schuh, 2013; Ward et al., 2007).

Arguing along the same lines, CI as well as SBD have a considerable influence on CKT since the objective evaluation and corresponding documentation of a large number of design alternatives drastically strengthens a company's knowledge base which is constantly verified, updated, and extended by CI initiatives (Haque and James-Moore, 2004; Morgan and Liker, 2006; Ward et al., 2007). Analogously, this explicit and up-to-date knowledge base as well as the mode of communication postulated by CKT is reported to serve as an enabling and facilitating factor for a multitude of LPD elements.

By far, the biggest influence on PM has been identified to come from CI which, according to literature, prevents reoccurring problems through root-cause[39] countermeasures, the reflection on past experiences such as best practices, encountered problems, and lessons learned which in turn, if improved upon, lead to more stable, less risky, increasingly robust, and more efficient development processes (Morgan and Liker, 2006; Ward et al., 1995). PM itself has a notable effect on CE as well as PVM primarily due to the standardised processes which not only drastically improve a company's ability to coordinate simultaneous development processes (Morgan and Liker, 2006; Oppenheim, 2004; Sobek II et al., 1999) but also facilitate making decisions about reusing existing parts as well as sourcing off-the-shelf products (Morgan and Liker, 2006). Simultaneously, the staggered release of development projects as well as the appropriate allocation of resources prevent development teams from over-burdening thus speed up the development process and overall increase the reliability of simultaneously executed processes (Cusumano and Nobeoka, 1998; Morgan and Liker, 2006).

Tying in with the foregoing LPD element, Table 52 identifies PVM to be influenced by PM, SBD as well as SPM which in the case of the former two elements has been already covered in the foregoing discussion. Regarding the latter, Karlsson and Åhlström (1996), Oppenheim (2004), and Sobek II et al. (1999) convincingly state that the SPM, in his effort to balance the business and engineering case as well as through making major technological decisions, sets guidelines for the use of off-the-shelf products, reuse of parts, and modularisation which facilitate the development of modules and components. On its active side, PVM presents itself

[39] A frequently employed tool in Lean to determine the root-cause of a problem thus see beyond possible superficial origins of an issue is '5 whys' which repeatedly asks the question 'why?' to identify the original, root-cause of a problem.

mutually reinforcing with SBD while also exerting notable influence on CE as well as SRI. Based on literature, this causal relationship might be due to the reduced complexity of simultaneous product development and the simplified sourcing due to a higher carry-over rate as well as use of off-the-shelf products through standardised modules and interfaces (Schuh, 2013). Furthermore, the development of parts, modules, and platforms with standardised interfaces and black-box character makes it considerably easier for customers to communicate and coordinate their design specifications with suppliers thus facilitate outsourcing (Hoppmann et al., 2011; Morgan and Liker, 2006; Ward et al., 2007).

Lastly and corresponding to the previous discussions, CI is identified to be susceptible to influence from T and exhibits a mutually reinforcing relationship with CKT while also showing a notable influence on PM. The mutually reinforcing relationship between CI and CKT is described by Middel et al. (2006) as well as Morgan and Liker (2006) to be rooted in the open-mode of communication which promotes the frequent sharing of preliminary information in a dialogue-mode and the explicit knowledge base which is constantly challenged and extended by the company's CI efforts. The influence on PM is, as previously discussed, hypothesised to be caused by the reduction of reoccurring problems and the in various ways enhanced development process through CI efforts (Morgan and Liker, 2006; Ward et al., 1995).

The influence matrix presented in Table 52 has provided numerous insights which not only deepen the understanding of the proposed LPD framework but will also inform the development of implementation recommendations in the subsequent section 5.2.3. After the preceding discussion has focused on the relationships between the individual LPD elements, the remainder of this section takes a step back and considers the cumulative effect sizes of the individual elements as well as their overall influenceability. Both dimensions, cumulative effect size and cumulative influenceability, form the x- and corresponding y-axis of the following Figure 44.

At the intersection of the two axes where both the effect size and influenceability are low, the chart depicts in the lower left quadrant so called inert items which are neither strongly influenced by other elements nor do they exert a notable influence on others. Inversely, LPD elements which find themselves in the upper right corner, in which both axes reach a high value, are considered critical due to the strong influence they have on others and their high influenceability. The upper left quadrant represents passive elements which are strongly influenced by others but do not cause notable effects on other elements within the framework. Conversely, the lower right quadrant contains active elements which exert a strong influence but are fairly little influenced by other components of the LPD framework (Gomez and Probst, 1999).

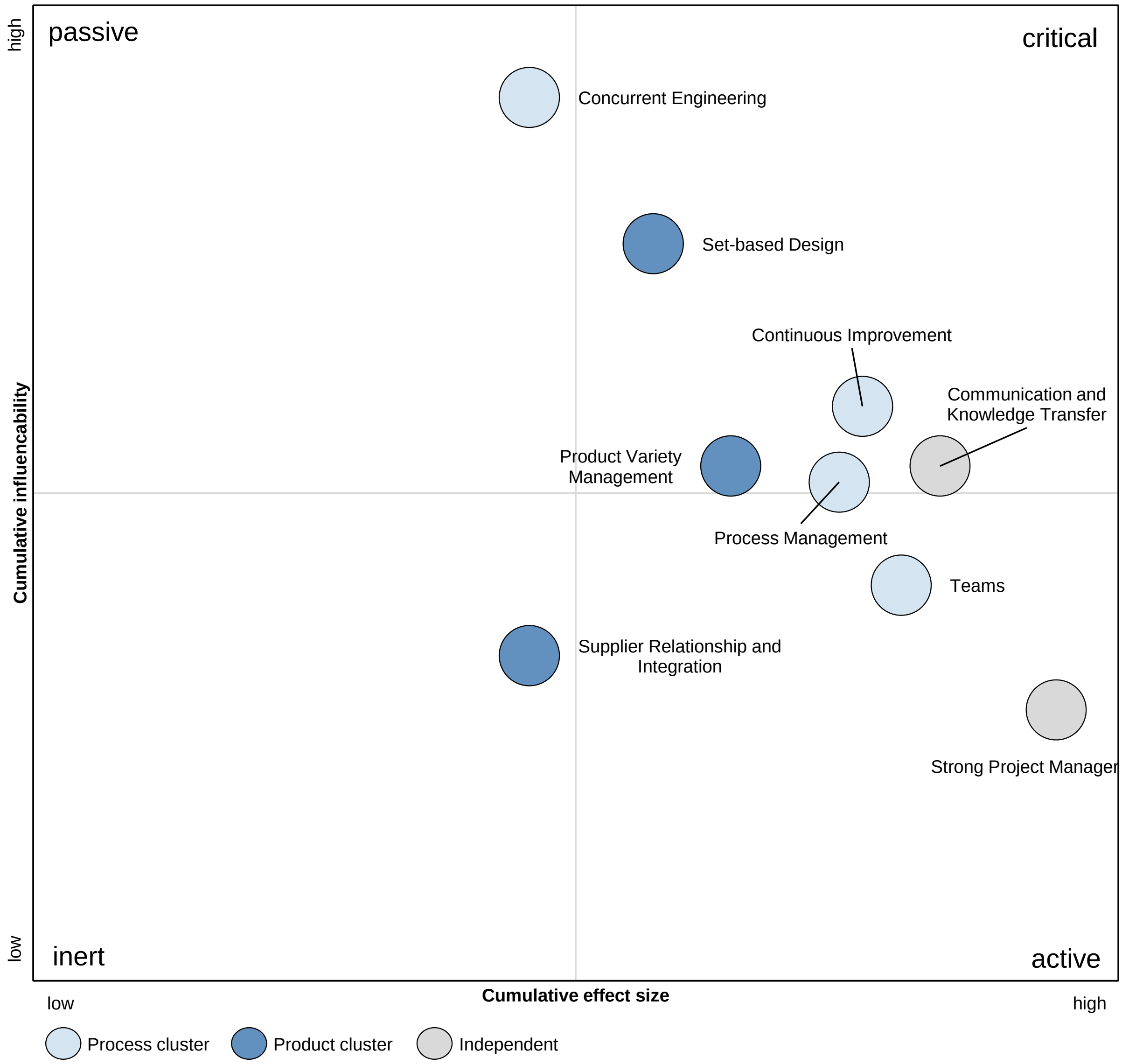

Figure 44: Influence chart

A first look at Figure 44 confirms the very active and influential nature of the 'strong project manager' and, on the other end of the spectrum, the more passive CE element. In between these two relatively extreme elements is a cluster of components which are more or less critical and predominantly closer to the active rather than the passive quadrant. Notably outside this conglomeration of LPD elements and closer to the inert quadrant lies the SRI element.

If integrating these findings with the results of the exploratory factor analysis and considering the very active nature of the SPM, which exerts a relatively strong influence while being fairly unaffected by other LPD elements, it might be recommendable to introduce this component first so that the ‘process’ correlation cluster can benefit from the strong effects of this element. This seems particularly advisable since the SPM heavily influences T and CE which have both been previously identified as intensely used, implemented early, and perceived as easy to introduce and to yield great benefits if implemented (see section 5.1.3). Moreover, a sizable number of companies have also reported the SPM to influence PM (16) and CI (12). Keeping in mind the high average use and good perceived benefit of the SPM, the previously summarised findings argue a strong case for introducing this element of the LPD framework first.

After a company has firmly established the role of the SPM, it might be well advised to start implementing the ‘process’ cluster (see light blue highlighted dots in Figure 44). Should the company consider concentrating its LPD implementation efforts, the findings of this analysis indicate to start with ‘teams’. After the highly influential cross-functional development teams have been integrated, they can exert their positive influence on ‘process management’ and particularly on CI. Given the mutually reinforcing relationship of the latter two and the relatively high degree of overlap in terms of establishing and continuously challenging standards, a company might want to consider implementing these LPD elements in conjunction. With three of the four components of the ‘process’ cluster in place, the fairly passive CE can reap the benefits of T, PM, and CI which have been frequently mentioned to exert a positive influence on this LPD element.

The company seeking to embrace the full range of LPD elements is now confronted with the decision whether to focus and improve on the already introduced components by implementing CKT for its positive effects on almost all established LPD elements and despite the perception of being hard to implement and yielding only little benefits or continue its efforts by starting to introduce the 'product' correlation cluster (dark blue highlighted dots in Figure 44). Solely judging by the data and the findings so far, the introduction of CKT before tackling new challenges seems advisable. However, organisational intricacies, the complexities of the overall business setting as well as the different starting points with regard to LPD might persuade companies to continue to roll-out LPD with the 'product' cluster instead.

Within the 'product' cluster, it appears recommendable to start with the introduction of PVM for its numerously reported positive influence on both SRI as well as SBD and the perception of yielding good benefits (see section 5.1.3). Subsequently, a company seeking to focus its attention on introducing a single element might want to continue its implementation efforts by establishing SRI before moving on to SBD. Judging by the correlations of average LPD use summarised in Table 45, it does not seem to make a difference but given the presence of the frequently reported influence SRI has on SBD and its absence vice versa suggest to start with the former and lastly implement the latter. Should a company has chosen earlier to postpone the introduction of CKT it can now do so and make use of the positive influence SBD has on the creation of a strong, explicit knowledge base.

The influence matrix has revealed a number of relationships which have previously gone unnoticed in the *R*-matrix (see Table 45) and further added a causal element to the previously undirected relationships. The merging of the findings of the correlation matrix, exploratory factor analysis, and influence matrix in combination with the previous findings of external influencing factors (see section 5.2.1), and the perceived ease and benefit of implementation as well as the overall average use of LPD elements will provide a strong foundation for the recommendation of implementation guidelines in the next section.

5.2.3 Implementation Recommendations

The foregoing analyses and the discussions of their results have identified a number of important findings which potentially have a large impact on the successful implementation of the LPD framework proposed in this study. This section sets out to formulate a number of implementation recommendations which integrate external influencing factors (see section 5.2.1), consider the internal interdependencies of the LPD framework (see section 5.2.2), and further takes the combined experiences respondents of this study have accumulated into account. These experiences include the participating companies' perception of the individual elements' ease and benefit of implementation, their chosen implementation order as well as the problems they have encountered throughout their efforts to introduce Lean practices in product development. These three areas, external influence factors, internal interdependencies, and implementation experiences, will be systematically combined starting with the former.

5.2.3.1 General Recommendations

Among the six variables which have been thoroughly investigated throughout section 5.2.1, the average use of LPD elements and their corresponding characteristics has been shown to significantly correlate on a number of levels with company size, a person responsible for implementing LPD, and LPD goals while the location of the PD division, the industry the participating companies mainly operate in, as well as the employment of external help have revealed to play a less significant role. Since a company may not significantly change in size solely for the purpose of introducing LPD or change the industry it mainly operates in exclusively to promote the use of a small number of LPD elements (see Table 44), these two external factors are not considered in the remainder of this section. Moreover, the insignificant role of the geographical location of the PD division does not justify its further consideration.

Assigning responsibilities for implementing LPD to an employee within the company has been demonstrated to significantly and positively correlate with seven out of nine LPD elements. The SPM as well as CKT have exhibited no significant changes in its average use when controlling for this variable. While all significantly correlating components of the proposed LPD framework have demonstrated considerable difference in their average use, PVM (mean difference 0.808) and CE (mean difference 0.570) seem to particularly benefit from a person responsible for the introduction of Lean practices in PD (see Table 30). All other elements have been found to be on average in the range of 0.339 to 0.390 more frequently in use if controlling for this nominal variable. In addition to the increase in average use of the individual LPD elements, the participating companies which employ a person responsible for implementing LPD have shown considerably more homogenous results in terms of standard deviation. In summary, companies embarking on implementing Lean practices in their product development division are well-advised to support their efforts with a dedicated person who is structuring and supporting the organisational change.

Companies entertaining the thought of encouraging and facilitating their first steps in the introduction of LPD might consider employing external help, for example in form of consultants. The findings in this study, however, indicate their severely limited use. While the collected data only justifies claiming that on average companies which resort to utilising external help employ the characteristics, representing the individual LPD elements, less frequently, it suggests that companies seek advice from outside only if they have fallen behind thus want to boost their initial efforts or promote the integration of specific components. Regarding the latter, only CKT has exhibited a significant difference if controlling for this variable (see Table 31). The significant difference, however, is negative, suggesting that participating companies only invite external help if they want to promote this particular aspect of LPD. The reverse conclusion that externals significantly worsen the situation with regard to this facet of LPD does not seem plausible. In summary, companies which consider employing external help are recommended only to do so if they intent to explore the LPD approach, boost their initial efforts, or promote the implementation of the CKT element. If trying to decide whether to employ externals or create the capacities for assigning a person responsible for LPD inside the company, a clear recommendation goes to the latter.

Among the early considerations of a person responsible for the implementation of LPD or the company employing external help should be the development of an overall strategy, the definition of actionable lower-level goals as well as the introduction of corresponding performance measurements. This study has conducted an in-depth analysis, not just on a LPD element but also characteristics level, to get a detailed picture of the influence the aforementioned measures have on the average use of LPD (see section 5.2.1.6). If considering the overall implementation of Lean practices in PD, the findings strongly suggest not only to develop a clear strategy for LPD but also to make this long-term plan actionable by translating it into specific, measurable, assignable, realistic, and time-related lower-level goals[40] and integrating suitable performance measurements which help to monitor, evaluate, and control the company's efforts. The investigation at hand has demonstrated that the sole development of

[40] In his 1981 publication, Doran has promoted the development of effective and meaningful goals and objectives through the acronym S.M.A.R.T. which refers to specific, measurable, assignable, realistic, and time-related. Although it is not always possible or practical to define each attribute for every goal and objective, the author advises to always strive towards translating each facet of the S.M.A.R.T. acronym for every target (Doran, 1981).

a strategy without integrating its operational aspects does not lead to significant changes in the average use of LPD. If, however, combined with effective, actionable goals and corresponding performance measurements, the definition of a LPD strategy is likely to have a significant impact on the company's LPD efforts. If the company seeking to embrace Lean practices in their PD division wants to gain deeper insights into the potential effects the LPD goal variable has on their LPD initiative, it is referred to the detailed discussion in section 5.2.1.6.

5.2.3.2 Further Influencing Factors

The previous discussion has uttered three concrete recommendations based on the findings of this study – promote LPD implementation by assigning a person responsible, seek external help if trying to make ground or particular aspects of LPD need to be advanced, develop a LPD strategy and make it actionable through defining lower-level goals and integrating suitable performance measurements. These recommendations can be considered external supporting and facilitating factors for the introduction and use of the proposed LPD framework. They have been formulated on an overall LPD level and should therefore be regarded as general recommendations. For an element or characteristic specific recommendation for these variables refer to the corresponding section in this work.

The bubble chart depicted in Figure 45 qualitatively explores further implementation recommendations by bringing together four different variables. The x-axis represents the perceived benefit of implementation and the y-axis the perceived ease of implementation. Both axes start at their intersection with a relatively high benefit and respectively easy perceived implementation[41]. Accordingly, companies seeking to introduce LPD would typically initially concern themselves with those elements which are relatively easy to implement while yielding comparably large benefits; with the elements in the lower left quadrant. In addition to these two dimensions, Figure 45 further includes the average use of the individual LPD elements, reflected in the bubble size as well as the figure within each bubble, and the different previously identified correlation clusters and independent elements, represented by the colouring of the bubbles.

Beginning with the most attractive LPD elements in terms of perceived ease and benefit of implementation, Figure 45 yields T, CE, and CI, all three belonging to the ‘process’ correlation cluster, as potential starting points for the introduction of LPD. All of these elements have also been reported to be used relatively frequently by the participating companies as reflected in the average use figures. Beyond this small conglomerate is another accumulation of four LPD elements; the cluster-independent SPM, PM as the fourth and last element of the ‘process’ cluster, and PVM as well as SRI belonging to the ‘product’ factor. Somewhat removed from this second conglomerate thus perceived as less beneficial if not easier to implement is the last element belonging to the ‘product’ cluster SBD as well as the independent CKT. Reading the bubble chart from the lower left to the upper right corner and looking at the individual figures representing the average use of the single LPD elements, it is interesting to note how the ease and benefit of implementation is, at least in the lower left and upper right quadrant, very well reflected in the average use figures. This qualitative trend seems only to hold true if following

[41] Benefit of implementation was measured on a 1-to-7 ‘very low-to-very high’ response scale while ease of implementation has been assessed on a ‘very difficult-to-very easy’ 7-point Likert scale. From intersection to its last measuring point, the x-axis ranges from 6.5 to 4.5 and the y-axis from 5.0 to 2.0.

the benefit of implementation from left to right or if considering both variables moving from the lower left corner to the upper right but not if only looking at the ease of implementation. Hence, Figure 45 cautiously indicates a positive correlation with the perceived benefit of implementation but leaves some doubt whether the ease of implementation stands in some kind of relationship with the frequency to which the characteristics of the individual LPD elements are used.

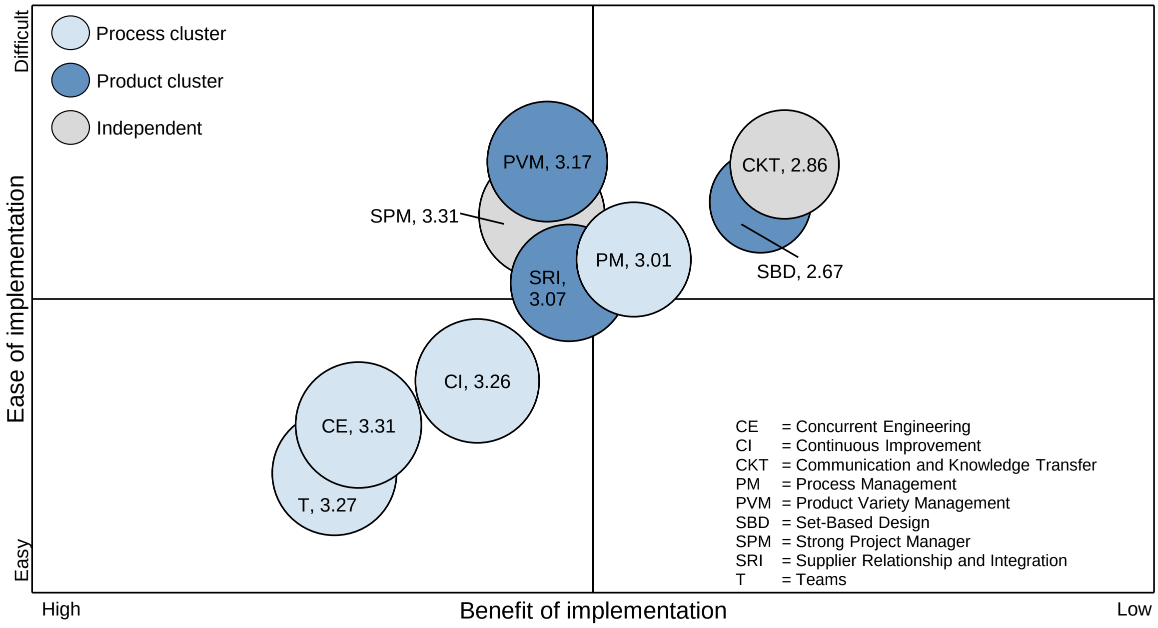

Figure 45: Average use of LPD elements over ease and benefit of implementation

Assessing this qualitative observation with statistical rigour using Pearson's *r*, the perceived benefit of implementation has been confirmed to significantly and positively correlate with the average use of LPD while the ease of implementation does not (see Appendix C 93).

If comparing these findings to Figure 46 in which the average use values and the corresponding bubble sizes have been changed to represent the implementation order variable, the overall picture in x as well as y direction looks relatively similar. A bivariate correlation using

Pearson's *r* confirms that benefit of implementation significantly correlates with the implementation order and ease of implementation does not. The correlations results in Appendix C 93 further yield a significant correlation on a 5% level between the average use of LPD and implementation order.

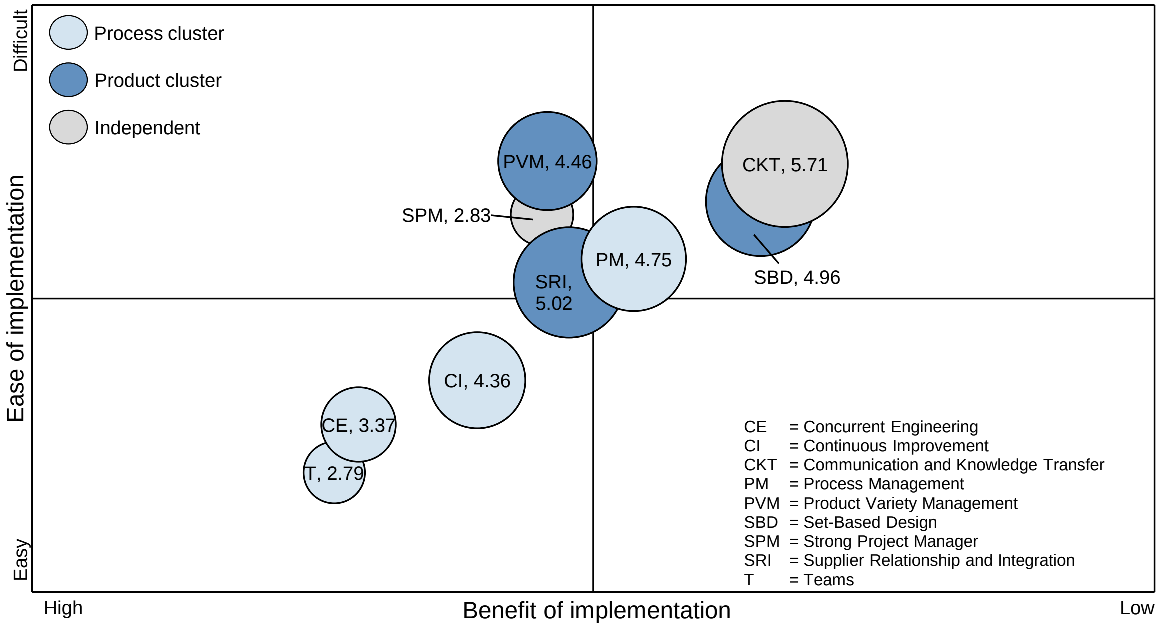

Figure 46: Implementation order over ease and benefit of implementation

Both the graphical qualitative observations as well as the quantitative statistical tests have yielded some interesting insights which will inform the development of further implementation recommendations. The data suggests that companies introduce and use LPD elements corresponding to the perceived benefit of the single components but independent of how difficult it is to implement them in the first place. Accordingly, the implementation recommendations formulated in the remainder of this section will consider the perceived benefits of implementation, average use of LPD elements, and the order in which participating companies have reported to have introduced LPD components. The perceived ease of implementation will also be highlighted throughout outlining the implementation recommendations but more to inform companies seeking to embrace LPD and not to influence the decision in which sequence to introduce the individual components of the framework. Since there is no known clear-cut way of merging the findings of correlation matrices, an exploratory factor analysis, influence matrix, content analysis, as well as the qualitative element relationships identified in literature (see section 3.3), the remaining LPD recommendations have to be formulated based on the subjective and qualitative discretion of the author of this work.

5.2.3.3 Implementation Plan

Now that a company is aware of how it can set itself up for the successful introduction of Lean principles in PD in terms of general recommendations, the following section formulates specific recommendations for the introduction of the individual elements based on the findings uncovered in the previous section 5.2.2 in conjunction with various practical experiences, as discussed in the preceding section. These recommendations not only define the implementation order through combining the previously mentioned findings but also further qualitatively describe the relationships between subsequently introduced elements based on the findings in literature (see section 3.3).

In an effort to preserve the advantages of quantitative results, the following implementation recommendations will be primarily based on the findings of the correlation matrix reporting the relationships between the use of the individual LPD elements, the exploratory factor analysis, and the influence matrix. The combined findings of these statistical tests will determine the overall order in which the LPD elements are recommended to be introduced. The previously significantly correlating variables perceived benefits of implementation, average use of LPD elements, and the implementation order participating companies have reported, will inform the sequence in which the following recommendations advise to introduce LPD and its main components. While the basic construct will be provided by the combined findings of section 5.2.2, the latter mentioned variables will help dealing with the less definite cluster-independent elements and confirm or raise doubts about the recommended implementation order. The qualitative descriptions of the relationships between the LPD elements found in literature (see section 3.3) will help adding an explanatory character to the implementation recommendations and the content analysis of problems participating companies have reported to have encountered during the introduction of LPD will provide further guidance and help companies seeking to embrace Lean practices in PD to stay clear of these obstacles by learning from the experience of others. Following this procedure will allow maintaining the empirical quantitative character the bulk of the findings the implementation recommendations are based on while enriching it with qualitative data from both literature and this study. The implementation recommendations formulated in the remainder of this section largely address the single LPD elements individually rather than suggesting to introduce a great number of framework components at once. Although this work recognises the highly interactive and interwoven character of LPD, this road is taken since it allows to have a thorough and well-structured discussion and further accommodates companies which want to focus their LPD efforts. Companies wishing to speed up their implementation might consider embracing a number of components at once. In this case, however, the main sequence laid out in the following should be followed and great care should be taken to accommodate for the effects the individual elements have on each other as well as the problems a company might encounter throughout their implementation (see section 3.3 and 5.2.2).

Based on the reported early implementation of the ‘strong project manager’ (2.83), its high average use (3.31), and its frequently reported influences on various LPD elements, makes this component the best choice for companies starting to introduce LPD. In the influence matrix, the SPM has presented itself as a highly active elements which exerts a lot of influence but remains relatively unaffected by other components of the LPD framework. In addition to the previously mentioned reported early implementation and its overall high average use, this element stood out in the exploratory factor analysis as an independent element after the factor it was allocated to has been dropped due to an overall unconvincing performance. This independent nature has been previously indicated by the relatively few significant correlations in the *R*-matrix reported in Table 45. Although the mediocre benefits of implementation (5.59) as well as the relative difficulty of implementing (3.07) the SPM might not render this aspect of the LPD framework the quickest and most rewarding elements, it does convince with its influential character and is backed by the experience of participating companies in terms of average use and implementation order.

The content analysis of implementation problems has determined a scarcity of qualified candidates, organisational resistance, and lack of management support as the main obstacles for a successful introduction of the SPM (see Figure 47). While the absence of qualified candidates has often been reported as lacking an in-house talent pool of technical experts with the required (project) managerial experience or insufficient availability of project managers with adequate technical depth, two respondents have remarked that able candidates moved on to positions with better prospects. This certainly stays in stark contrasts to Toyota’s practices culture of continuous learning in which engineers are constantly trained and the position of the SPM holds tremendous prestige which plenty of able candidates strive towards to (Hoppmann et al., 2011; Morgan and Liker, 2006). Most other problems allocated to organisational resistance and lack of management support can be assigned to a missing or insufficient top-down initiative which clearly defined the roles and responsibilities of the SPM from a position of power. This in turn limits the SPM's authority to lead the project from concept to market and makes the position vulnerable to political trench-fighting over responsibilities.

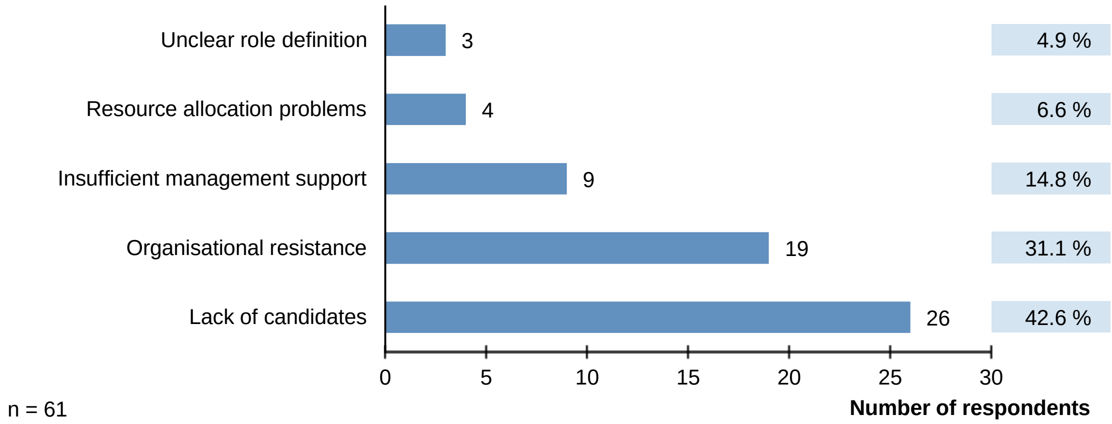

Figure 47: Implementation problems for SPM

The second component of the LPD framework this study recommends to implement is 'teams'. This element has been introduced on average the earliest by participating companies (2.79), reported as being perceived to be easiest (4.39) and most beneficial to implement (5.96), and among the most frequently used (3.27). In the correlation matrix presented in Table 45, T has been identified to be significantly and highly correlating with a number of elements. The subsequent exploratory factor analysis allocated T to the 'process' correlation cluster (see Table 50) and the influence matrix (see Table 52) further refined its role within the LPD framework. In addition to the previous findings, T is recommended to be introduced secondly due to its susceptibility to the positive influence of the SPM and its frequently reported positive effects on the other elements within its correlation cluster. Literature reported the SPM to strengthen the cross-functional development team's commitment, help them keep their focus, coordinate their efforts, and foster learning by sharing knowledge (Karlsson and Åhlström, 1996; Morgan and Liker, 2006).

Participating companies have specified a number of problems they have encountered during their introduction of the T element. These organisational challenges have been categorised in the six groups listed in Figure 48. Among those problems, organisational and cultural resistance has been identified as the most frequently encountered obstacle. The various statements summarised in these two groups name a general unwillingness to freely and openly collaborate and interdepartmental differences as main contributors. Furthermore, various respondents have reported that cross-functional team members appear to be restricted in their commitment to the development projects by the remaining departmental responsibilities which are often prioritised over the joint efforts to bring a new product to the market.

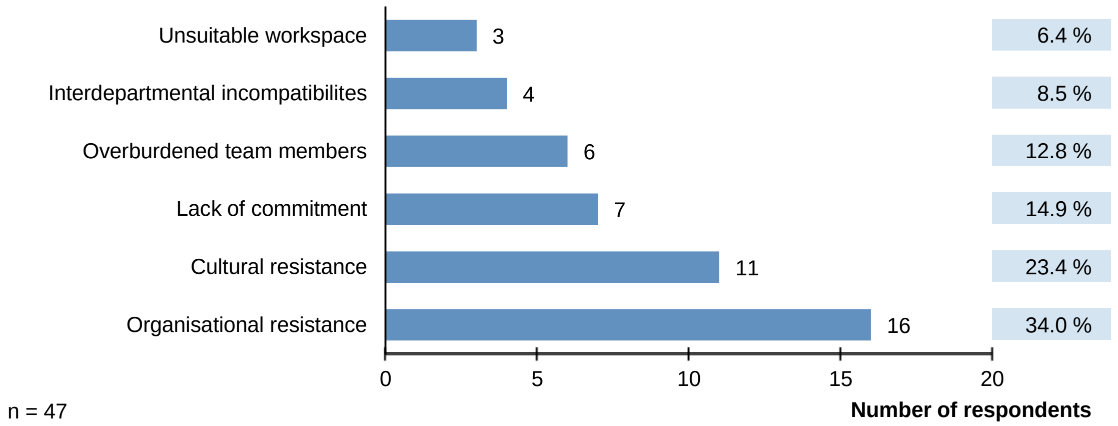

Figure 48: Implementation problems for T

After the successful introduction of T, the findings of this study strongly suggest to continue implementing LPD elements of the same correlation cluster to maximise the synergetic effects. In an attempt to get the most out of these effects and considering the frequently reported positive influence of T (see Table 52), it is recommended to continue the implementation of LPD with CI. This element has on average been implemented relatively early (4.36), used very frequently (3.26), and perceived as fairly easy (3.92) and beneficial to implement (5.71). Given the strong positive and significant correlation with 'process management' (see Table 45), its previously identified mutually reinforcing relationship with this element, the positive influence the previously established SPM exerts (see Table 52) as well as the communalities in respect of content in terms of establishing and challenging standards, lead to the recommendation to introduce both CI and PM simultaneously. Asides from these interdependencies, PM, as defined in the LPD framework, has been reported to be moderately frequently used (3.01), on average implemented sixth (4.75), and achieved mediocre results in ease (3.30) and benefit of implementation (5.43). Despite these average results, the strong synergetic effects with CI as well as the in literature described nature of the interdependencies between these two elements make a convincing case to implement CI and PM simultaneously. Ballé and Ballé (2005), Morgan and Liker (2006), and Sobek II et al. (1999) identified standardisation, one of the core characteristics of PM, as a prerequisite for CI and Middel et al. (2006) determined the formal problem-solving cycle PM brings with it as a requirement for CI. These findings in LPD literature add the element of dependency to the previously identified causal link. Vice versa, CI has been stated to prevent reoccurring problems through root-cause countermeasures and their subsequent integration in new standards (Ward et al., 1995). Furthermore, the ceaseless optimisation of standards lead to less risky, more reliable, increasingly transparent processes and overall speed up development time (Morgan and Liker, 2006). Throughout the implementation of CI, participating companies have reported to primarily experience resistance in the workforce mainly rooted in a general unwillingness to change (see Figure 49). Additionally, participating companies have remarked to be overly restricted in their freely available time to be experimenting with new approaches and thinking about improving their working environment. A number of respondents have further reported to be lacking the funds to push improvement initiatives at their workplace as well as lacking the backing or encouragement of their superiors.

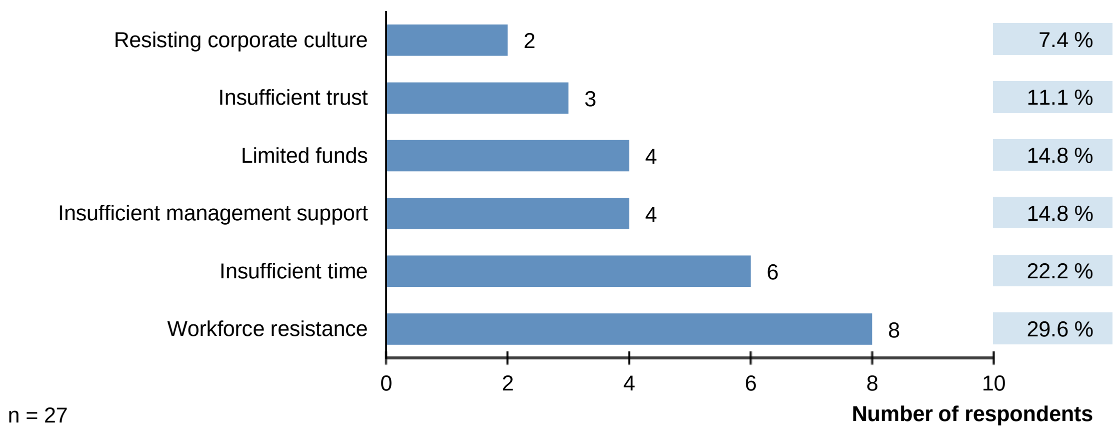

Figure 49: Implementation problems for CI

In terms of ‘process management’, most respondents determined the lacking flexibility of standardised processes which, as some companies have remarked, would be stifling their creativity or generally be unsuitable for the highly-iterative product development environment (see Figure 50). Others who feel very strongly about the restrictive character of standardised processes and the time constraint they potentially induce in the creative design process, have reported a resisting workforce as a main obstacle to the introduction of PM. A general lack of resources, which prohibits an appropriate resource allocation across a number of development projects, as well as a lack of time which does not permit the adherence to schedule, let alone the challenging of existing standards, have also been frequently identified as causing problems while implementing PM as defined in the LPD framework.

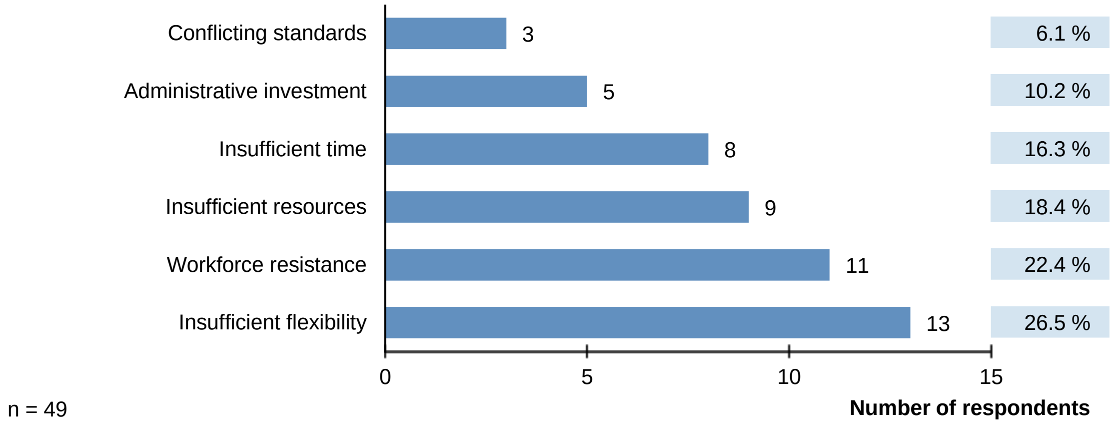

Figure 50: Implementation problems for PM

After the first four elements have firmly established their position, a company on its way to fully embrace LPD is recommended to introduce ‘concurrent engineering’ next. This element has overall achieved very strong scores in terms of average use (3.31), when it was implemented by participating companies (3.37), and how easy (4.14) as well as beneficial its introduction has been perceived (5.92). The *R*-matrix reporting the correlations between the average use of LPD elements has identified CE to strongly and significantly positively correlate with the previously implemented elements with the only exception being the SPM (see Table 45). These positive relationships are confirmed in the influence matrix by the frequently declared positive effects the earlier introduced LPD elements have on CE (see Table 52). In the deducted influence chart, this element has been classified as belonging to the passive quadrant. In other words, it only modestly exerts influence on other elements while being very susceptible to the positive effects of other components of the LPD framework. This makes CE, the last element belonging to the 'process' cluster (see Table 50), a suitable candidate for implementation at this point. Literature identifies the SPM as a strong facilitator for CE since the former assures and coordinates the collaboration between functional departments (Kennedy, 2003). Beyond that, PM has frequently been stated not just to serve as a facilitator but an enabler since standardised processes are considerably more robust and reliable which consequently facilitates process coordination across functional borders (Morgan and Liker, 2006; Oppenheim, 2004; Sobek II et al., 1999). This effect is even strengthened by continuously improved processes and functional interfaces (Morgan and Liker, 2006). Moreover, the staggered release of development projects and appropriately allocated resources further increase the reliability and stability of simultaneously executed processes (Cusumano and Nobeoka, 1998; Morgan and Liker, 2006). During the introduction of CE, participating companies have stated to be frequently opposed by a lack of functional collaboration which, in a number of cases, has been stated to be rooted in a general unwillingness to cooperate with other departments (see Figure 51). The second largest group of encountered problems is allocated to an interdepartmental dysfunctional communication which one respondent boiled down to 'they don't speak our language'. Next to the discrepancies caused by the use of a different technical language and professional background, other participating companies have reported to have encountered severe synchronisation issues, partly due to diverging prioritisation, capacity limitations, and a general lack of resources which would not allow for the simultaneous execution of development processes.

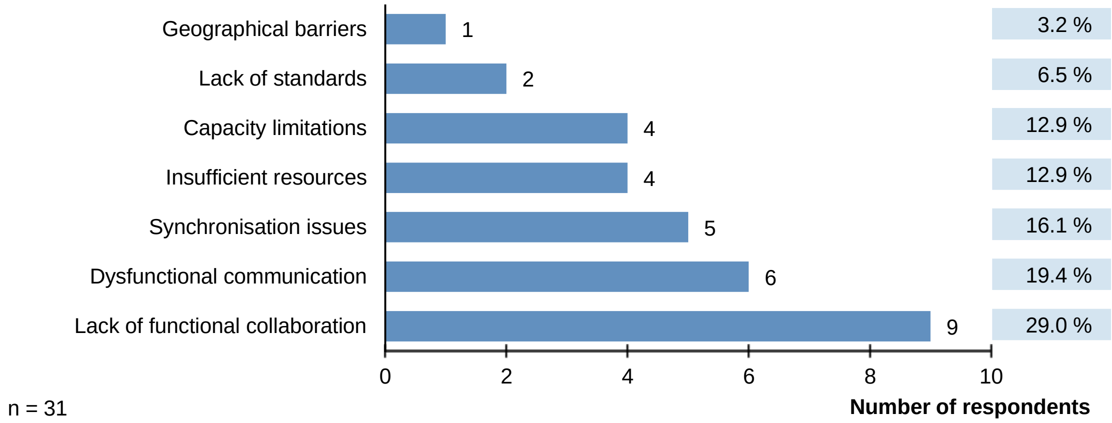

Figure 51: Implementation problems for CE

Following the implementation of the SPM and the entire 'process' correlation cluster, this study recommends to introduce 'product variety management' not only for its numerously reported positive effects on other LPD elements but also for the relatively good responses for average use (3.17), perceived benefit of implementation (5.58), as well as its position in the implementation order reported by participating companies (4.46). Although PVM has been identified to be perceived as hardest to introduce (2.80), previous statistical tests have shown that the ease of implementation does not significantly correlate with neither the average use nor the implementation order. Consequently, ease of benefit fades into the background in the face of the previously reported good results and particularly because of this LPD element's position within the influence matrix and chart. Within the 'product' correlation cluster, the influence matrix has assigned PVM a critical role since it exerts a frequently reported positive influence on its peers (see Table 52). It further strongly correlates with the previously implemented CE (see Table 45) which, according to literature, is at least partly rooted in the early integration of all involved functions, which reduce overall variability, as well as the formal design evaluation and frequent review meetings which increase assembly compatibility, improve manufacturability, and make the PD process generally more robust (Morgan and Liker, 2006).

Companies with experiences in the introduction of PVM have stated to be majorly opposed by the challenge to reduce the complexity of a large and diverse product portfolio which one respondent reported is 'simply too big of an undertaking' (see Figure 52). Others see the difficulties in fully establishing PVM to the specifications of the proposed LPD framework in highly-complex products which hardly permit the use of modules or platforms which could bridge product lines.

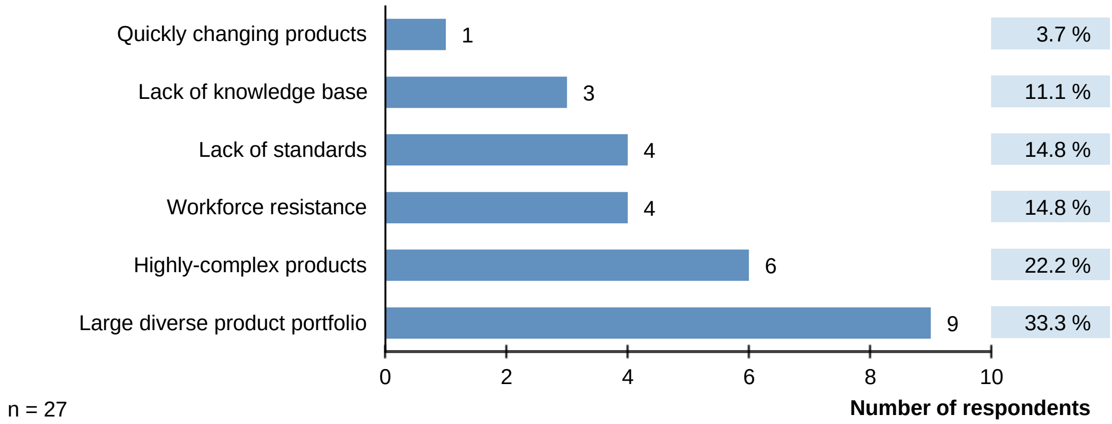

Figure 52: Implementation problems for PVM

The next LPD element this study recommends to implement is 'supplier relationship and integration'. This aspect of LPD has scored similarly well in average use (3.07) and perceived benefit of implementation (5.54) compared to the previously introduced PVM but has been implemented on average very late (5.02) despite the perceived ease of implementation (3.42). In addition to the retrieved results for these variables, this element has shown to strongly and significantly correlate with the previously introduced elements (see Table 45) which is supported by the influence matrix which frequently reports a positive influence of PVM on SRI (see Table 52). Findings in literature at least partly reason this causal link to be rooted in the increased use of off-the-shelf parts and a higher carry-over rate which considerably simplifies sourcing. Hoppmann et al. (2011), Morgan and Liker (2006) as well as Ward et al. (2007) further argue that clearly defined modules with standardised interfaces facilitate a company's outsourcing efforts. Its position within the 'product' cluster further suggests strong synergetic effects with the previously implemented element (see Table 50). In the course of introducing SRI, participating companies have remarked to have faced major obstacles because of a significant risk of being deprived of intellectual property as well as slipping into a position of dependency by reducing the supply base to only a few highly-capable suppliers (see Figure 53). A common notion across these two biggest problems companies have experienced throughout their implementation efforts, is the risk of potentially losing a competitive advantage and the fear of strengthening the suppliers' bargaining power.

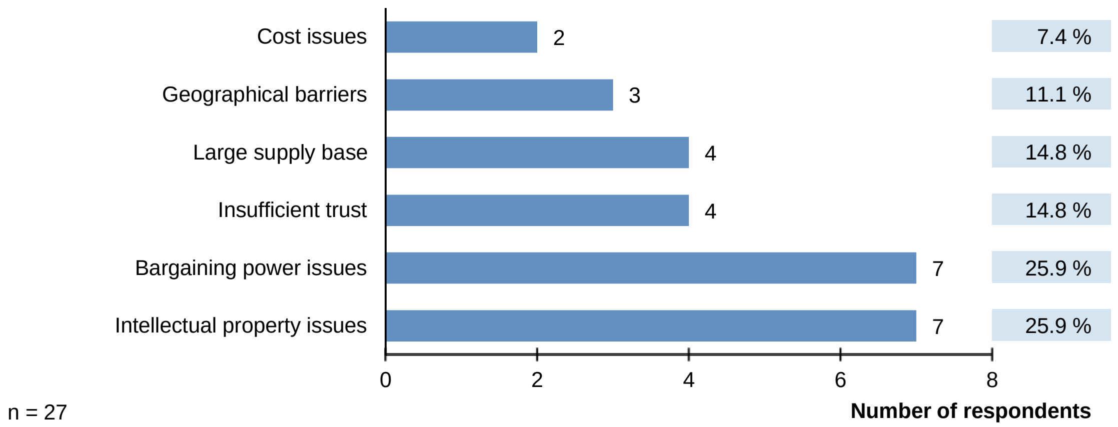

Figure 53: Implementation problems for SRI

Based on the available data and grounded in literature, the next implementation recommendation goes to the last element of the 'product' cluster, 'set-based design' (see Table 50). This element has been identified as the least frequently used (2.67), perceived as second least beneficial (5.20), on average implemented seventh (4.96), and reported to be fairly difficult to introduce (3.00). Within the LPD framework, SBD has shown to strongly and significantly positively correlate with the other elements of its correlation cluster, PVM and SRI, as well as PM and CI (see Table 45). In the influence chart, SBD falls into the critical upper right quadrant close to the passive quadrant in the upper left (see Figure 44). It has been classified as such since it has not only been frequently reported to exert a positive influence on other elements but also since it exhibited a high influenceability (see Table 52). Due to its susceptibility to positive effects of previously implemented LPD elements as well as its lacking effect on SRI and its below average performance in the previously reported variables, the recommendation to introduce this component of the 'product' correlation cluster at this point has been made. While literature has reported that the previous integration of suppliers help developing design alternatives and facilitate the design space reduction by sharing knowledge and augmenting a company's development capacities (Cusumano and Takeishi, 1991; Morgan and Liker, 2006; Schuh, 2013), the other element belonging to the same correlation cluster, PVM has been identified as a major enabling factor as the parallel development of a number of design solutions is considerably facilitated by clearly defined modules and platforms with standardised interfaces (Ward et al., 2007). Beyond these relationships, literature has frequently expressed the important influence of the SPM, T, and CE on SBD (see Table 6 et seq. in section 3.3). Companies which have participated in this study have most frequently stated to have encountered major capacity limitations during the introduction of SBD which would not allow for the front-loading of the development process with a large number of design solutions, let alone for their objective evaluation and elimination (see Figure 54). Others were more specific and reduced the experienced inability to handle a large solution space to time restrictions or a lack of resources such as testing and prototyping facilities.

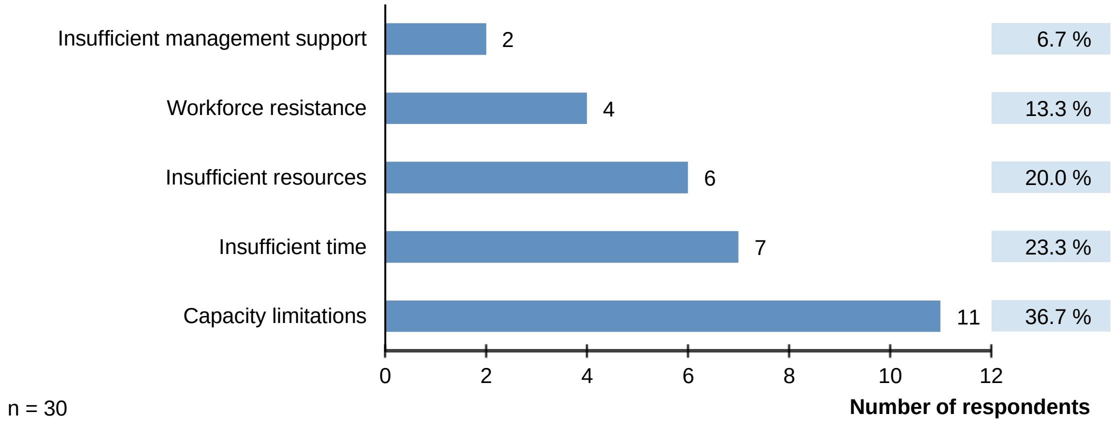

Figure 54: Implementation problems for SBD

Last but not least, the findings of the work at hand recommend to introduce the correlation cluster independent 'communication and knowledge transfer'. This element has overall performed least impressive in terms of average use (2.86), perceived ease (2.81) as well as benefit of implementation (5.16) and, maybe partly as a result of the former, questionnaire respondents have listed CKT to be implemented lastly (5.71). Although Table 45 has reported this component of the LPD framework to significantly correlate with all other elements, a closer look at the *R*-matrix on a characteristics level raised some doubt since in most cases only one half of the attributes of CKT actually stood in a significant relationship with another LPD element (see Appendix C 15 et seq.). In the influence matrix, participating companies have repeatedly reported the positive influence this LPD framework component has on other elements as well as its susceptibility to others (see Table 52). Since the former clearly outweigh the latter, CKT has been categorised as relatively active and critical (see Figure 44). In literature the positive effects other elements have on this aspect of LPD can be largely summarised to a strongly increasing knowledge base due to more effective, shorter, and more frequent problem-solving cycles as well as the promotion of the mode of communication encouraged by this component (see Table 6 et seq. in section 3.3 for a detailed account). Participating companies with experience in implementing CKT, as defined by the LPD framework, have reported to be lacking the information technological backbone which would accommodate the needs of the company (see Figure 55). While some simply stated the absence of a suitable tool which would permit creating and effectively maintaining a growing explicit knowledge base, two respondents made aware of the challenge to consolidate a number of specialised systems which would be necessary to establish such a support structure. Six participating companies also encountered accountability issues rooted in an inappropriate electronic signing off system as well as a blind reliance on stored data which might be outdated. A general lack of resources and the inability to make time to continuously update such a central knowledge base have also been repeatedly stated to cause problems throughout the implementation of CKT.

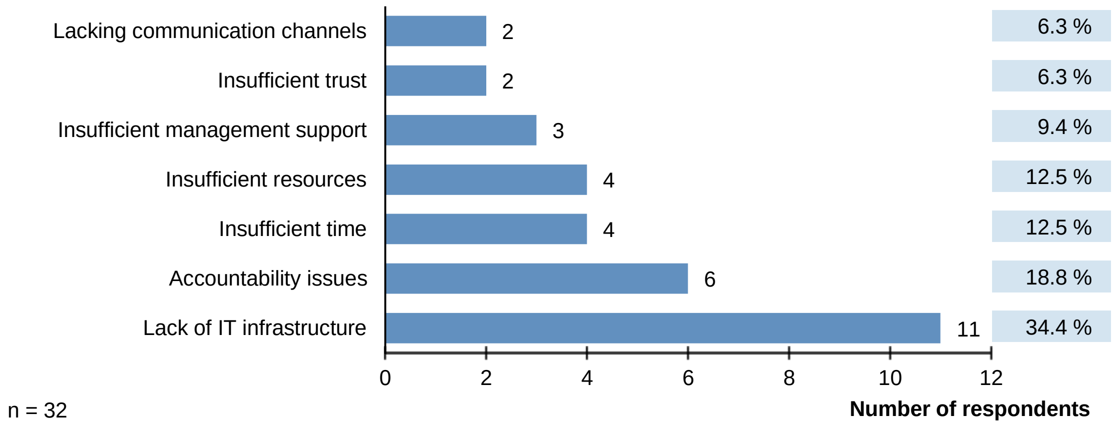

Figure 55: Implementation problems for CKT

The preceding discussion has not only developed three general recommendations but also formulated an effective implementation plan rooted in the findings of the inner relationships of the proposed LPD framework and including a number of variables which reflect the experiences of the companies which have participated in this study. The findings of this section are summarised in Figure 56.

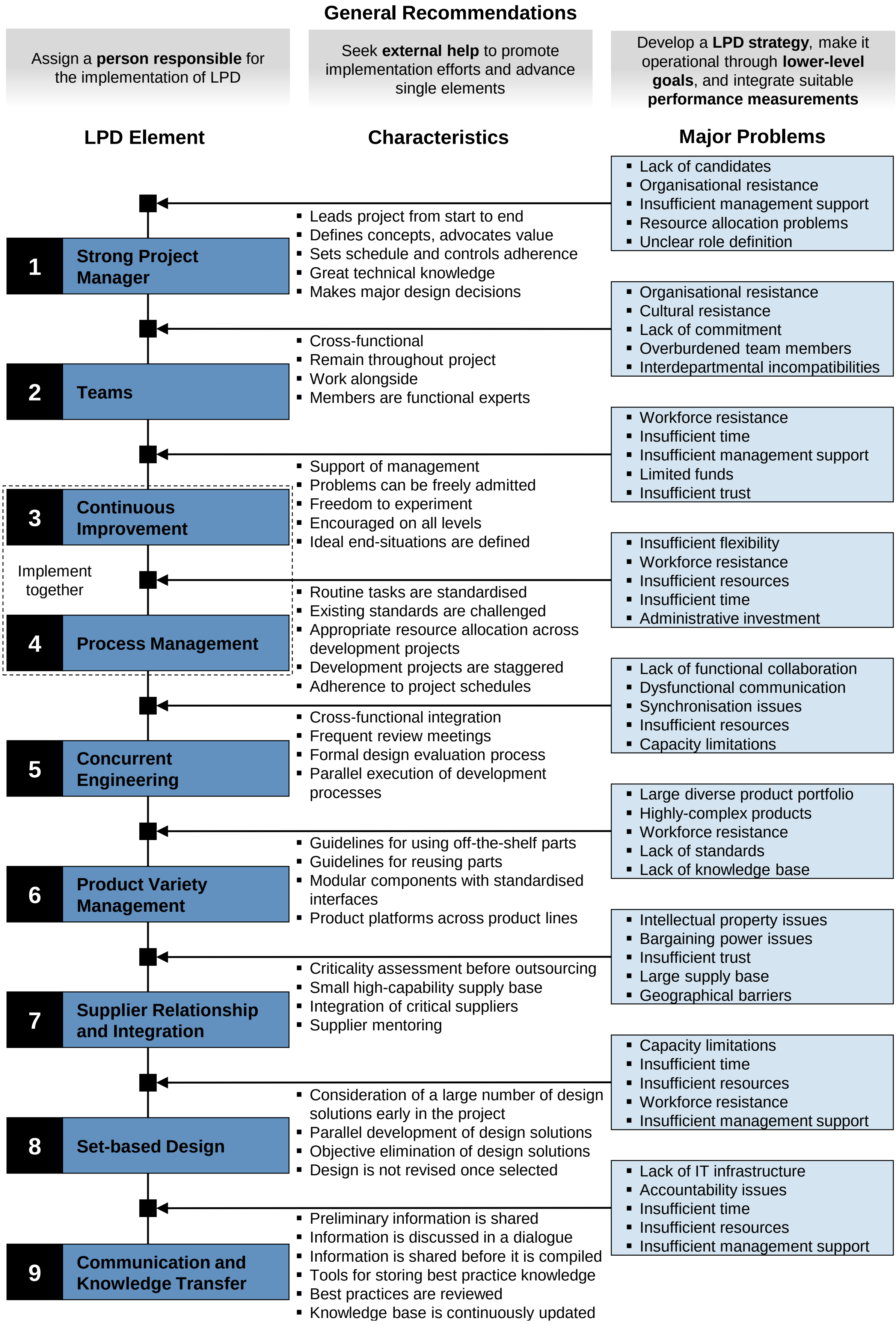

Figure 56: Summary of implementation recommendations

The previously detailed implementation plan sets itself notably apart from other, comparable approaches since it has been based on a sound empirical basis, takes the inherent complexities of LPD into account, and provides an appropriate level of detail. It is the combination of these three aspects which renders this implementation plan unique in comparison with existing approaches. A few of studies such as Gingnell et al. (2012), Oosterwal (2010), and Radeka (2013) have provided first insights into the implementation of LPD by conducting a number of qualitative case studies. Gingnell et al.'s (2012) investigation into three Swedish companies yielded several general implementation recommendations, while Oosterwal's (2010) detailed account of his experience with the introduction of Lean into one of Harley-Davidson's product development divisions resulted in a detailed company-specific account with a strong focus on the operational level. Radeka's (2013) relatively general implementation recommendations are based on two years of fieldwork during which she interviewed numerous companies. The resulting roadmap, however, lacks an appropriate level of detail which renders it difficult to access for practitioners. Kennedy (2003) and Mynott's (2012) implementation recommendations are grounded in their practical experiences in the field but lack the scientific basis which might lend the needed transparency and rigour. All of these publications share the highly subjective qualitative basis which prohibits the formulation of generalisable recommendations. The single exception to the otherwise case-study based publications is Hoppmann's (2009), previously in detail discussed (see section 1.1 and 2.3.1), diploma thesis which was the first to quantitatively explore this aspect of the LPD research stream. In summary, the author's strong focus on a considerably limited framework and the insufficient understanding of the interrelationships inherently constrained his efforts which has been appreciated in Hoppmann et al. (2011). Other publications such as Wang et al.'s (2012) conceptual paper have based their implementation plan solely on existing literature without drawing on primary data which would enrich this severely under-investigated area of LPD. On the other end of the spectrum, the empirically well-grounded publications by Morgan and Liker (2006) as well as Schuh (2013) propose very general implementation models lacking the appropriate level of detail the intricate LPD framework requires.

In addition to the previously indicated shortcomings, all of the above mentioned implementation recommendations are specifically tailored towards the corresponding interpretation of a LPD framework. The coherent and comprehensive LPD framework developed throughout this research, the empirical investigation into its inner workings, and the deduction of a systematic implementation plan which considers the complex interdependencies of the LPD framework at an element level distinguishes the implementation plan summarised in Figure 56.

5.3 Concluding Remarks

This extensive chapter has in its smaller first part presented numerous measurement items which in the beginning describe a variety of sample characteristics, before reporting three variables which provide some initial insights into the current implementation status of LPD and supporting factors a company seeking to embrace Lean practices in PD might want to employ. The descriptive analysis concluded by outlining the average use of the individual characteristics the single LPD elements are composed of and further elaborated on a number of aspects surrounding the experiences participating companies had throughout the introduction of the LPD components. This first part not only presented various aspects of the sample but also provided some first important findings such as the fact that 42% of participating companies have chosen a person responsible for the implementation of LPD. This impressive figure highlights the attention this approach is currently attracting and further underlines the importance of this study. In addition, another 27% of respondents have reported to already use or intent to use external help to support their implementation efforts. Even without further analysis, both findings constitute highly interesting results with potentially great implications. Another important contribution the descriptive analysis made to the remainder of this work was the evaluation of the average use of the LPD element characteristics which was used throughout the analysis as an important measure which other variables have been controlled against to determine their impact on LPD, its elements, and characteristics.

The second part of the chapter started out to determine potential external influencing factors by analysing the impact of various previously presented variables on the average use of LPD. The identification of these factors not only yielded important findings in its own right but also constitutes a starting point for the formulation of implementation recommendations later in the chapter. Additionally, this first part of the advanced analysis deepened the understanding of LPD and unearthed a great number of important findings. Corresponding with the depth of the analyses, these findings are scattered across all levels of LPD and accordingly describe noteworthy insights for the LPD framework in its entirety, its elements, and the characteristics the latter are composed of. For example, the analysis of the LPD goal variable has yielded that while the development of a strategy alone does not have a significant impact on the use of LPD, the additional definition of actionable lower-level goals and integration of corresponding performance measurements amount to a significant difference in the frequency in which LPD is employed. On an element level, this finding was further refined by determining that PM particularly benefits from suitable performance measurements. Taking this finding to the characteristics level of PM revealed that the 'appropriate resource allocation across development projects' as well as 'adherence to schedule' especially benefit from performance measurements. The detailed analysis of the influence the various variables have has yielded numerous interesting findings which have extended the understanding of LPD and its elements as well as laid a basis for the following formulation of implementation recommendations.

The second part of the advanced analysis set its focus firmly on addressing the second research question which enquires into the interrelationships between the individual elements of the LPD framework. In pursuit of a thorough answer, the variables which measure the frequency with which the characteristics of the single LPD elements are employed throughout have been scrutinised by analysing their general relationship in a correlation matrix. Amongst other findings, the *R*-matrix confirmed León and Farris, (2011), Hoppmann et al. (2011), Morgan and Liker (2006), and other contemporary LPD publications in the view on LPD as a system of tightly-interwoven elements. The sheer amount and intensity of significant relationships, however, prohibited drawing detailed conclusions. Consequently, an exploratory factor analysis was conducted to reveal hidden structures underlying this close network of strongly correlating elements. The last section in this second part of the analysis introduced an element of causality to further specify the interrelationships. The influence matrix and its corresponding influence chart have identified numerous interdependencies which shed further light on the inner workings of the proposed LPD framework. While the depths of the analyses in the previous part and the multifarious aspects of the internal relationships yielded a large number of interesting insights, the most noteworthy findings are compiled in Table 53.

Area	Findings	Discussed in
LPD General	74 % of all companies intent to develop LPD goals (11.1%) or already have a strategy (317 %) in combination with lower-level goals (14.9 %) and suitable performance measurements (16.3 %)	5.12
	A LPD strategy alone does not lead to significant changes in the use of LPD elements	5.2.16
	The formulation of operational goals and corresponding performance measurements has a significant influence on the use of LPD elements. Goals alone often do not achieve the intented results	5.2.16
	42 % of participating companies have assigned a person responsible for the implementation of LPD	5.12
	Dessignating a person to implementing LPD makes a significant difference to the average use of LPD	5.2.14
	27 % of participating companies are using or are planning to use external help for implementing LPD	5.12
	External help is an implementation tool for stragglers, not LPD pioneers	5.2.15
	LPD is equally used in the USA and Germany	5.2.11
	Machinery, electrical, and transport equipment industry makes among the various industrial sectors the most use of LPD practices (Ø = 3.24)	5.2.12
	LPD is overall heavily dependent on company size	5.2.13
	LPD practices are very infrequently used by small companies with 1-99 employees (Ø = 155) but the average use of LPD significantly increases until reaching 9999 employees (Ø = 3.39)	5.2.13
	LPD consists of strongly positively correlating elements with the 'strong project manager' asserting a somewhat more independent role	5.2.2.1
	Companies less invested in LPD apply Lean practices in product development across the board but on a lower level of intensity	5.2.2.1
Strong Project Manager	The most widely used LPD element next to 'concurrent engineering'	5.12
	Very frequently used in small, 1-99 employee companies and significantly drops when growing in size	5.2.13
	Correlates very little with other LPD elements with the exception of 'communication and knowledge transfer'	5.2.2.1
	Highly active LPD component which excerts a lot of influence while being relatively little influenced by others	5.2.2.3
Teams	Perceived as easiest to implement	5.12
	Perceived as yielding the biggest benefits if implemented	5.12
	On average implemented firstly	5.12
	Technical knowledge of development teams is only marginally increased if companies grow in size; the retention, integration, and colocation is vital when pushing this element	5.2.13
Continuous Improvement	Exhibits mutually reinforcing positive effects with 'process management'	5.2.2.3
	The ability to freely admit problems significantly correlates with some of the largely independent 'strong project manager's' characteristics	5.2.2.1
Process Management	Standardisation of routine tasks, their continued challenge as well as appropriate resource allocation are very infrequently used in small companies	5.2.13
	The challenging of existing standards is relatively infrequently used and overall remains behind the all characteristics	5.2.13
	Significantly benefits from performance measurements (LPD goal variable)	5.2.16
	The characteristics 'appropriate allocation of resources' as well as the 'adherence to schedules' particularly benefit from the implementation of suitable performance measurements	5.2.16
	Exhibits mutually reinforcing positive effects with 'continuous improvement'	5.2.2.3
Concurrent Engineering	The most widely used LPD element next to the 'strong project manager'	5.12
	Hardly used in small, 1-99 employees companies but very quickly focused on if growing in size	5.2.13
	Passive LPD element which exhibits a high susceptibility to the influence of other framework components while having only relatively little effect on others	5.2.2.3
Product Variety Management	Perceived as most difficult to implement	5.12
	Small companies almost never make any use of 'product variety management'	5.2.13
Supplier Relationship and Integration	'Use of a small number of high-capability suppliers for critical parts' does not significantly change with company size	5.2.13
	Small and medium-sized companies (1-999 employees) are very reluctant to integrate critical suppliers into their concept definition phase	5.2.13
	Inert LPD component with low influenceability and little positive effects on other elements	5.2.2.3
Set-based Design	Least often used LPD element	5.12
	'Decisions are delayed' characteristic behaves quite differently and is far less company size dependent. It also significantly and positively correlates with knowledge-focused 'communication and knowledge transfer' characteristics	5.2.13
	Definition of actionable and measurable lower-level goals makes a significant difference	5.2.16
Communication and Knowledge Transfer	Perceived as yielding the least benefits if implemented	5.12
	On average implemented lastly	5.12
	Communication-focused characteristics are considerably reduced by an increasingly formalised working envinonment	5.2.13
	External help is likely to be employed to help companies struggling with the introduction of this element and its knowledge-based characteristics in particular	5.2.15
	Shows severe internal incoherences on multiple levels	5.2.17

Table 53: Summary of findings

In addition to these highly interesting findings, the various analyses have also cast a shadow on the 'communication and knowledge transfer' element. Although, the reliability analysis resulted in a Cronbach α-value of 0.743, which is well above the in literature postulated threshold of 0.7, various subsequent statistical tests have raised severe doubts regarding this scale's internal consistency. The internal incoherence and inhomogeneity of CKT became obvious when discussing the detailed *R*-matrix provided in Appendix C 15 et seq. The excerpt of this matrix provided in Table 54 clearly shows the lacking correlations between the communication-focused (items 22-24) and knowledge-focused characteristics (items 25-27). This lacking internal coherence translates into the element's intricate relationships with other components of the LPD framework which is not only apparent in the detailed *R*-matrix but was also picked up by various other statistical tests which examined CKT on a characteristics-level (see 5.2.1.3 and 5.2.1.6). It is further assumed that the lacking internal coherence played a part in the dropping of the 'administration' factor in the exploratory factor analysis. Considering the strong theoretical basis for both the communication and knowledge-focused characteristics and the unearthed problems regarding the interplay of these two sub-scales, the CKT scale is split in two scales 'communication' and 'knowledge transfer'. The revealed differences between the two new scales, their conceptual consistency as well as their theoretical basis speak in favour of splitting CKT rather than dropping it in whole or part. Both new scales 'communication' (0.837) and 'knowledge transfer' (0.851) reliably represent the measured characteristics (see Appendix C 94).

			22	23	24	25	26	27
Communication and Knowledge Transfer	Information is passed on before it is compiled (e.g. in hand-over reports)	22	1	.753**	.902**	.040	.032	-.121
	Information is discussed in a dialogue-mode	23	.753**	1	.722**	.095	.059	-.055
	Preliminary information is shared	24	.902**	.722**	1	.153*	.104	-.034
	There are methods and devices to collect information on successful procedures, tools, and designs across projects	25	.040	.095	.153*	1	.748**	.776**
	Best practices and lessons learned from previous projects are reviewed	26	.032	.059	.104	.748**	1	.708**
	Documented knowledge is continuously updated by the engineers	27	-.121	-.055	-.034	.776**	.708**	1

* $p < 0.05$ ** $p < 0.01$

Table 54: *R*-matrix excerpt

The last part of the analysis exclusively focused on convincingly answering the third research question which asked for an effective implementation plan for LPD. On this endeavour, the last part combined findings of the previous analyses with a number of newly introduced variables as well as the qualitative relationships between the individual elements identified in literature. The general recommendations were formulated drawing on the previously identified influence factors and their potential to make a significant difference in the successful implementation of LPD. Subsequently, a number of variables were investigated and integrated into the development of a suitable and effective implementation plan. The lastly defined implementation plan made use of the continuously refined understanding gained throughout the previous sections and further included the measurement items which assessed the experience of participating companies in the introducing of LPD. Striving to further enrich the implementation plan, the section also integrated the qualitative descriptions of the relationships between the LPD elements previously identified in literature. The culmination of these efforts constitutes an implementation plan grounded in both empirical data and literature and embedded in the respondents' implementation experiences.

6 Conclusion and Future Work

This last chapter initially provides a concise summary relating the research's findings and discussions to the research questions unearthed at the outset of this work. The chapter proceeds to highlight the investigation's most important contributions, discuss its limitations, and concludes by formulating a number of recommendations for future research opportunities.

6.1 Research Summary

The work at hand set out to address a number of gaps in contemporary LPD literature which currently pose major obstacles not just for academics striving to push this field of research but also for practitioners seeking ways to practically apply the advancements in organisational research. The identified gaps led to the formulation of three research questions which firstly asked for the development of a coherent and comprehensive LPD framework, secondly enquired into the interrelationships of the elements the framework consists of and lastly called for an effective implementation plan. The pursuit of thoroughly addressing these intrinsically tied research questions led the study into reviewing a number of aspects and concepts in Lean, Product Development, and Lean Product Development to establish a firm understanding of the research subject and contextualise the investigation.

The first research question was addressed by developing a LPD framework which not only combined existing, academically-sound, and original frameworks but also included findings and discussions from the wider PD research area. The proposed LPD framework, illustrated in Figure 57, has been formulated based on a thorough review of existing approaches which have been abstracted using content analysis. The resulting framework consisting of nine elements was thoroughly discussed using the results of an extensive content analysis to define key aspects and including the fruitful discussions from outside LPD literature to bolster the individual elements with most recent empirical results. The outcome of this process is a coherent and comprehensive LPD framework which effectively answers the first research question.

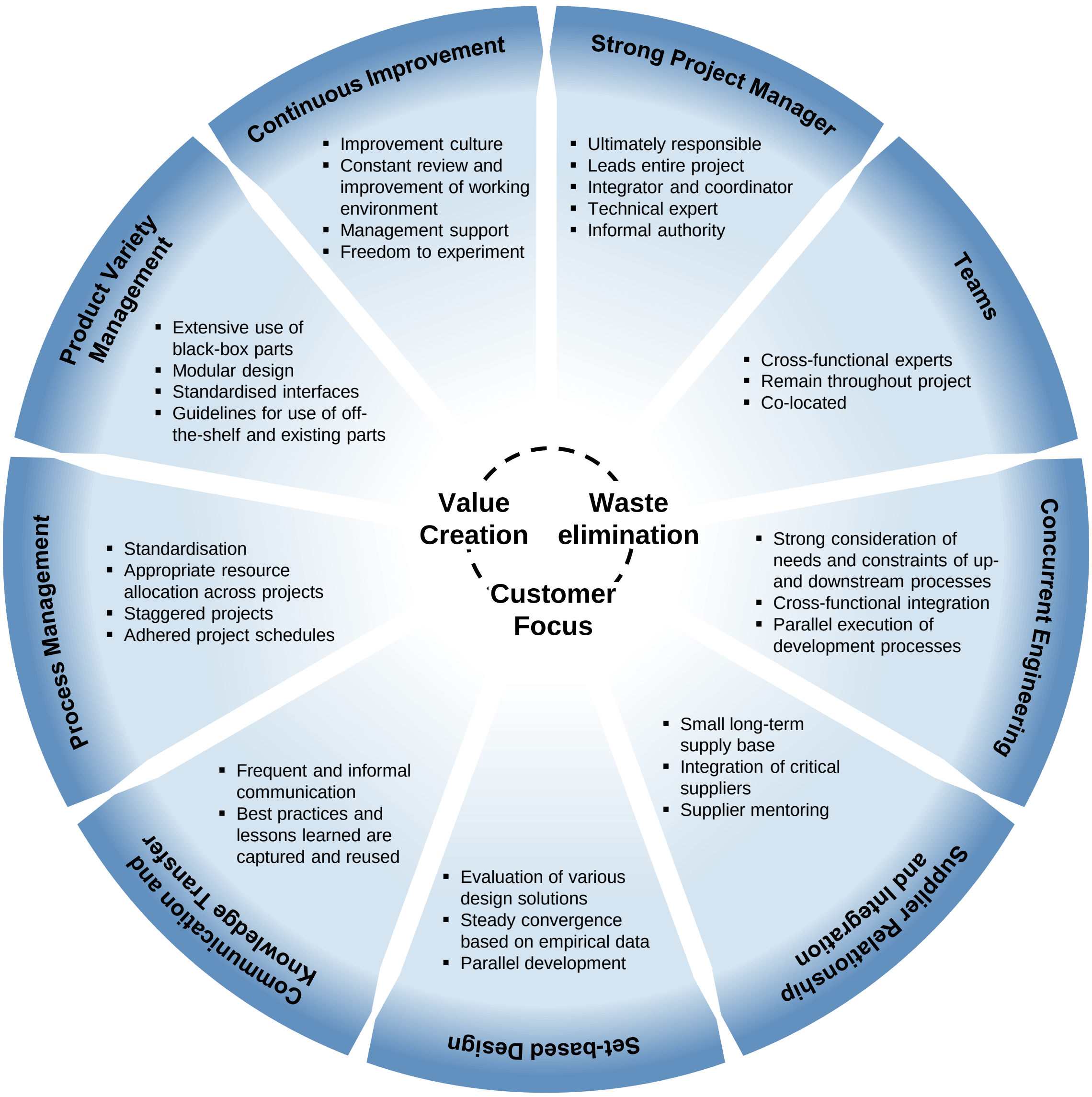

Figure 57: Summary of the proposed LPD framework

The identification and compilation of qualitative descriptions of the interrelationships between the framework's components, in the course of developing the LPD framework, laid the foundation for addressing the second research question. The additional analysis of the largely quantitative results of an inductively approached questionnaire survey including 208 participating companies provided the means to effectively address the inquiry about the inner workings of the proposed LPD framework. The statistically rigorous analysis and synthesis with literature yielded deep insights into the interrelationships and causal links between the LPD elements which thoroughly answered the second research question.

The development of a coherent and comprehensive LPD framework as well as the understanding of its inner dynamics prepared the ground for approaching the third research question. The pursuit of developing and formulating an effective implementation plan led to the combination of previously discovered findings with experiences participating companies have accumulated throughout their LPD efforts and insights gained from literature. The careful unification of this heterogeneous dataset resulted in the definition of three general recommendations and formulation of an effective implementation plan which answered the third and last research question.

6.2 Contributions

The research at hand makes several considerable contributions to the LPD and, in a broader sense, product development research area.

The first important contribution of this work is the proposal of a comprehensive LPD framework. The consolidation of existing frameworks with complementary approaches from the wider field of PD, aligned with best practice study results led to the development of a coherent and comprehensive LPD framework. The combination of existing concepts and the definition of clearly distinguishable elements within the framework seek to overcome the current controversies in the focus and scope of existing concepts. This newly developed understanding of LPD resulting from the consolidation of the frameworks, which have gradually emerged over time reflecting the increasing understanding of Toyota's development practices, and extension through integrating findings from the wider PD research area, marks a major contribution to this nascent research area and helps to eliminate ambiguity among researchers and practitioners. The proposed and thoroughly discussed framework also contributes to the differentiation of LPD and its practices from other approaches thus helps to draw a clearer picture of the emerging LPD research stream.

The second major contribution comes with the deepened understanding of the relationships between the single elements. The theoretical and empirical analysis of the interdependencies promotes the idea of LPD as a holistic system which is supported by recent research in this area. The findings of this study provide rich insights into a complex and interwoven system in which the different components relate to, depend on, and support each other. The inclusion of causal measurement items and accounts of qualitative relationships identified in literature allow the understanding of the framework's inner dynamics to grow beyond the descriptive limitations of many quantitative studies and introduce an explanatory dimension. This causal element not only provides further insights but also allows the development of an effective and empirically grounded implementation plan.

The third substantial contribution constitutes the development of solid reasoned implementation recommendations which offer an appropriate level of detail and take the inherent complexities of a LPD framework into account. An implementation plan based on empirical data as well as findings from literature complements existing literature which predominantly focused on case studies to derive best practices or gave merely more than intuition-based suggestions. In most cases, the implementation of a LPD system has been treated as supplementary to the description of LPD practices. General implementation recommendations and an implementation plan derived from both an extensive theoretical investigation and empirical data represents a considerable advancement which not only could serve as a catalyst in this nascent research area but also support companies to apply the Lean approach to product development. The deepened understanding of the LPD framework's inner workings as well as the formulation of detailed implementation recommendations which considers the qualitative and quantitative insights into participating companies' experiences will support and guide companies striving to introduce Lean practices in PD and help anticipating, avoiding, or mitigating potential problems.

In addition to these significant contributions which result from thoroughly addressing the research questions that have shaped this inquiry, the statistical analysis of the largely quantitative dataset has yielded a great amount of noteworthy insights such as the fact that 42% of participating companies have assigned a person responsible to the introduction of LPD and 27% are either using or are planning to use external help to implement Lean practices in PD. Furthermore, 74% of all companies intent to develop LPD goals (11.1%) or already have a strategy (31.7%) in combination with lower-level goals (14.9%) and suitable performance measurements (16.3%). The results further yielded the significant role of having a dedicated person for the introduction of LDP, heightened the importance of defining an overall strategy for the implementation of LPD along with actionable goals and corresponding performance measurements which translates the strategy to an operational level. The development of a strategy alone does not lead to significant differences in the average use of LPD and its elements. A close examination of the role external help may play in the implementation of LPD has shown that most companies only make use of consultancies and other third parties once they have fallen behind or seek to promote single aspects of the Lean approach in PD. Overall, the use of external help represents a tool for stragglers, not LPD pioneers, and has revealed to be not as significant as assigning a person to implementing LPD and formulating a strategy down to an operational level. These findings, which have been translated into general implementation recommendations, constitute notable contributions to LPD, raise awareness to the attention this holistic approach to managing and organising PD is currently receiving, and overall underline the importance of this research.

Further important contributions arise with the depth of the analysis this study offers and the corresponding detailed findings which investigate multitudinous aspects of LPD not only on a general framework or element level but all the way down to a characteristics level. This detailed analysis has provided rich and insightful results which allowed investigating various phenomena in considerable depth. The description and discussion of these highly-detailed findings, however, go far beyond the scope of this section thus need to be considered in the corresponding part of this work.

6.3 Limitations

Despite the careful preparation and thoughtful execution, this research and its findings bear a number of inherent limitations which will be clarified in the following.

First and foremost, the entire investigation into the relationships between individual LPD elements and the development of an implementation plan rest upon the proposed framework which drew on existing LPD frameworks to define its basic structure and key elements. It therefore relies on the quality of these frameworks which provided a major input. In an effort to mitigate any problems at the foundation of this work, the frameworks subjected to content analysis have been carefully chosen and the derived basic structure of LPD thoroughly enriched by insights gained in the wider PD research area. The input from outside the nascent LPD research area further provided contemporary input which helped defining the individual elements and aligned many aspects of the framework with current best practices in PD.

Another limiting factor which could not have been avoided is the lacking validity of constructs and its corresponding measurement items which were employed to determine the frequency with which the LPD elements and respective characteristics are being used in participating companies. The exploratory aspect of defining a new LPD framework and the unique character of many of its elements prohibited the use of established valid constructs. This might raise doubts as to whether the different items actually measure what they purport to measure (Cronbach and Meehl, 1955; Nunally, 1978). The corresponding limitation was attempted to be mitigated by resorting to Hoppmann's (2009) survey items where appropriate and possible but the novel character of the LPD framework did in many cases not permit to fall back on existing surveys or otherwise already tried and tested constructs and measurement items.

A direct consequence and drawback of this issue constitute the problems associated with ‘communication and knowledge transfer’ which ultimately led to the splitting of this LPD element. Considering the implications of splitting this component of the framework, caution is advised when dealing with this aspect of LPD. On a first glance, this might not severely affect the framework itself, but taking this thought a step further and considering the implications the splitting of CKT has on the established understanding of the framework’s inner workings as well as the knock-on effects on the implementation recommendations, prudence is recommended when being confronted with this element.

Further limitations associated with the issue of developing an original framework is the choice of method for the exploratory factor analysis. According to Field (2013) the results of the employed principal axis factoring method are limited in its application to the sample collected since the used measurement items do not constitute the entire population of variables. Consequently, the claims about the internal relationships of the LPD framework might only be applicable to the sample but not be generalised to the whole population without cross-validating this aspect of the investigation.

The importance of retrieving the same factor structure from analysing a different sample is heightened when considering how the retrieved results have largely shaped the sequence in which the implementation plan recommends to introduce the LPD elements. Another aspect which limits the general applicability of the implementation plan is the inclusion of the qualitative descriptions of the element interrelationships found in literature. While some of these descriptions are based on generalisable quantitative study results, the majority of claims has been derived from small-scale in-depth case studies. Although the detailed investigations, particularly into Toyota’s practices, have been invaluable for this research stream, the inherent limitations of qualitative data do not permit applying these findings to the wider population without validation.

A further limitation tightly connected to the development of a novel LPD framework concerns the restricted applicability of the deduced general implementation recommendations as well as the subsequently formulated implementation plan. General applicability beyond this framework and its unique composition cannot be claimed due to the specific nature of the individual elements, the characteristics they comprise of as well as the corresponding relationships and interdependencies between them. Moreover, the specifics of a business such as organisational structure, resource availability, corporate culture, the often extremely diverse external business environment as well as the different starting point with regards to LPD render a universally applicable implementation plan with a sufficient level of detail very hard to define. Hence, the formulated implementation plan does not claim general applicability, especially not in the light of the previously highlighted limitations, and should be considered as guidelines which provide orientation and well-reasoned insights into the interplay of the framework's elements.

6.4 Future Work

In pursuit of answering the research questions which have guided and shaped this inquiry and based on this research's findings and limitations, a number of possible trajectories for future research have been identified and will be laid out in the following.

In the course of developing the LPD framework, three best practice studies have been examined and their findings discreetly integrated into the discussion of its elements. Great care was taken when including the best practices to ensure their fit and alignment with the corresponding aspect of the LPD framework. This process not only enriched the LPD framework with contemporary research but also identified a number of methods and techniques which are being recognised as superior but have not found their way into the LPD framework. These best practices offer valuable insights into further development trajectories or how LPD might be effectively complemented by other concepts and tools. The list compiled in Appendix A 1 et seq. provides an overview for specific development opportunities and larger development areas such as the extensions of the LPD framework beyond the fuzzy front-end into the ideation process or in the diametrical direction into the product launch and post launch phase.

Furthermore, the examination of contemporary Lean approaches in the literature review and its comparison with the current understanding of LPD, as discussed in this work, has identified a disparate view on the customer. While current LPD literature holds on to a conservative interpretation of the customer, Murman et al. (2002) as well as Nightingale and Srinivasan (2011) convey a more progressive understanding in line with stakeholder theory as postulated by Freeman (2010). Contemporary Lean research recognises the importance of all stakeholders and respectively aligns its focus with this heterogeneous set of interest groups. The tools developed by Nightingale and Srinivasan (2011) to identify, evaluate, and prioritise stakeholders and their translation into the LPD context might provide a promising starting point for this research trajectory.

Another opportunity for future research constitutes the re-evaluation of the ‘communication and knowledge transfer’ element and its role within the framework. Various findings have shown that the employed communication-focused and knowledge-focused characteristics do not form an internally consistent and homogenous element which ultimately led to the splitting of this scale. Consequently, the newly established two elements need to be defined, their relationships elucidated, and their place in the implementation plan reconsidered. The detailed *R*-matrix in Appendix C 15 et seq. as well as the findings revealed throughout the in-depth analysis of external influence factors in 5.2.1 might provide some orientation and first insights for this endeavour.

Further research opportunities lie in the transfer of the proposed LPD framework to an operational level. This research has conscientiously limited its scope to a strategic level free of methods and techniques which would render LPD actionable and readily applicable. The integration of supporting tools into this strategic macro framework is further expected to make it easier accessible for practitioners thus further lower the entry barriers for companies seeking to adopt Lean practices in PD. The extensive publications on LPD of Morgan and Liker (2006), Schuh (2013), and Ward et al. (2007) have been identified as stimulating and insightful references for this research trajectory. Furthermore, Markham and Lee’s (2013) reported results of the most recent PDMA best practice study offer rich insights into the operational level of various aspects of the PD process.

A number of practitioner-oriented research opportunities concern various aspects of the implementation of LPD. More specifically, assessing the role of external help in terms of when their services are requested, which services are asked for, and what third parties are currently able to offer might prove a worthwhile endeavour. The rather underwhelming results compared to assigning a person responsible for implementing LPD strongly indicate great potential for both research and business alike. Further future work offers the investigation into the combination of the formulated implementation plan with supporting tools and concepts such as value stream mapping which would support practitioners in their implementation efforts. Moreover, the integration of the implementation plan into an organisational change model analogue to the 'Lean Maturity Model' advocated by Schuh (2013) which constitutes a variant of a 'Capability Maturity Model' would not only make the findings of this work easier accessible to the industry but also advance this emerging research stream.

Last but not least, an important direction for future research constitutes the validation of this work in terms of establishing reliable and robust constructs representing the elements of the proposed LPD framework and cross-validating the findings unearthed during the exploratory factor analysis. Valid constructs and corresponding measurement items as well as the needed cross-validation of the identified factors would not only render the findings of this work generalisable to the entire population but also constitute a significant advancement of the nascent LPD research area thus considerably push the research frontier of science.

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Appendix A: Best Practices in Product Development

Kahn et al., 2012	Markham and Lee, 2013 (2012 PDMA study)	Cooper et al., 2004a, b, c (2003 APQC study)
Strategy	**Strategy**	**Strategy**
Clearly defined and organisationally visible PD goals	Use specialised global PD tools*	PD plays a role in business goals
The organisation views PD as a long-term strategy	Manage transnational transfer of ideas*	Strategic arenas are defined
PD goals are clearly aligned with organisation mission and strategic plan	Manage multinational PD project teams*	Clearly defined PD goals
PD projects and programmes are reviewed on a regular basis*	Manage PD idea creation globally*	Long-term commitment to PD
Opportunity identification is ongoing and can redirect the strategic plan real time to respond to market forces and new technologies*	Develop global sustainable advantages*	Strategic buckets of resources*
	Leverage the firm's unique ability*	Product roadmap in place*
	Global collection of the voice of the customer	
	Leverage the firm's global assets*	
	Manage the firm's global PD portfolio*	
	Segment/select market, design positions*	
	Leverage the firm's organisational culture	
	Global competition*	
Climate and culture	**Climate and culture**	**Climate and culture**
Top management supports the PD process	Failure is understood	Climate supports entrepreneurship and innovation
Management rewards and recognises entrepreneurship	Managers establish objectives	Product champions recognised/rewarded
Cross-functional teams underlie the PD process	Objectives in performance review*	PD team is rewarded/recognised
PD activities between functional areas are coordinated through formal and informal communication	Recruiting parameters in innovation potential*	Employees understand PD process ideas-to-launch
	Effective communication externally	Open communication among employees across functions/locations
	Innovation and risk-taking are valued*	Business climate is not risk averse - invest in future some projects*
	Open to constructive conflict	No punishment for product failure
	Effective communication internally	Resources available for creative work
		Skunkworks and unofficial projects encouraged*
		Time-off for creative work
		New product idea suggestions rewarded/recognised
		New product idea suggestion scheme in place

* Not included or not explicitly specified in LPD framework

Appendix A 1: Summary of best practices (Part 1) (Cooper et al., 2004a, b, c; Kahn et al., 2012; Markham and Lee, 2013)

Process	Development Tools	Process
A common PD process cuts across organisational groups Go/no-go criteria are clear and predefined for each review gate* The PD process is flexible and adaptable to meet the needs, size, and risk of individual projects The PD process is visible and well documented The PD process can be circumvented without management approval*	*Author's note: Considers only operational aspects which lie beyond this resaerch's scope.*	Emphasis on pre-development homework* Project performance measurement* Process performance measurement* Tough and demanding go/no-go decision points*

Research	Portfolio Management	Portfolio Management
Ongoing market research is used to anticipate/identify future customer needs and problems Concept, product, and market testing is consistently undertaken and expected with all PD projects Customer/user is an integral part of the PD process* Results of testing (concept, product, and market) are formally evaluated	Formulate project selection decisions* Formulate decisions within active projects Formulate project continuation decisions * Formulate platform decisions Formulate investment decisions*	Portfolio contains high value-to-the- business projects* Portfolio has excellent balance in project types* Resource breakdown reflects business' strategy Good job of ranking/prioritising projects* Good balance between number of projects and resources Projects are aligned with business strategy Formal and systematic portfolio management process in place*

Commercialisation	Front End of Innovation	Senior Management
The launch team is cross-functional in nature* A project postmortem meeting is held after the new product is launched Logistics and marketing work closely together on new product launch* Customer service and support are part of the launch team* A launch process exists*	*Author's note: Considers mostly operational aspects of the ideation process and therefore goes beyond the scope of this work.*	Senior management strongly committed to PD PD metrics part of management's annual objectives* Understand PD process idea-to-launch Helped to design and shape the PD process Overall PD results are measured Provide strong support and empowerment to team members Leave day-to-day activities to team Senior management involved in go/no-go decisions

* Not included or not explicitly specified in LPD framework

Appendix A 2: Summary of best practices (Part 2) (Cooper et al., 2004a, b, c; Kahn et al., 2012; Markham and Lee, 2013)

Project Team
Team remains from beginning to end of project
Clearly assigned team of players
Identifiable project team leader
Leader from beginning to end of project
Project teams are accountable for the project's end results
Decisions made outside the team are handled efficiently
Teams share information via a central information system
Good cross-functional cooperation on project team
Cross-functional project teams
Team focus and resource dedication
Resources are allocated based on project merit
Adequate resources assigned to PD projects
Teams are focused and not spread over too many projects
Teams are focused and not doing too much other w ork
A dedicated PD team exists
Pre-development market information quality
Information on customer needs, w ants and problems
Competitive information (products, pricing and strategies)
Information on customer reaction to the proposed product*
Information on customer price sensitivity*
Data on expected non-revenue performance of the product*
Data on market size and potential*
Expected sales revenue*

* Not included or not explicitly specified in LPD framework

Appendix A 3: Summary of best practices (Part 3) (Cooper et al., 2004a, b, c; Kahn et al., 2012; Markham and Lee, 2013)

Voice-of-Customer information
Market and buyer-behaviour studies are a valuable source for planning the market launch*
Market research helps defining the product
Customer/user is an integral part of the PD process*
Real/unarticulated needs and problems are strongly considered
Working with highly innovative users/customers*
Quality of Execution
Conducting a post-launch review
Value assessment of project*
Test market or trial sell to a limited set of customers*
Concept with the customer*
Idea generation*
Customer tests product under real-life conditions*
Detailed market study/research
Pre-launch business analysis*
Product Definition
Benefits clearly delivered to customer
Well-defined target market
Defined positioning strategy vs. competitors*
Defined product concept
Stable product definition
Defined requirements, features and specifications
Contact between project team and management
Product Advantage
Main benefits are important to the customer
Offer customer new and unique products
Better value for money for customer
Superior to competing products in meeting customer needs
Superior quality vs. competitors

* Not included or not explicitly specified in LPD framework

Appendix A 4: Summary of best practices (Part 4) (Cooper et al., 2004a, b, c; Kahn et al., 2012; Markham and Lee, 2013)

Appendix B: Survey

Lean Product Development is an approach to leverage the successful Lean concept in product development. Academics and practitioners alike are increasingly focusing on of how development processes can be structured and managed effectively and efficiently. A number of characteristical elements have been identified which form a Lean Product Development system.

This survey is part of a self-funded PhD research project at the University of Birmingham, England.

The goal of this survey is to investigate the single elements that make up the Lean Product Development system, their interrelationships and how they can be implemented effectively.

Your benefit for participating in this survey is the support of the study which will allow you gaining insights in the single elements, their interactions and how they can be successfully introduced in your company.

Your participation involves the completion of this survey which will require about 20 to 30 minutes. Your participation is entirely voluntary and you are free to refuse or withdraw from the study at any given time during and up to three month after the survey. If you would like to withdraw from this study, you should contact the researcher.

The results of this study are solely used for the PhD thesis, academic research papers, and presentations.

Your information provided in this survey is, in compliance with the strict ethical guidelines of the University of Birmingham, treated as highly confidential and carefully handled to preserve your anonymity. Your information will solely be accessed and used by the doctoral researcher and his two supervisors. Your identity will be anonymous in the research, and any publications that arise from the research. No information provided by you that would enable others to identify individuals will be permitted to enter the public domain. All data collected will be stored securely. The information will be processed by the researchers only and in accordance with the provisions of the Data Protection Act 1998.

For questions related to this survey, please contact Joachim Freudenberg (jgf192@bham.ac.uk), Dr Eric Shiu (e.c.shiu@bham.ac.uk), Dr Robert Cressy (r.cressy@bham.ac.uk) or the university's research ethics officer Susan Cottam (s.l.cottam@bham.ac.uk).

I have read and understand the above consent form and, by clicking the 'Next' button to enter the survey I indicate my willingness to voluntarily take part in the study.

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Appendix B 1: Questionnaire (Part 1) (adapted from Hoppmann, 2009)

Unit of Analysis

This survey uses the department of a company as unit of analysis and therefore asks to answer all of the following questions with regard to the department you are currently working in.

Information on Lean Product Development Implementation

Please answer some general questions regarding the implementation of Lean Product Development.

Has your company defined goals for implementing Lean principles in product development?

- ○ We do not have any goals and we are not planning to develop any
- ○ We do not have any goals but we are planning to develop some
- ○ We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements
- ○ We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet
- ○ We have an overall strategy, measurable lower-level goals, and suitable performance measurements

Has your company chosen a person responsible for implementing Lean principles in product development?

○ Yes ○ No

Is your company using or planning to use external help (e.g. consultants, etc.) to implement Lean principles in product development?

○ Yes ○ No

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Appendix B 2: Questionnaire (Part 2) (adapted from Hoppmann, 2009)

Element 1: Strong Project Manager
Product development projects are led by an experienced project leader and knowledgeable engineer who is largely responsible for defining customer value, making major technological decisions and securing the overall success of the project.

Please specify to which extent the characteristics of the element 'Strong Project Manager' are used in your company.

	Never	Rarely	Some-times	Often	Always
Project manager leads the product development project from concept to market	○	○	○	○	○
Project manager defines the product concept and advocates customer value	○	○	○	○	○
Project manager sets the project timeframe and controls adherence to it	○	○	○	○	○
Project manager has great technical knowledge	○	○	○	○	○
Project manager chooses technology and makes major component choices	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of a 'Strong Project Manager' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing a 'Strong Project Manager' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 3: Questionnaire (Part 3) (adapted from Hoppmann, 2009)

Element 2: Teams

Development teams form early and typically remain throughout the whole project, consist of technical experts from all involved functions reaching from marketing, to design, engineering, and production, and are integrated to work alongside each other rather than coordinated by liaison function.

Please specify to which extent the characteristics of the element 'Teams' are used in your company.

	Never	Rarely	Some-times	Often	Always
Development teams are made up by all involved functions, from marketing, to design, engineering, and production	○	○	○	○	○
Development teams remain throughout the entire development project	○	○	○	○	○
Team members are integrated to work alongside in the development team	○	○	○	○	○
Team members have deep reaching technical knowledge	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Teams' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Teams' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 4: Questionnaire (Part 4) (adapted from Hoppmann, 2009)

Element 3: Concurrent Engineering

Representatives from all relevant functions are integrated into the early stages of product development. Up- and downstream activities are considered through frequent review meetings and formalised processes evaluate design proposals with regard to their manufacturability and assembly compatibility. The design of production processes and facilities is conducted in parallel to the development of the product.

Please specify to which extent the characteristics of the element 'Concurrent Engineering' are used in your company.

	Never	Rarely	Some-times	Often	Always
All involved functions are integrated into the concept definition phase of the development project	○	○	○	○	○
There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	○	○	○	○	○
There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	○	○	○	○	○
Development and testing of production facilities is conducted in parallel to product development	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Concurrent Engineering' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Concurrent Engineering' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 5: Questionnaire (Part 5) (adapted from Hoppmann, 2009)

Element 4: Supplier Relationship and Integration
Suppliers of critical parts are identified early in the project, integrated into the development process and actively supported to improve their performance.

Please specify to which extent the characteristics of the element 'Supplier Relationship and Integration' are used in your company.

	Never	Rarely	Some-times	Often	Always
Parts are evaluated according to their criticality before making outsourcing decisions	○	○	○	○	○
A small number of high-capability suppliers are used for critical parts	○	○	○	○	○
Critical suppliers are integrated in the concept definition phase	○	○	○	○	○
Suppliers are mentored to improve their performance	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Supplier Relationship and Integration' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Supplier Relationship and Integration' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 6: Questionnaire (Part 6) (adapted from Hoppmann, 2009)

Element 5: Set-based Design
A large number of alternative design solutions is considered early in the development process and gradually narrowed down to a single solution based on simultaneous development and testing of alternatives which yield objective data.

Please specify to which extent the characteristics of the element 'Set-based Design' are used in your company.

	Never	Rarely	Some-times	Often	Always
A large number of possible solutions for a design problem is considered early in the process	○	○	○	○	○
Alternative solutions for a design problem are developed and tested simultaneously	○	○	○	○	○
Decisions are delayed until objective data allow the elimination of competing design solutions	○	○	○	○	○
A concept for a design solution is not revised once it has been selected	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Set-based Design' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Set-based Design' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 7: Questionnaire (Part 7) (adapted from Hoppmann, 2009)

Element 6: Communication and Knowledge Transfer

Successful tools, methods, and designs as well as areas for improvement are documented on a cross-project basis and actively used and refined in subsequent projects. Information is passed on in a dialogue-mode before it is formalised and preliminary information is shared.

Please specify to which extent the characteristics of the element 'Communication and Knowledge Transfer' are used in your company.

	Never	Rarely	Some-times	Often	Always
Information is passed on before it is compiled (e.g. in hand-over reports)	○	○	○	○	○
Information is discussed in a dialogue-mode	○	○	○	○	○
Preliminary information is shared	○	○	○	○	○
There are methods and devices to collect information on successful procedures, tools, and designs across projects	○	○	○	○	○
Best practices and lessons learned from previous projects are reviewed	○	○	○	○	○
Documented knowledge is continuously updated by the engineers	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Communication and Knowledge Transfer' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Communication and Knowledge Transfer' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 8: Questionnaire (Part 8) (adapted from Hoppmann, 2009)

Element 7: Process Management
Successful process management is the result of a myriad of Lean Product Development elements and their harmonious interaction. This element therefore solely covers the concepts of standardisation and workload-levelling which is mainly achieved through resource allocation and careful scheduling.

Please specify to which extent the characteristics of the element 'Process Management' are used in your company.

	Never	Rarely	Some-times	Often	Always
Repetitive routine tasks are standardised	○	○	○	○	○
Existing standards are continuously challenged	○	○	○	○	○
Human, technical, and financial resources are appropriately allocated across development projects	○	○	○	○	○
Development projects are staggered	○	○	○	○	○
Development project schedules are adhered to	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Process Management' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Process Management' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 9: Questionnaire (Part 9) (adapted from Hoppmann, 2009)

Element 8: Product Variety Management
Achievement of economies of scale and synergistic effects through systematic buying-in of off-the-shelf components, reuse of existing parts, development of modular components with standardised interfaces and their integration across product lines using platforms.

Please specify to which extent the characteristics of the element 'Product Variety Management' are used in your company.

	Never	Rarely	Some-times	Often	Always
There are clear goals for the use of off-the-shelf components within a product	○	○	○	○	○
There are clear goals for the reuse of product parts among different modules, products and product families	○	○	○	○	○
There are modular components with standardised interfaces	○	○	○	○	○
There are common product platforms encompassing several product lines	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Product Variety Management' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Product Variety Management' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 10: Questionnaire (Part 10) (adapted from Hoppmann, 2009)

Element 8: Continuous Improvement
Senior management encourages continuous improvement efforts from top to bottom and empowers employees on all levels to experiment with new approaches in an environment where problems can be freely admitted. An ideal final state is defined to provide guidance for continuous improvement.

Please specify to which extent the characteristics of the element 'Continuous Improvement' are used in your company.

	Never	Rarely	Some-times	Often	Always
Management encourages continuous and sustained improvement efforts	○	○	○	○	○
Problems can be freely admitted	○	○	○	○	○
There is freedom to experiment with new approaches	○	○	○	○	○
Improvement efforts are encouraged on all levels	○	○	○	○	○
Ideal situations are defined to provide guidance for continuous improvement efforts	○	○	○	○	○

	Very difficult	Difficult	Somewhat difficult	Neutral	Somewhat easy	Easy	Very easy
In my opinion, the introduction of 'Continuous Improvement' with the above mentioned characteristics is	○	○	○	○	○	○	○

	Very low	Low	Somewhat low	Average	Somewhat high	High	Very high
In my opinion, the benefit of introducing 'Continuous Improvement' with the above mentioned characteristics is	○	○	○	○	○	○	○

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Appendix B 11: Questionnaire (Part 11) (adapted from Hoppmann, 2009)

Element Relationships

Please provide some information with regard to the relationships between the different elements.

Reading the following matrix row by row, please check the box if you think the element in the row has a positive influence on the respective element in the column. Multiple answers are possible.

	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Knowledge Transfer	Process Management	Product Variety Management	Continuous Improvement
Strong Project Manager	-	☐	☐	☐	☐	☐	☐	☐	☐
Teams	☐	-	☐	☐	☐	☐	☐	☐	☐
Concurrent Engineering	☐	☐	-	☐	☐	☐	☐	☐	☐
Supplier Relationship and Integration	☐	☐	☐	-	☐	☐	☐	☐	☐
Set-based Design	☐	☐	☐	☐	-	☐	☐	☐	☐
Communication and Knowledge Transfer	☐	☐	☐	☐	☐	-	☐	☐	☐
Process Management	☐	☐	☐	☐	☐	☐	-	☐	☐
Product Variety Management	☐	☐	☐	☐	☐	☐	☐	-	☐
Continuous Improvement	☐	☐	☐	☐	☐	☐	☐	☐	-

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Appendix B 12: Questionnaire (Part 12) (adapted from Hoppmann, 2009)

Implementation Order

Please provide some information in which sequence the single elements have been implemented in your company.

For each element please select the order in which it has been implemented. Start with '1' for the element that has been implemented the earliest. If more than one element has been implemented simultaneously, you may select the same number for those elements. For elements your company has not yet implemented, please leave the space blank.

Strong Project Manager
Product development projects are led by an experienced project leader and knowledgeable engineer who is largely responsible for defining customer value, making major technological decisions and securing the overall success of the project. ☐

Teams
Development teams form early and typically remain throughout the whole project, consist of technical experts from all involved functions reaching from marketing, to design, engineering, and production, and are integrated to work alongside each other rather than coordinated by liaison function. ☐

Concurrent Engineering
Representatives from all relevant functions are integrated into the early stages of product development. Up- and downstream activities are considered through frequent review meetings and formalised processes evaluate design proposals with regard to their manufacturability and assembly compatibility. The design of production processes and facilities is conducted in parallel to the development of the product. ☐

Supplier Relationship and Integration
Suppliers of critical parts are identified early in the project, integrated into the development process and actively supported to improve their performance. ☐

Set-based Design
A large number of alternative design solutions is considered early in the development process and gradually narrowed down to a single solution based on simultaneous development and testing of alternatives which yield objective data. ☐

Communication and Knowledge Transfer
Successful tools, methods, and designs as well as areas for improvement are documented on a cross-project basis and actively used and refined in subsequent projects. Information is passed on before it is formalised in a dialogue-mode and preliminary information is shared. ☐

Process Management
Successful process management is the result of a myriad of Lean Product Development elements and their harmonious interaction. This element therefore solely covers the concepts of standardisation and workload-levelling which is mainly achieved through resource allocation and careful scheduling. ☐

Product Variety Management
Achievement of economies of scale and synergistic effects through systematic buying-in of off-the-shelf components, reuse of existing parts, development of modular components with standardised interfaces and their integration across product lines using platforms. ☐

Continuous Improvement
Senior management encourages continuous improvement efforts from top to bottom and empowers employees on all levels to experiment with new approaches in an environment where problems can be freely admitted. An ideal final state is defined to provide guidance for continuous improvement. ☐

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Appendix B 13: Questionnaire (Part 13) (adapted from Hoppmann, 2009)

Implementation Problems

Please provide some information in regards to the problems you have encountered during the implementation of the individual elements.

Please describe briefly any major problems you have encountered during the implementation of a particular element.

Strong Project Manager	
Teams	
Concurrent Engineering	
Supplier Relationship and Integration	
Set-based Design	
Communication and Knowledge Transfer	
Process Management	
Product Variety Management	
Continuous Improvement	

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Appendix B 14: Questionnaire (Part 14) (adapted from Hoppmann, 2009)

Company Information

Please provide some general information about your company.

In which country is your product development division is located?

[ ]

In which industrial sector does your company mainly operate?

- Automotive
- Aerospace
- Chemicals
- Machinery, electrical, and transport equipment
- Mining and quarrying
- Other: [ ]

How many employees does your company have?

[ ]

What position do you hold in your company?

- Chief Innovation Manager
- Chief Product Development Officer
- Chief Engineer (company level)
- Chief Engineer (department level)
- Product Development Engineer
- Other: [ ]

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Appendix B 15: Questionnaire (Part 15) (adapted from Hoppmann, 2009)

Thank you very much for taking the time to participate in this study.
Your opinions are greatly appreciated.

Appendix B 16: Questionnaire (Part 16) (adapted from Hoppmann, 2009)

ID	Variable label	Value	Value label	Measure-ment level
1**	Has your company defined goals for implementing Lean principles in product development?	-1	Missing	Ordinal
		1	No goals, no plans to develop any***	
		2	No goals, but planning to develop some***	
		3	Strategy, but no goals or performance measurements***	
		4	Strategy and goals but no performance measurments***	
		5	Strategy, goals, and performance measurements***	
2**	Has your company chosen a person responsible for implementing Lean principles in PD	-1	Missing	Nominal
		1	Yes	
		2	No	
3**	Is your company using or planning to use external help (e.g. consultants, etc.) to implement LPD	-1	Missing	Nominal
		1	Yes	
		2	No	
4*	Strong Project Manager-Project manager leads the product development project from concept to market	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
5*	Strong Project Manager-Project manager defines the product concept and advocates the customer value	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
6*	Strong Project Manager-Project manager sets the project time frame and controls adherence to it	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
7	Strong Project Manager-Project manager has great technical knowledge	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
8*	Strong Project Manager-Project manager chooses the technology and makes major component choices	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
9*	Introduction of a 'Strong Project Manager' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	

***shortened description, see Appendix B 2 ** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 17: Questionnaire variable sheet (Part 1)

ID	Variable label	Value	Value label	Measure-ment level
10*	Benefit of introducing a 'Strong Project Manager' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
11	Teams-Development teams are made up by all involved functions, from marketing, to design, engineering, and production	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
12	Teams-Development teams remain throughout the entire development project	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
13	Teams-Team members are integrated to work alongside in the development team	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
14	Teams-Team members have deep reaching technical knowledge	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
15	Introduction of 'Teams' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
16	Benefit of introducing 'Teams' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 18: Questionnaire variable sheet (Part 2)

ID	Variable label	Value	Value label	Measure-ment level
17*	Concurrent Engineering-All involved functions are integrated into the concept definition phase of the development project	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
18*	Concurrent Engineering-There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
19*	Concurrent Engineering-There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
20*	Concurrent Engineering-Development and testing of production facilities is conducted in parallel to product development	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
21*	Introduction of 'Concurrent Engineering' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
22*	Benefit of introducing 'Concurrent Engineering' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
23*	Supplier Relationships and Integration-Parts are evaluated according to their criticality before making outsourcing decisions	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 19: Questionnaire variable sheet (Part 3)

ID	Variable label	Value	Value label	Measure-ment level
24*	Supplier Relationships and Integration-A small number of high-capability suppliers are used for critical parts	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
25*	Supplier Relationships and Integration-Critical suppliers are integrated in the concept definition phase	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
26*	Supplier Relationships and Integration-Suppliers are mentored to improve their performance	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
27*	Introduction of 'Supplier Relationships and Integration' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
28*	Benefit of introducing 'Supplier Relationships and Integration' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
29*	Set-based Design-A large number of possible solutions for a design problem is considered early in the process	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
30*	Set-based Design-Alternative solutions for a design problem are developed and tested simultaneously	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 20: Questionnaire variable sheet (Part 4)

ID	Variable label	Value	Value label	Measure-ment level
31*	Set-based Design-Decision are delayed until objective data allow the elimination of competing design solutions	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
32*	Set-based Design-A concept for a design solution is not revised once it has been selected	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
33*	Introduction of 'Set-based Design' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
34*	Benefit of introducing 'Set-based Design' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
35	Communication and Knowledge Transfer-Information is passed on before it is compiled (e.g. in hand-over reports)	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
36	Communication and Knowledge Transfer-Information is discussed in a dialogue-mode	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
37	Communication and Knowledge Transfer-Preliminary information is shared	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 21: Questionnaire variable sheet (Part 5)

ID	Variable label	Value	Value label	Measure-ment level
38*	Communication and Know ledge Transfer-There are methods and devices to collect information on successful procedures, tools, and designs across projects	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
39*	Communication and Know ledge Transfer-Best practices and lessons learned from previous projects are review ed	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
40*	Communication and Know ledge Transfer-Documented know ledge is continuously updated by the engineers	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
41*	Introduction of 'Communication and Know ledge Transfer' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somew hat difficult	
		4	Neutral	
		5	Somew hat easy	
		6	Easy	
		7	Very easy	
42*	Benefit of introducing 'Communication and Know ledge Transfer' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somew hat low	
		4	Average	
		5	Somew hat high	
		6	High	
		7	Very high	
43	Process Management-Repetitive routine tasks are standardised	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
44	Process Management-Existing standards are continuously challenged	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 22: Questionnaire variable sheet (Part 6)

ID	Variable label	Value	Value label	Measure-ment level
45	Process Management-Human, technical, and financial resources are appropriately allocated across development projects	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
46	Process Management-Development projects are staggered	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
47	Process Management-Development project schedules are adhered to	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
48	Introduction of 'Process Management' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
49	Benefit of introducing 'Process Management' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
50*	Product Variety Management-There are clear goals for the use of off-the-shelf components within a product	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
51*	Product Variety Management-There are clear goals for the reuse of product parts among different modules, products and product families	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 23: Questionnaire variable sheet (Part 7)

ID	Variable label	Value	Value label	Measure-ment level
52*	Product Variety Management-There are modular components w ith standardised interfaces	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
53*	Product Variety Management-There are common product platforms encompassing several product lines	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
54*	Introduction of 'Product Variety Management' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somew hat difficult	
		4	Neutral	
		5	Somew hat easy	
		6	Easy	
		7	Very easy	
55*	Benefit of introducing 'Product Variety Management' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somew hat low	
		4	Average	
		5	Somew hat high	
		6	High	
		7	Very high	
56	Continuous Improvement-Management encourages continuous and sustained improvement efforts	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
57	Continuous Improvement-Problems can be freely admitted	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	
58	Continuous Improvement-There is freedom to experiment w ith new approaches	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Alw ays	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 24: Questionnaire variable sheet (Part 8)

ID	Variable label	Value	Value label	Measure-ment level
59	Continuous Improvement-Improvement efforts are encouraged on all levels	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
60	Continuous Improvement-Ideal situations are defined to provide guidance for continuous improvement efforts	-1	Missing	Ordinal
		1	Never	
		2	Rarely	
		3	Sometimes	
		4	Often	
		5	Always	
61	Introduction of 'Continuous Improvement' is	-1	Missing	Ordinal
		1	Very difficult	
		2	Difficult	
		3	Somewhat difficult	
		4	Neutral	
		5	Somewhat easy	
		6	Easy	
		7	Very easy	
62	Benefit of introducing 'Continuous Improvement' is	-1	Missing	Ordinal
		1	Very low	
		2	Low	
		3	Somewhat low	
		4	Average	
		5	Somewhat high	
		6	High	
		7	Very high	
63	Strong Project Manager-Teams	0	No influence (missing)	Nominal
		1	Influence	
64	Strong Project Manager-Concurrent Engineering	0	No influence (missing)	Nominal
		1	Influence	
65	Strong Project Manager-Supplier Relationships and Integration	0	No influence (missing)	Nominal
		1	Influence	
66	Strong Project Manager-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
67	Strong Project Manager-Communication and Knowledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
68	Strong Project Manager-Process Management	0	No influence (missing)	Nominal
		1	Influence	
69	Strong Project Manager-Product Variety Management	0	No influence (missing)	Nominal
		1	Influence	
70	Strong Project Manager-Continuous Improvement	0	No influence (missing)	Nominal
		1	Influence	
71	Teams-Strong Project Manager	0	No influence (missing)	Nominal
		1	Influence	
72	Teams-Concurrent Engineering	0	No influence (missing)	Nominal
		1	Influence	
73	Teams-Supplier Relationships and Integration	0	No influence (missing)	Nominal
		1	Influence	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 25: Questionnaire variable sheet (Part 9)

ID	Variable label	Value	Value label	Measure-ment level
74	Teams-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
75	Teams-Communication and Know ledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
76	Teams-Process Management	0	No influence (missing)	Nominal
		1	Influence	
77	Teams-Product Variety Management	0	No influence (missing)	Nominal
		1	Influence	
78	Teams-Continuous Improvement	0	No influence (missing)	Nominal
		1	Influence	
79	Concurrent Engineering-Strong Project Manager	0	No influence (missing)	Nominal
		1	Influence	
80	Concurrent Engineering-Teams	0	No influence (missing)	Nominal
		1	Influence	
81	Concurrent Engineering-Supplier Relationships and Integration	0	No influence (missing)	Nominal
		1	Influence	
82	Concurrent Engineering-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
83	Concurrent Engineering-Communication and Know ledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
84	Concurrent Engineering-Process Management	0	No influence (missing)	Nominal
		1	Influence	
85	Concurrent Engineering-Product Variety Management	0	No influence (missing)	Nominal
		1	Influence	
86	Concurrent Engineering-Continuous Improvement	0	No influence (missing)	Nominal
		1	Influence	
87	Supplier Relationships-Strong Project Manager	0	No influence (missing)	Nominal
		1	Influence	
88	Supplier Relationships-Teams	0	No influence (missing)	Nominal
		1	Influence	
89	Supplier Relationships-Concurrent Engineering	0	No influence (missing)	Nominal
		1	Influence	
90	Supplier Relationships-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
91	Supplier Relationships-Communication and Know ledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
92	Supplier Relationships-Process Management	0	No influence (missing)	Nominal
		1	Influence	
93	Supplier Relationships-Product Variety Management	0	No influence (missing)	Nominal
		1	Influence	
94	Supplier Relationships-Continuous Improvement	0	No influence (missing)	Nominal
		1	Influence	
95	Set-based Design-Strong Project Manager	0	No influence (missing)	Nominal
		1	Influence	
96	Set-based Design-Teams	0	No influence (missing)	Nominal
		1	Influence	
97	Set-based Design-Concurrent Engineering	0	No influence (missing)	Nominal
		1	Influence	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 26: Questionnaire variable sheet (Part 10)

ID	Variable label	Value	Value label	Measure-ment level
98	Set-based Design-Supplier Relationships and Integration	0 1	No influence (missing) Influence	Nominal
99	Set-based Design-Communication and Know ledge Transfer	0 1	No influence (missing) Influence	Nominal
100	Set-based Design-Process Management	0 1	No influence (missing) Influence	Nominal
101	Set-based Design-Product Variety Management	0 1	No influence (missing) Influence	Nominal
102	Set-based Design-Continuous Improvement	0 1	No influence (missing) Influence	Nominal
103	Communication and Know ledge Transfer-Strong Project Manager	0 1	No influence (missing) Influence	Nominal
104	Communication and Know ledge Transfer-Teams	0 1	No influence (missing) Influence	Nominal
105	Communication and Know ledge Transfer-Concurrent Engineering	0 1	No influence (missing) Influence	Nominal
106	Communication and Know ledge Transfer-Supplier Relationships and Integration	0 1	No influence (missing) Influence	Nominal
107	Communication and Know ledge Transfer-Set-based Design	0 1	No influence (missing) Influence	Nominal
108	Communication and Know ledge Transfer-Process Management	0 1	No influence (missing) Influence	Nominal
109	Communication and Know ledge Transfer-Product Variety Management	0 1	No influence (missing) Influence	Nominal
110	Communication and Know ledge Transfer-Continuous Improvement	0 1	No influence (missing) Influence	Nominal
111	Process Management-Strong Project Manager	0 1	No influence (missing) Influence	Nominal
112	Process Management-Teams	0 1	No influence (missing) Influence	Nominal
113	Process Management-Concurrent Engineering	0 1	No influence (missing) Influence	Nominal
114	Process Management-Supplier Relationships and Integration	0 1	No influence (missing) Influence	Nominal
115	Process Management-Set-based Design	0 1	No influence (missing) Influence	Nominal
116	Process Management-Communication and Know ledge Transfer	0 1	No influence (missing) Influence	Nominal
117	Process Management-Product Variety	0 1	No influence (missing) Influence	Nominal
118	Process Management-Continuous Improvement	0 1	No influence (missing) Influence	Nominal
119	Product Variety Management-Strong Project	0 1	No influence (missing) Influence	Nominal
120	Product Variety Management-Teams	0 1	No influence (missing) Influence	Nominal
121	Product Variety Management-Concurrent	0 1	No influence (missing) Influence	Nominal
122	Product Variety Management-Supplier Relationships and Integration	0 1	No influence (missing) Influence	Nominal

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 27: Questionnaire variable sheet (Part 11)

ID	Variable label	Value	Value label	Measure-ment level
123	Product Variety Management-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
124	Product Variety Management-Communication and Know ledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
125	Product Variety Management-Process	0	No influence (missing)	Nominal
		1	Influence	
126	Product Variety Management-Continuous	0	No influence (missing)	Nominal
		1	Influence	
127	Continuous Improvement-Strong Project Manager	0	No influence (missing)	Nominal
		1	Influence	
128	Continuous Improvement-Teams	0	No influence (missing)	Nominal
		1	Influence	
129	Continuous Improvement-Concurrent Engineering	0	No influence (missing)	Nominal
		1	Influence	
130	Continuous Improvement-Supplier Relationships and Integration	0	No influence (missing)	Nominal
		1	Influence	
131	Continuous Improvement-Set-based Design	0	No influence (missing)	Nominal
		1	Influence	
132	Continuous Improvement-Communication and Know ledge Transfer	0	No influence (missing)	Nominal
		1	Influence	
133	Continuous Improvement-Process Management	0	No influence (missing)	Nominal
		1	Influence	
134	Continuous Improvement-Product Management	0	No influence (missing)	Nominal
		1	Influence	
135**	Implementation order-Strong Project Manager	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
136**	Implementation order-Teams	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 28: Questionnaire variable sheet (Part 12)

ID	Variable label	Value	Value label	Measure-ment level
137**	Implementation order-Concurrent Engineering	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
138**	Implementation order-Supplier Relationships and Integration	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
139**	Implementation order-Set-based Design	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
140**	Implementation order-Communication and Knowledge Transfer	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
141**	Implementation order-Process Management	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 29: Questionnaire variable sheet (Part 13)

ID	Variable label	Value	Value label	Measure-ment level
142**	Implementation order-Product Variety Management	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
143**	Implementation order-Continuous Improvement	-1	Not yet implemented (missing)	Ordinal
		1	1st implemented LPD element	
		2	2nd implemented LPD element	
		3	3rd implemented LPD element	
		4	4th implemented LPD element	
		5	5th implemented LPD element	
		6	6th implemented LPD element	
		7	7th implemented LPD element	
		8	8th implemented LPD element	
		9	9th implemented LPD element	
144**	Implementation problems-Teams	-	*Text input (String variable type)*	Nominal
145**	Implementation problems-Concurrent Engineering	-	*Text input (String variable type)*	Nominal
146**	Implementation problems-Supplier Relationships and Integration	-	*Text input (String variable type)*	Nominal
147**	Implementation problems-Set-based Design	-	*Text input (String variable type)*	Nominal
148**	Implementation problems-Communication and Know ledge Transfer	-	*Text input (String variable type)*	Nominal
149**	Implementation problems-Process Management	-	*Text input (String variable type)*	Nominal
150**	Implementation problems-Product Variety	-	*Text input (String variable type)*	Nominal
151**	Implementation problems-Continuous	-	*Text input (String variable type)*	Nominal
152**	Implementation problems-Strong Project Manager	-	*Text input (String variable type)*	Nominal
153**	In w hich country is your product development division is located?	-	*Text input (String variable type)*	Nominal
154*	In w hich industrial sector does your company mainly operate?	-1	Missing	Ordinal
		1	Automotive	
		2	Aerospace	
		3	Chemicals	
		4	Machinery, electrical, and transport	
		5	Mining and quarrying	
		6	Other	
155**	How many employees does your company	-1	Missing	Scale
156*	What position do you hold in your company?	-1	Missing	Nominal
		1	Chief innovation manager	
		2	Chief product development officer	
		3	Chief engineer (company level)	
		4	Chief engineer (department level)	
		5	Product development engineer	
		6	Other	

** Hoppmann (2009) * adapted from Hoppmann (2009) (different measurement scale)

Appendix B 30: Questionnaire variable sheet (Part 14)

Appendix C: Raw Data Analysis

Scale	Cronbach α	Characteristic	Corrected Item - Total Correlation
Strong Project Manager	0.798	Project manager leads the product development project from concept to market	0.481
		Project manager defines the product concept and advocates the customer value	0.671
		Project manager sets the project time frame and controls adherence to it	0.695
		Project manager has great technical know ledge	0.443
		Project manager chooses the technology and makes major component choices	0.628
Teams	0.870	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	0.847
		Development teams remain throughout the entire development project	0.812
		Team members are integrated to w ork alongside in the development team	0.693
		Team members have deep reaching technical know ledge	0.574
Concurrent Engineering	0.931	All involved functions are integrated into the concept definition phase of the development project	0.841
		There are frequent review meetings w ith development, manufacturing, quality assurance, and purchasing	0.878
		There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	0.843
		Development and testing of production facilities is conducted in parallel to product development	0.802
Supplier Relationship and Integration	0.853	Parts are evaluated according to their criticality before making outsourcing decisions	0.655
		A small number of high-capability suppliers are used for critical parts	0.651
		Critical suppliers are integrated in the concept definition phase	0.695
		Suppliers are mentored to improve their performance	0.789
Set-based Design	0.843	A large number of possible solutions for a design problem is considered early in the process	0.686
		Alternative solutions for a design problem are developed and tested simultaneously	0.740
		Decision are delayed until objective data allow the elimination of competing design solutions	0.510
		A concept for a design solution is not revised once it has been selected	0.788
Communication and Know ledge Transfer	0.743	Information is passed on before it is compiled (e.g. in hand-over reports)	0.462
		Information is discussed in a dialogue-mode	0.447
		Preliminary information is shared	0.544
		There are methods and devices to collect information on successful procedures, tools, and designs across projects	0.554
		Best practices and lessons learned from previous projects are review ed	0.492
		Documented know ledge is continuously updated by the engineers	0.386
Process Management	0.92	Repetitive routine tasks are standardised	0.828
		Existing standards are continuously challenged	0.745
		Human, technical, and financial resources are appropriately allocated across development projects	0.772
		Development projects are staggered	0.877
		Development project schedules are adhered to	0.771
Product Variety Management	0.953	There are clear goals for the use of off-the-shelf components w ithin a product	0.882
		There are clear goals for the reuse of product parts among different modules, products and product families	0.91
		There are modular components w ith standardised interfaces	0.897
		There are common product platforms encompassing several product lines	0.903
Continuous Improvement	0.948	Management encourages continuous and sustained improvement efforts	0.846
		Problems can be freely admitted	0.837
		There is freedom to experiment w ith new approaches	0.865
		Improvement efforts are encouraged on all levels	0.893
		Ideal situations are defined to provide guidance for continuous improvement efforts	0.844

Appendix C 1: Reliability test results for LPD elements

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Strong Project Manager / Concurrent Engineering	Equal variances assumed	16.797	.000	.024	414	.981	.00240	.10207	-.19824	.20305
	Equal variances not assumed			.024	390.862	.981	.00240	.10207	-.19828	.20309
Concurrent Engineering / Teams	Equal variances assumed	9.204	.003	.368	414	.713	.03846	.10452	-.16700	.24393
	Equal variances not assumed			.368	400.202	.713	.03846	.10452	-.16702	.24395
Teams / Continuous Improvement	Equal variances assumed	.158	.692	.107	414	.915	.01010	.09422	-.17512	.19531
	Equal variances not assumed			.107	413.998	.915	.01010	.09422	-.17512	.19531
Continuous Improvement / Product Variety Management	Equal variances assumed	32.514	.000	.871	414	.384	.09688	.11127	-.12184	.31559
	Equal variances not assumed			.871	383.031	.384	.09688	.11127	-.12189	.31564
Product Variety Management / Supplier Relationship and Integration	Equal variances assumed	29.894	.000	.837	414	.403	.09375	.11206	-.12653	.31403
	Equal variances not assumed			.837	386.613	.403	.09375	.11206	-.12658	.31408
Supplier Relationship and Integration / Process Management	Equal variances assumed	1.618	.204	.591	414	.555	.05457	.09227	-.12680	.23594
	Equal variances not assumed			.591	411.200	.555	.05457	.09227	-.12680	.23594
Process Management / Communication and Knowledge Transfer	Equal variances assumed	13.538	.000	1.924	414	.055	.15256	.07930	-.00331	.30844
	Equal variances not assumed			1.924	391.067	.055	.15256	.07930	-.00334	.30846
Communication and Knowledge Transfer / Set-based Design	Equal variances assumed	9.392	.002	2.436	414	.015	.19071	.07830	.03679	.34462
	Equal variances not assumed			2.436	394.424	.015	.19071	.07830	.03677	.34464

Appendix C 2: Independent t-test results for average use of LPD elements between neighbouring ranks

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Teams / Concurrent Engineering	Equal variances assumed	1.477	.225	1.958	414	.051	.24519	.12522	-.00096	.49134
	Equal variances not assumed			1.958	413.084	.051	.24519	.12522	-.00096	.49134
Concurrent Engineering / Continuous Improvement	Equal variances assumed	7.098	.008	1.650	414	.100	.22596	.13693	-.04320	.49512
	Equal variances not assumed			1.650	397.603	.100	.22596	.13693	-.04323	.49516
Continuous Improvement / Supplier Relationship and Integration	Equal variances assumed	2.890	.090	3.605	414	.000	.50000	.13869	.22737	.77263
	Equal variances not assumed			3.605	402.015	.000	.50000	.13869	.22734	.77266
Supplier Relationship and Integration / Process Managament	Equal variances assumed	0.154	.695	.915	414	.360	.12019	.13129	-.13788	.37827
	Equal variances not assumed			.915	411.580	.360	.12019	.13129	-.13789	.37827
Process Managament / Strong Project Manager	Equal variances assumed	0.820	.366	1.708	414	.088	.22596	.13228	-.03407	.48599
	Equal variances not assumed			1.708	412.489	.088	.22596	.13228	-.03407	.48600
Strong Project Manager / Set-based Design	Equal variances assumed	1.816	.179	.547	414	.584	.06731	.12295	-.17439	.30900
	Equal variances not assumed			.547	410.858	.584	.06731	.12295	-.17439	.30901
Set-based Design / Communication and Knowledge Transfer	Equal variances assumed	1.851	.174	1.602	414	.110	.19231	.12007	-.04371	.42832
	Equal variances not assumed			1.602	413.236	.110	.19231	.12007	-.04371	.42832
Communication and Knowledge Transfer / Product Variety Management	Equal variances assumed	0.612	.434	0.122	414	.903	.01442	.11856	-.21863	.24748
	Equal variances not assumed			0.122	412.000	.903	.01442	.11856	-.21863	.24748

Appendix C 3: Independent t-test results for perceived ease of implementation of LPD elements between neighbouring ranks

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Teams / Concurrent Engineering	Equal variances assumed	1.459	.228	.375	414	.708	.04327	.11539	-.18356	.27010
	Equal variances not assumed			.375	409.227	.708	.04327	.11539	-.18357	.27010
Concurrent Engineering / Continuous Improvement	Equal variances assumed	0.544	.461	1.850	414	.065	.21154	.11432	-.01319	.43626
	Equal variances not assumed			1.850	407.240	.065	.21154	.11432	-.01320	.43627
Continuous Improvement / Strong Project Manager	Equal variances assumed	1.304	.254	1.043	414	.298	.11538	.11067	-.10217	.33294
	Equal variances not assumed			1.043	411.955	.298	.11538	.11067	-.10217	.33294
Strong Project Manager / Product Variety Management	Equal variances assumed	2.252	.134	.077	414	.939	.00962	.12464	-.23539	.25462
	Equal variances not assumed			.077	404.164	.939	.00962	.12464	-.23541	.25464
Product Variety Management / Supplier Relationship and Integration	Equal variances assumed	0.807	.369	.301	414	.764	.03846	.12789	-.21293	.28986
	Equal variances not assumed			.301	410.063	.764	.03846	.12789	-.21294	.28986
Supplier Relationship and Integration / Process Managament	Equal variances assumed	0.316	.575	.982	414	.327	.11538	.11751	-.11560	.34637
	Equal variances not assumed			.982	412.070	.327	.11538	.11751	-.11561	.34638
Process Managament / Set-based Design	Equal variances assumed	0.616	.433	1.898	414	.058	.22596	.11907	-.00810	.46002
	Equal variances not assumed			1.898	410.471	.058	.22596	.11907	-.00810	.46003
Set-based Design / Communication and Knowledge Transfer	Equal variances assumed	0.498	.481	0.330	414	.742	.04327	.13121	-.21466	.30120
	Equal variances not assumed			0.330	409.888	.742	.04327	.13121	-.21466	.30120

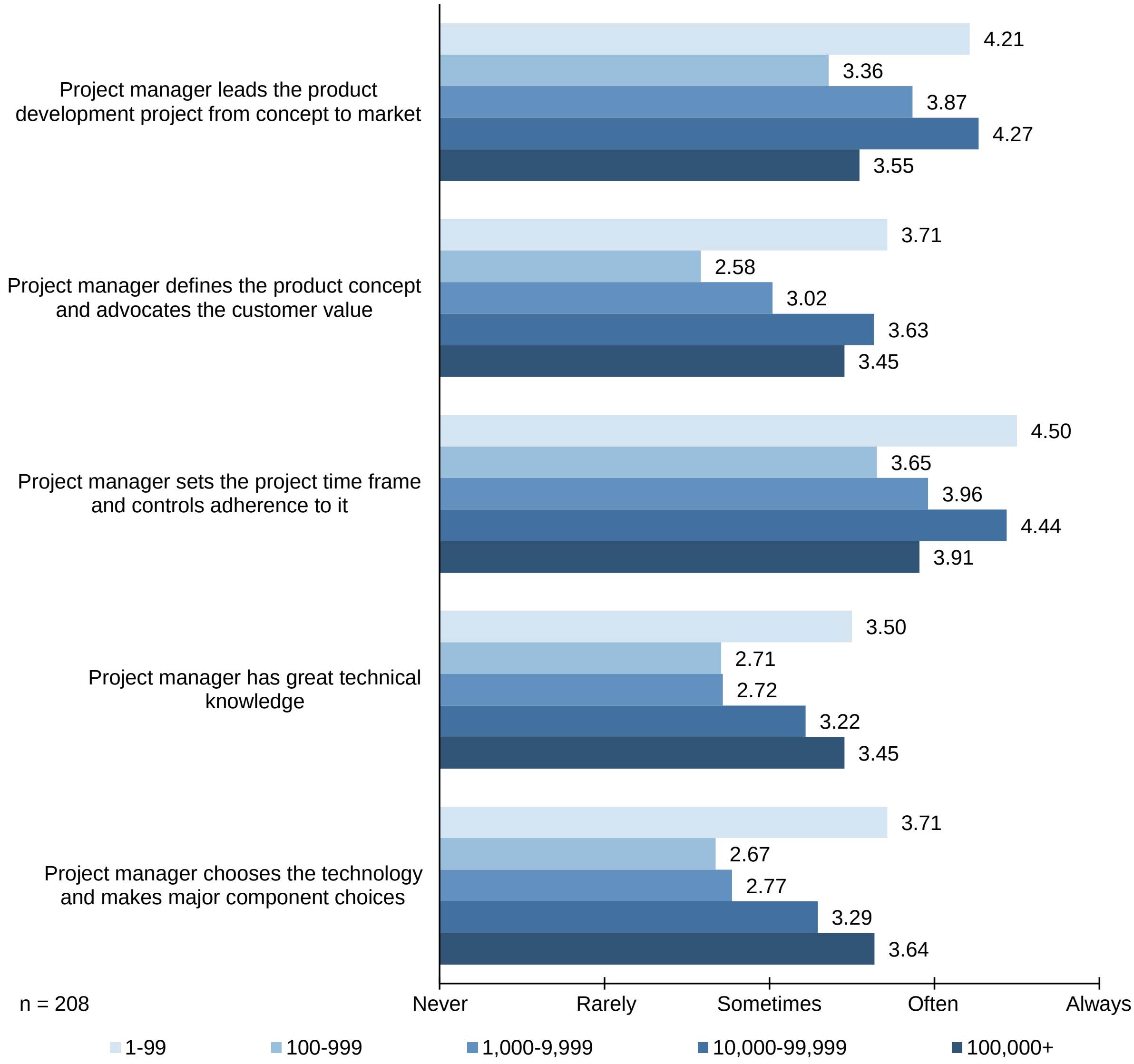
Appendix C 4: Independent t-test results for perceived benefit of implementation of LPD elements between neighbouring ranks

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference	
									Lower	Upper
Teams / Strong Project Manager	Equal variances assumed	0.089	.766	-1.220	230	.224	-.09534	.07817	-.24935	.05868
	Equal variances not assumed			-1.219	229.252	.224	-.09534	.07818	-.24938	.05870
Strong Project Manager / Concurrent Engineering	Equal variances assumed	26.783	.000	-7.296	230	.000	-.73607	.10089	-.93485	-.53730
	Equal variances not assumed			-7.219	190.457	.000	-.73607	.10196	-.93719	-.53496
Concurrent Engineering / Continuous Improvement	Equal variances assumed	21.190	.000	-9.774	230	.000	-1.56823	.16045	-1.88436	-1.25210
	Equal variances not assumed			-9.668	188.702	.000	-1.56823	.16221	-1.88820	-1.24826
Continuous Improvement / Product Variety Management	Equal variances assumed	1.227	.269	1.392	230	.165	.26742	.19208	-.11104	.64588
	Equal variances not assumed			1.397	228.660	.164	.26742	.19144	-.10980	.64464
Product Variety Management / Process Managament	Equal variances assumed	2.972	.086	-7.710	230	.000	-1.60586	.20829	-2.01626	-1.19546
	Equal variances not assumed			-7.671	216.829	.000	-1.60586	.20935	-2.01849	-1.19323
Process Managament / Set-based Design	Equal variances assumed	0.744	.389	3.018	230	.003	.71741	.23773	.24899	1.18582
	Equal variances not assumed			3.025	229.536	.003	.71741	.23714	.25016	1.18465
Set-based Design / Supplier Relationship and Integration	Equal variances assumed	10.897	.001	-4.836	230	.000	-1.03354	.21373	-1.45466	-.61242
	Equal variances not assumed			-4.862	224.510	.000	-1.03354	.21258	-1.45245	-.61463
Supplier Relationship and Integration / Communication and Knowledge Transfer	Equal variances assumed	0.316	.575	-5.237	230	.000	-1.09720	.20950	-1.50998	-.68441
	Equal variances not assumed			-5.236	229.241	.000	-1.09720	.20953	-1.51005	-.68435

Appendix C 5: Independent t-test results for implementation order of LPD elements between neighbouring ranks

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval Lower	Upper
Strong Project Manager	Equal variances assumed	2.320	.129	-.917	187	.360	-.12147	.13247	-.38280	.13986
	Equal variances not assumed			-.920	186.083	.359	-.12147	.13204	-.38195	.13901
Teams	Equal variances assumed	0.443	.506	1.568	187	.119	.22168	.14139	-.05725	.50061
	Equal variances not assumed			1.566	185.213	.119	.22168	.14156	-.05761	.50096
Concurrent Engineering	Equal variances assumed	.863	.354	1.738	187	.084	.28958	.16662	-.03911	.61828
	Equal variances not assumed			1.735	184.250	.084	.28958	.16692	-.03974	.61891
Supplier Relationship and Integration	Equal variances assumed	0.625	.430	-.052	187	.959	-.00748	.14376	-.29108	.27612
	Equal variances not assumed			-.052	184.986	.959	-.00748	.14396	-.29149	.27653
Set-based Design	Equal variances assumed	0.499	.481	-.245	187	.807	-.03168	.12936	-.28688	.22352
	Equal variances not assumed			-.245	186.938	.807	-.03168	.12924	-.28665	.22328
Communication and Know ledge Transfer	Equal variances assumed	2.539	.113	.585	187	.559	.05864	.10029	-.13921	.25650
	Equal variances not assumed			.583	180.441	.561	.05864	.10066	-.13999	.25727
Process Management	Equal variances assumed	0.493	.484	0.398	187	.691	.05166	.12991	-.20461	.30793
	Equal variances not assumed			0.398	187.000	.691	.05166	.12972	-.20424	.30756
Product Variety Management	Equal variances assumed	0.000	.992	0.804	187	.422	.14932	.18573	-.21708	.51571
	Equal variances not assumed			0.804	186.398	.422	.14932	.18575	-.21712	.51575
Continuous Improvement	Equal variances assumed	1.970	.162	0.994	187	.322	.13563	.13651	-.13366	.40493
	Equal variances not assumed			0.990	180.520	.324	.13563	.13700	-.13470	.40597

Appendix C 6: Independent t-test results for the average use of LPD elements in the US and Germany



Appendix C 7: Use of 'strong project manager' characteristics by company size

Strong project manager characteristic	Levene statistic	df1	df2	Sig.
Project manager leads the product development project from concept to market	3.439	4	203	.010
Project manager defines the product concept and advocates the customer value	1.161	4	203	.329
Project manager sets the project time frame and controls adherence to it	3.667	4	203	.007
Project manager has great technical knowledge	1.647	4	203	.164
Project manager chooses the technology and makes major component choices	1.445	4	203	.221

Appendix C 8: Results of Levene's test for the average use of 'strong project manager' characteristics for different company sizes

Strong project manager characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Project manager leads the product development project from concept to market	-	-	.001**	.001**
Project manager defines the product concept and advocates the customer value	6.417	.000**	-	-
Project manager sets the project time frame and controls adherence to it	-	-	.000**	.000**
Project manager has great technical knowledge	3.004	.019*	-	-
Project manager chooses the technology and makes major component choices	4.578	.001**	-	-

* p < 0.05 ** p < 0.01

Appendix C 9: Results of significance tests for the average use of 'strong project manager' characteristics for different company sizes

	Project manager leads the product development project from concept to market	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)
1	1-99 (Ø = 4.21)		.145	.865	1.000	.676
2	100-999 (Ø = 3.36)			.135	.000**	.991
3	1,000-9,999 (Ø = 3.87)				.326	.937
4	10,000-99,999 (Ø = 4.27)					.440
5	100,000+ (Ø = 3.55)					

Games-Howell

* p < 0.05 ** p < 0.01

	Project manager defines the product concept and advocates the customer value	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)
1	1-99 (Ø = 3.71)		.009**	.436	1.000	1.000
2	100-999 (Ø = 2.58)	.022*		.382	.000**	.165
3	1,000-9,999 (Ø = 3.02)	.507	.393		.183	.954
4	10,000-99,999 (Ø = 3.63)	1.000	.000**	.186		1.000
5	100,000+ (Ø = 3.45)	1.000	.281	.970	1.000	

Gabriel

* p < 0.05 ** p < 0.01

Hochberg's GT2

	Project manager sets the project time frame and controls adherence to it	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)
1	1-99 (Ø = 4.50)		.012*	.213	.999	.586
2	100-999 (Ø = 3.65)			.450	.000**	.951
3	1,000-9,999 (Ø = 3.96)				.061	1.000
4	10,000-99,999 (Ø = 4.44)					.597
5	100,000+ (Ø = 3.91)					

Games-Howell

* p < 0.05 ** p < 0.01

Appendix C 10: Post hoc test results for the average use of 'strong project manager' characteristics for different company sizes (Part 1)

	Project manager has great technical know ledge	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 3.50)		.132	.222	.997	1.000	Gabriel
2	100-999 (Ø = 2.71)	.215		1.000	.213	.288	
3	1,000-9,999 (Ø = 2.72)	.281	1.000		.380	.406	
4	10,000-99,999 (Ø = 3.22)	.998	.233	.382		1.000	
5	100,000+ (Ø = 3.45)	1.000	.430	.500	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Project manager chooses the technology and makes major component choices	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 3.71)		.013*	.067	.936	1.000	Gabriel
2	100-999 (Ø = 2.67)	.030*		1.000	.059	.059	
3	1,000-9,999 (Ø = 2.77)	.096	1.000		.326	.198	
4	10,000-99,999 (Ø = 3.29)	.948	.068	.329		.991	
5	100,000+ (Ø = 3.64)	1.000	.124	.274	.994		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 11: Post hoc test results for the average use of 'strong project manager' characteristics for different company sizes (Part 2)

Concurrent engineering characteristic	Levene statistic	df1	df2	Sig.
All involved functions are integrated into the concept definition phase of the development project	12.482	4	203	.000
There are frequent review meetings w ith development, manufacturing, quality assurance, and purchasing	11.390	4	203	.000
There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	7.445	4	203	.000
Development and testing of production facilities is conducted in parallel to product development	10.042	4	203	.000

Appendix C 12: Results of Levene's test for the average use of 'concurrent engineering' characteristics for different company sizes

Concurrent engineering characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brow n-Forsythe F
All involved functions are integrated into the concept definition phase of the development project	-	-	#	#
There are frequent review meetings w ith development, manufacturing, quality assurance, and purchasing	-	-	.000**	.000**
There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	-	-	.000**	.000**
Development and testing of production facilities is conducted in parallel to product development	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Test couldn't be performed because at least one group has 0 variance

Appendix C 13: Results of significance tests for the average use of 'concurrent engineering' characteristics for different company sizes

	All involved functions are integrated into the concept definition phase of the development project	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.00)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 3.06)			.010*	.000**	.000**	
3	1,000-9,999 (Ø = 3.70)				.896	.000**	
4	10,000-99,999 (Ø = 3.88)					.001**	
5	100,000+ (Ø = 4.73)						

* $p < 0.05$ ** $p < 0.01$

	There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.29)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 3.40)			.000**	.004**	.000**	
3	1,000-9,999 (Ø = 4.17)				.879	.003**	
4	10,000-99,999 (Ø = 4.02)					.001**	
5	100,000+ (Ø = 4.82)						

* $p < 0.05$ ** $p < 0.01$

	There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.21)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.70)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.92)				.999	.326	
4	10,000-99,999 (Ø = 3.88)					.290	
5	100,000+ (Ø = 4.45)						

* $p < 0.05$ ** $p < 0.01$

	Development and testing of production facilities is conducted in parallel to product development	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.14)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.46)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.68)				.997	.048*	
4	10,000-99,999 (Ø = 3.61)					.034*	
5	100,000+ (Ø = 4.55)						

* $p < 0.05$ ** $p < 0.01$

Appendix C 14: Post hoc test results for the average use of 'concurrent engineering' characteristics for different company sizes

Element	Characteristic	#	1	2	3	4	5	6	7	8	9	10	11	12	13
Strong Project Manager	Project manager leads the product development project from concept to market	1	1	.527**	.797**	.027	.191**	.050	.084	.033	.123	.004	.036	.073	.120
	Project manager defines the product concept and advocates the customer value	2	.527**	1	.665**	.263**	.414**	.101	.119	.036	.159*	.021	.046	.014	.079
	Project manager sets the project time frame and controls adherence to it	3	.797**	.665**	1	.195**	.370**	.067	.081	.034	.130	-.021	.003	.008	.050
	Project manager has great technical knowledge	4	.027	.263**	.195**	1	.891**	.049	.091	.047	.106	-.004	.010	-.041	.015
	Project manager chooses the technology and makes major component choices	5	.191**	.414**	.370**	.891**	1	.042	.096	.018	.103	-.030	-.017	-.056	-.011
Teams	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	6	.050	.101	.067	.049	.042	1	.852**	.712**	.524**	.630**	.614**	.544**	.534**
	Development teams remain throughout the entire development project	7	.084	.119	.081	.091	.096	.852**	1	.623**	.567**	.549**	.517**	.458**	.456**
	Team members are integrated to work alongside in the development team	8	.033	.036	.034	.047	.018	.712**	.623**	1	.465**	.599**	.663**	.664**	.609**
	Teams-Team members have deep reaching technical knowledge	9	.123	.159*	.130	.106	.103	.524**	.567**	.465**	1	.272**	.268**	.329**	.264**
Concurrent Engineering	All involved functions are integrated into the concept definition phase of the development project	10	.004	.021	-.021	-.004	-.030	.630**	.549**	.599**	.272**	1	.824**	.750**	.758**
	There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	11	.036	.046	.003	.010	-.017	.614**	.517**	.663**	.268**	.824**	1	.748**	.831**
	There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	12	.073	.014	.008	-.041	-.056	.544**	.458**	.664**	.329**	.750**	.748**	1	.745**
	Development and testing of production facilities is conducted in parallel to product development	13	.120	.079	.050	.015	-.011	.534**	.456**	.609**	.264**	.758**	.831**	.745**	1
Supplier Relationship and Integration	Parts are evaluated according to their criticality before making outsourcing decisions	14	.091	.091	.071	.050	.059	.448**	.370**	.538**	.233**	.414**	.466**	.545**	.471*
	A small number of high-capability suppliers are used for critical parts	15	.050	.121	.081	.128	.114	.146*	.184**	.204**	.159*	.074	.137*	.158*	.114
	Critical suppliers are integrated in the concept definition phase	16	.167*	.140*	.153*	.096	.100	.448**	.374**	.439**	.231**	.457**	.444**	.438**	.429**
	Suppliers are mentored to improve their performance	17	.112	.178*	.167*	.084	.076	.394**	.336**	.365**	.204**	.326**	.371**	.312**	.303**
Set-based Design	A large number of possible solutions for a design problem is considered early in the process	18	.185**	.120	.091	-.099	-.057	.383**	.346**	.389**	.155*	.389**	.412**	.444**	.383**
	Alternative solutions for a design problem are developed and tested simultaneously	19	.111	.093	.043	.007	.042	.426**	.366**	.420**	.211**	.319**	.363**	.397**	.365**
	Decision are delayed until objective data allow the elimination of competing design solutions	20	.124	.103	.085	.034	.052	.111	.069	.089	.047	.116	.163*	.172*	.210**
	A concept for a design solution is not revised once it has been selected	21	.176*	.145*	.106	-.034	-.002	.427**	.327**	.373**	.183**	.393**	.422**	.485**	.401*

* p < 0.05   ** p < 0.01

Appendix C 15: Average use of LPD element characteristics correlations (Part 1)

			1	2	3	4	5	6	7	8	9	10	11	12	13
Communication and Knowledge Transfer	Information is passed on before it is compiled (e.g. in hand-over reports)	22	.219**	.210**	.195**	.078	.073	-.173*	-.102	-.165*	-.031	-.226**	-.245**	-.278**	-.069
	Information is discussed in a dialogue-mode	23	.159*	.074	.136	.061	.048	-.109	-.088	-.066	-.113	-.164*	-.115	-.227**	-.016
	Preliminary information is shared	24	.215**	.169*	.173*	.084	.078	-.126	-.083	-.098	-.037	-.158*	-.171*	-.203**	-.038
	There are methods and devices to collect information on successful procedures, tools, and designs across projects	25	.217**	.219**	.153*	.040	.065	.538**	.505**	.568**	.273**	.496**	.556**	.545**	.514**
	Best practices and lessons learned from previous projects are reviewed	26	.270**	.217**	.217**	.081	.118	.549**	.453**	.459**	.200**	.483**	.499**	.485**	.458**
	Documented knowledge is continuously updated by the engineers	27	.160*	.202**	.107	.143*	.151*	.470**	.450**	.474**	.283**	.368**	.450**	.503**	.394**
Process Management	Repetitive routine tasks are standardised	28	.133	.079	.086	.059	.064	.547**	.474**	.636**	.270**	.539**	.671**	.646**	.596**
	Existing standards are continuously challenged	29	.047	-.002	-.009	.102	.102	.380**	.373**	.457**	.203**	.390**	.468**	.448**	.408**
	Human, technical, and financial resources are appropriately allocated across development projects	30	.194**	.123	.104	.079	.094	.493**	.465**	.484**	.261**	.413**	.442**	.430**	.409**
	Development projects are staggered	31	.224**	.181**	.178*	.143*	.155*	.529**	.467**	.537**	.255**	.498**	.529**	.573**	.514**
	Development project schedules are adhered to	32	.218**	.175*	.157*	.118	.144*	.464**	.457**	.476**	.306**	.377**	.448**	.370**	.432**
Product Variety Management	There are clear goals for the use of off-the-shelf components within a product	33	.173*	.082	.123	.068	.048	.433**	.358**	.548**	.253**	.486**	.539**	.682**	.552**
	There are clear goals for the reuse of product parts among different modules, products and product families	34	.248**	.147*	.157*	.023	.036	.447**	.372**	.550**	.244**	.571**	.572**	.731**	.581**
	There are modular components with standardised interfaces	35	.189**	.103	.123	.070	.059	.444**	.383**	.536**	.223**	.530**	.538**	.654**	.494**
	There are common product platforms encompassing several product lines	36	.170*	.086	.096	.040	.043	.459**	.386**	.553**	.230**	.569**	.578**	.705**	.525**
Continuous Improvement	Management encourages continuous and sustained improvement efforts	37	.072	.124	.071	-.003	.020	.513**	.451**	.539**	.241**	.454**	.530**	.552**	.506**
	Problems can be freely admitted	38	.180**	.158*	.116	-.053	-.034	.468**	.451**	.410**	.227**	.403**	.467**	.442**	.496**
	There is freedom to experiment with new approaches	39	.127	.130	.117	.026	.031	.446**	.406**	.419**	.211**	.397**	.431**	.446**	.461**
	Improvement efforts are encouraged on all levels	40	.155*	.136	.125	-.108	-.058	.453**	.408**	.454**	.215**	.391**	.431**	.449**	.444**
	Ideal situations are defined to provide guidance for continuous improvement efforts	41	.195**	.152*	.151*	-.028	.019	.484**	.441**	.504**	.255**	.399**	.465**	.536**	.468**

* $p < 0.05$ ** $p < 0.01$

Appendix C 16: Average use of LPD element characteristics correlations (Part 2)

			14	15	16	17	18	19	20	21	22	23	24	25	26	27
Strong Project Manager	Project manager leads the product development project from concept to market	1	.091	.050	.167*	.112	.185**	.111	.124	.176*	.219**	.159*	.215**	.217**	.270**	.160*
	Project manager defines the product concept and advocates the customer value	2	.091	.121	.140*	.178*	.120	.093	.103	.145*	.210**	.074	.169*	.219**	.217**	.202**
	Project manager sets the project time frame and controls adherence to it	3	.071	.081	.153*	.167*	.091	.043	.085	.106	.195**	.136	.173*	.153*	.217**	.107
	Project manager has great technical knowledge	4	.050	.128	.096	.084	-.099	.007	.034	-.034	.078	.061	.084	.040	.081	.143*
	Project manager chooses the technology and makes major component choices	5	.059	.114	.100	.076	-.057	.042	.052	-.002	.073	.048	.078	.065	.118	.151*
Teams	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	6	.448**	.146*	.448**	.394**	.383**	.426**	.111	.427**	-.173*	-.109	-.126	.538**	.549**	.470**
	Development teams remain throughout the entire development project	7	.370**	.184**	.374**	.336**	.346**	.366**	.069	.327**	-.102	-.088	-.083	.505**	.453**	.450**
	Team members are integrated to work alongside in the development team	8	.538**	.204**	.439**	.365**	.389**	.420**	.089	.373**	-.165*	-.066	-.098	.568**	.459**	.474**
	Teams-Team members have deep reaching technical knowledge	9	.233**	.159*	.231**	.204**	.155*	.211**	.047	.183**	-.031	-.113	-.037	.273**	.200**	.283**
Concurrent Engineering	All involved functions are integrated into the concept definition phase of the development project	10	.414**	.074	.457**	.326**	.389**	.319**	.116	.393**	-.226**	-.164*	-.158*	.496**	.483**	.368**
	There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	11	.466**	.137*	.444**	.371**	.412**	.363**	.163*	.422**	-.245**	-.115	-.171*	.556**	.499**	.450**
	There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	12	.545**	.158*	.438**	.312**	.444**	.397**	.172*	.485**	-.278**	-.227**	-.203**	.545**	.485**	.503**
	Development and testing of production facilities is conducted in parallel to product development	13	.471**	.114	.429**	.303**	.383**	.365**	.210**	.401**	-.069	-.016	-.038	.514**	.458**	.394**
Supplier Relationship and Integration	Parts are evaluated according to their criticality before making outsourcing decisions	14	1	.512**	.601**	.582**	.426**	.477**	.214**	.462**	-.215**	-.135	-.128	.615**	.516**	.636**
	A small number of high-capability suppliers are used for critical parts	15	.512**	1	.482**	.704**	.137*	.289**	.150*	.216**	-.207**	-.171*	-.156*	.296**	.236**	.391**
	Critical suppliers are integrated in the concept definition phase	16	.601**	.482**	1	.690**	.403**	.351**	.220**	.440**	-.164*	-.178**	-.099	.557**	.634**	.580**
	Suppliers are mentored to improve their performance	17	.582**	.704**	.690**	1	.342**	.421**	.232**	.384**	-.178*	-.116	-.110	.468**	.524**	.547**
Set-based Design	A large number of possible solutions for a design problem is considered early in the process	18	.426**	.137*	.403**	.342**	1	.751**	.329**	.645**	-.117	-.069	-.024	.610**	.614**	.542**
	Alternative solutions for a design problem are developed and tested simultaneously	19	.477**	.289**	.351**	.421**	.751**	1	.409**	.667**	-.098	.025	.001	.584**	.546**	.551**
	Decision are delayed until objective data allow the elimination of competing design solutions	20	.214**	.150*	.220**	.232**	.329**	.409**	1	.619**	.072	.065	.067	.381**	.417**	.418**
	A concept for a design solution is not revised once it has been selected	21	.462**	.216**	.440**	.384**	.645**	.667**	.619**	1	-.085	-.067	-.043	.616**	.605**	.576**

* p < 0.05 ** p < 0.01

Appendix C 17: Average use of LPD element characteristics correlations (Part 3)

			14	15	16	17	18	19	20	21	22	23	24	25	26	27
Communication and Knowledge Transfer	Information is passed on before it is compiled (e.g. in hand-over reports)	22	-.215**	-.207**	-.164*	-.178*	-.117	-.098	.072	-.085	1	.753**	.902**	.040	.032	-.121
	Information is discussed in a dialogue-mode	23	-.135	-.171*	-.178**	-.116	-.069	.025	.065	-.067	.753**	1	.722**	.095	.059	-.055
	Preliminary information is shared	24	-.128	-.156*	-.099	-.110	-.024	.001	.067	-.043	.902**	.722**	1	.153*	.104	-.034
	There are methods and devices to collect information on successful procedures, tools, and designs across projects	25	.615**	.296**	.557**	.468**	.610**	.584**	.381**	.616**	.040	.095	.153*	1	.748**	.776**
	Best practices and lessons learned from previous projects are reviewed	26	.516**	.236**	.634**	.524**	.614**	.546**	.417**	.605**	.032	.059	.104	.748**	1	.708**
	Documented knowledge is continuously updated by the engineers	27	.636**	.391**	.580**	.547**	.542**	.551**	.418**	.576**	-.121	-.055	-.034	.776**	.708**	1
Process Management	Repetitive routine tasks are standardised	28	.672**	.274**	.541**	.440**	.447**	.462**	.283**	.454**	-.235**	-.172*	-.130	.650**	.563**	.587**
	Existing standards are continuously challenged	29	.444**	.160*	.378**	.265**	.304**	.326**	.196**	.243**	-.113	-.105	-.044	.476**	.413**	.540**
	Human, technical, and financial resources are appropriately allocated across development projects	30	.469**	.212**	.437**	.334**	.468**	.450**	.198**	.398**	-.004	-.030	.056	.567**	.473**	.511**
	Development projects are staggered	31	.583**	.222**	.513**	.409**	.452**	.423**	.272**	.461**	-.073	-.109	-.001	.613**	.565**	.552**
	Development project schedules are adhered to	32	.369**	.105	.383**	.261**	.406**	.333**	.213**	.368**	.107	.063	.173*	.583**	.520**	.447**
Product Variety Management	There are clear goals for the use of off-the-shelf components within a product	33	.623**	.243**	.525**	.349**	.477**	.423**	.255**	.514**	-.235**	-.194**	-.159*	.602**	.480**	.568**
	There are clear goals for the reuse of product parts among different modules, products and product families	34	.602**	.238**	.526**	.381**	.542**	.460**	.288**	.577**	-.220**	-.194**	-.134	.622**	.513**	.576**
	There are modular components with standardised interfaces	35	.634**	.292**	.508**	.400**	.465**	.427**	.243**	.545**	-.227**	-.222**	-.159*	.577**	.484**	.590**
	There are common product platforms encompassing several product lines	36	.642**	.306**	.529**	.407**	.483**	.484**	.243**	.571**	-.304**	-.272**	-.210**	.599**	.498**	.595**
Continuous Improvement	Management encourages continuous and sustained improvement efforts	37	.549**	.230**	.494**	.405**	.509**	.457**	.144*	.432**	-.188**	-.141*	-.113	.605**	.541**	.537**
	Problems can be freely admitted	38	.410**	.124	.390**	.363**	.414**	.341**	.200**	.374**	.062	.054	.109	.554**	.513**	.464**
	There is freedom to experiment with new approaches	39	.466**	.222**	.384**	.377**	.414**	.352**	.188**	.358**	-.037	-.028	.021	.556**	.453**	.448**
	Improvement efforts are encouraged on all levels	40	.429**	.109	.334**	.287**	.474**	.404**	.178*	.379**	-.056	-.028	-.001	.561**	.465**	.454**
	Ideal situations are defined to provide guidance for continuous improvement efforts	41	.570**	.208**	.480**	.383**	.464**	.420**	.245**	.443**	-.158*	-.136	-.138*	.601**	.561**	.588**

* p < 0.05 ** p < 0.01

Appendix C 18: Average use of LPD element characteristics correlations (Part 4)

			28	29	30	31	32	33	34	35	36	37	38	39	40	41
Strong Project Manager	Project manager leads the product development project from concept to market	1	.133	.047	.194**	.224**	.218**	.173*	.248**	.189**	.170*	.072	.180**	.127	.155*	.195**
	Project manager defines the product concept and advocates the customer value	2	.079	-.002	.123	.181**	.175*	.082	.147*	.103	.086	.124	.158*	.130	.136	.152*
	Project manager sets the project time frame and controls adherence to it	3	.086	-.009	.104	.178*	.157*	.123	.157*	.123	.096	.071	.116	.117	.125	.151*
	Project manager has great technical knowledge	4	.059	.102	.079	.143*	.118	.068	.023	.070	.040	-.003	-.053	.026	-.108	-.028
	Project manager chooses the technology and makes major component choices	5	.064	.102	.094	.155*	.144*	.048	.036	.059	.043	.020	-.034	.031	-.058	.019
Teams	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	6	.547**	.380**	.493**	.529**	.464**	.433**	.447**	.444**	.459**	.513**	.468**	.446**	.453**	.484**
	Development teams remain throughout the entire development project	7	.474**	.373**	.465**	.467**	.457**	.358**	.372**	.383**	.386**	.451**	.451**	.406**	.408**	.441**
	Team members are integrated to work alongside in the development team	8	.636**	.457**	.484**	.537**	.476**	.548**	.550**	.536**	.553**	.539**	.410**	.419**	.454**	.504**
	Teams-Team members have deep reaching technical knowledge	9	.270**	.203**	.261**	.255**	.306**	.253**	.244**	.223**	.230**	.241**	.227**	.211**	.215**	.255**
Concurrent Engineering	All involved functions are integrated into the concept definition phase of the development project	10	.539**	.390**	.413**	.498**	.377**	.486**	.571**	.530**	.569**	.454**	.403**	.397**	.391**	.399**
	There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	11	.671**	.468**	.442**	.529**	.448**	.539**	.572**	.538**	.578**	.530**	.467**	.431**	.431**	.465**
	There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	12	.646**	.448**	.430**	.573**	.370**	.682**	.731**	.654**	.705**	.552**	.442**	.446**	.449**	.536**
	Development and testing of production facilities is conducted in parallel to product development	13	.596**	.408**	.409**	.514**	.432**	.552**	.581**	.494**	.525**	.506**	.496**	.461**	.444**	.468**
Supplier Relationship and Integration	Parts are evaluated according to their criticality before making outsourcing decisions	14	.672**	.444**	.469**	.583**	.369**	.623**	.602**	.634**	.642**	.549**	.410**	.466**	.429**	.570**
	A small number of high-capability suppliers are used for critical parts	15	.274**	.160*	.212**	.222**	.105	.243**	.238**	.292**	.306**	.230**	.124	.222**	.109	.208**
	Critical suppliers are integrated in the concept definition phase	16	.541**	.378**	.437**	.513**	.383**	.525**	.526**	.508**	.529**	.494**	.390**	.384**	.334**	.480**
	Suppliers are mentored to improve their performance	17	.440**	.265**	.334**	.409**	.261**	.349**	.381**	.400**	.407**	.405**	.363**	.377**	.287**	.383**
Set-based Design	A large number of possible solutions for a design problem is considered early in the process	18	.447**	.304**	.468**	.452**	.406**	.477**	.542**	.465**	.483**	.509**	.414**	.414**	.474**	.464**
	Alternative solutions for a design problem are developed and tested simultaneously	19	.462**	.326**	.450**	.423**	.333**	.423**	.460**	.427**	.484**	.457**	.341**	.352**	.404**	.420**
	Decision are delayed until objective data allow the elimination of competing design solutions	20	.283**	.196**	.198**	.272**	.213**	.255**	.288**	.243**	.243**	.144*	.200**	.188**	.178*	.245**
	A concept for a design solution is not revised once it has been selected	21	.454**	.243**	.398**	.461**	.368**	.514**	.577**	.545**	.571**	.432**	.374**	.358**	.379**	.443**

* p < 0.05   ** p < 0.01

Appendix C 19: Average use of LPD element characteristics correlations (Part 5)

			28	29	30	31	32	33	34	35	36	37	38	39	40	41
Communication and Knowledge Transfer	Information is passed on before it is compiled (e.g. in hand-over reports)	22	-.235**	-.113	-.004	-.073	.107	-.235**	-.220**	-.227**	-.304**	-.188**	.062	-.037	-.056	-.158*
	Information is discussed in a dialogue-mode	23	-.172*	-.105	-.030	-.109	.063	-.194**	-.194**	-.222**	-.272**	-.141*	.054	-.028	-.028	-.136
	Preliminary information is shared	24	-.130	-.044	.056	-.001	.173*	-.159*	-.134	-.159*	-.210**	-.113	.109	.021	-.001	-.138*
	There are methods and devices to collect information on successful procedures, tools, and designs across projects	25	.650**	.476**	.567**	.613**	.583**	.602**	.622**	.577**	.599**	.605**	.554**	.556**	.561**	.601**
	Best practices and lessons learned from previous projects are reviewed	26	.563**	.413**	.473**	.565**	.520**	.480**	.513**	.484**	.498**	.541**	.513**	.453**	.465**	.561**
	Documented knowledge is continuously updated by the engineers	27	.587**	.540**	.511**	.552**	.447**	.568**	.576**	.590**	.595**	.537**	.464**	.448**	.454**	.588**
Process Management	Repetitive routine tasks are standardised	28	1	.739**	.667**	.815**	.677**	.646**	.624**	.605**	.636**	.572**	.453**	.469**	.458**	.576**
	Existing standards are continuously challenged	29	.739**	1	.624**	.684**	.602**	.405**	.382**	.432**	.447**	.405**	.285**	.281**	.312**	.415**
	Human, technical, and financial resources are appropriately allocated across development projects	30	.667**	.624**	1	.759**	.681**	.431**	.446**	.450**	.451**	.488**	.366**	.379**	.367**	.439**
	Development projects are staggered	31	.815**	.684**	.759**	1	.764**	.552**	.551**	.543**	.567**	.541**	.446**	.463**	.437**	.557**
	Development project schedules are adhered to	32	.677**	.602**	.681**	.764**	1	.409**	.420**	.401**	.402**	.465**	.435**	.404**	.414**	.446**
Product Variety Management	There are clear goals for the use of off-the-shelf components within a product	33	.646**	.405**	.431**	.552**	.409**	1	.880**	.816**	.820**	.535**	.417**	.458**	.459**	.561**
	There are clear goals for the reuse of product parts among different modules, products and product families	34	.624**	.382**	.446**	.551**	.420**	.880**	1	.846**	.853**	.528**	.426**	.439**	.471**	.553**
	There are modular components with standardised interfaces	35	.605**	.432**	.450**	.543**	.401**	.816**	.846**	1	.909**	.470**	.381**	.414**	.395**	.533**
	There are common product platforms encompassing several product lines	36	.636**	.447**	.451**	.567**	.402**	.820**	.853**	.909**	1	.524**	.357**	.413**	.422**	.528**
Continuous Improvement	Management encourages continuous and sustained improvement efforts	37	.572**	.405**	.488**	.541**	.465**	.535**	.528**	.470**	.524**	1	.714**	.760**	.823**	.815**
	Problems can be freely admitted	38	.453**	.285**	.366**	.446**	.435**	.417**	.426**	.381**	.357**	.714**	1	.819**	.803**	.741**
	There is freedom to experiment with new approaches	39	.469**	.281**	.379**	.463**	.404**	.458**	.439**	.414**	.413**	.760**	.819**	1	.827**	.755**
	Improvement efforts are encouraged on all levels	40	.458**	.312**	.367**	.437**	.414**	.459**	.471**	.395**	.422**	.823**	.803**	.827**	1	.791**
	Ideal situations are defined to provide guidance for continuous improvement efforts	41	.576**	.415**	.439**	.557**	.446**	.561**	.553**	.533**	.528**	.815**	.741**	.755**	.791**	1

* p < 0.05 ** p < 0.01

Appendix C 20: Average use of LPD element characteristics correlations (Part 6)

Teams characteristic	Levene statistic	df1	df2	Sig.
Development teams are made up by all involved functions, from marketing, to design, engineering, and production	3.831	4	203	.005
Development teams remain throughout the entire development project	14.156	4	203	.000
Team members are integrated to w ork alongside in the development team	8.013	4	203	.000
Team members have deep reaching technical know ledge	1.308	4	203	.268

Appendix C 21: Results of Levene's test for the average use of 'teams' characteristics for different company sizes

Teams characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brow n-Forsythe F
Development teams are made up by all involved functions, from marketing, to design, engineering, and production	-	-	.000**	.000**
Development teams remain throughout the entire development project	-	-	#	#
Team members are integrated to w ork alongside in the development team	-	-	#	#
Team members have deep reaching technical know ledge	7.263	.000**	-	-

* p < 0.05 ** p < 0.01

Test couldn't be performed because at least one group has 0 variance

Appendix C 22: Results of significance tests for the average use of 'teams' characteristics for different company sizes

	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.14)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 3.07)			.001**	.000**	.000**	
3	1,000-9,999 (Ø = 3.70)				.089	.016*	
4	10,000-99,999 (Ø = 4.15)					.521	
5	100,000+ (Ø = 4.55)						

* p < 0.05 ** p < 0.01

	Development teams remain throughout the entire development project	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.00)		.000**	.000**	.000**	.003**	Games-Howell
2	100-999 (Ø = 2.40)			.002**	.000**	.199	
3	1,000-9,999 (Ø = 3.02)				.009**	.759	
4	10,000-99,999 (Ø = 3.66)					1.000	
5	100,000+ (Ø = 3.64)						

* p < 0.05 ** p < 0.01

Appendix C 23: Post hoc test results for the average use of 'teams' characteristics for different company sizes (Part 1)

	Team members are integrated to work alongside in the development team	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.00)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.80)			.000**	.000**	.109	
3	1,000-9,999 (Ø = 3.75)				.588	.978	
4	10,000-99,999 (Ø = 4.02)					1.000	
5	100,000+ (Ø = 4.00)						

* p < 0.05 ** p < 0.01

	Team members have deep reaching technical knowledge	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 3.21)		.982	.063	.002**	.325	Gabriel
2	100-999 (Ø = 3.43)	.990		.023*	.000**	.368	
3	1,000-9,999 (Ø = 3.87)	.091	.025*		.676	1.000	
4	10,000-99,999 (Ø = 4.15)	.004**	.000**	.679		.991	
5	100,000+ (Ø = 3.91)	.327	.516	1.000	.994		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 24: Post hoc test results for the average use of 'teams' characteristics for different company sizes (Part 2)

Continuous improvement characteristic	Levene statistic	df1	df2	Sig.
Management encourages continuous and sustained improvement efforts	0.410	4	203	.801
Problems can be freely admitted	1.887	4	203	.114
There is freedom to experiment with new approaches	1.769	4	203	.136
Improvement efforts are encouraged on all levels	1.041	4	203	.387
Ideal situations are defined to provide guidance for continuous improvement efforts	0.343	4	203	.849

Appendix C 25: Results of Levene's test for the average use of 'continuous improvement' characteristics for different company sizes

Continuous improvement characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Management encourages continuous and sustained improvement efforts	45.914	.000**	-	-
Problems can be freely admitted	22.525	.000**	-	-
There is freedom to experiment with new approaches	21.984	.000**	-	-
Improvement efforts are encouraged on all levels	29.843	.000**	-	-
Ideal situations are defined to provide guidance for continuous improvement efforts	39.672	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 26: Results of significance tests for the average use of 'continuous improvement' characteristics for different company sizes

	Management encourages continuous and sustained improvement efforts	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.86)		.000**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 3.15)	.000**		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 4.04)	.000**	.000**		.172	.291	
4	10,000-99,999 (Ø = 4.41)	.000**	.000**	.174		1.000	
5	100,000+ (Ø = 4.55)	.000**	.000**	.379	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Problems can be freely admitted	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 2.00)		.108	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.62)	.182		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.51)	.000**	.000**		.723	.589	
4	10,000-99,999 (Ø = 3.80)	.000**	.000**	.725		.999	
5	100,000+ (Ø = 4.00)	.000**	.000**	.675	.999		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	There is freedom to experiment w ith new approaches	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 2.07)		.011*	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.87)	.026*		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.64)	.000**	.000**		.274	.895	
4	10,000-99,999 (Ø = 4.05)	.000**	.000**	.277		1.000	
5	100,000+ (Ø = 4.00)	.000**	.001**	.928	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Improvement efforts are encouraged on all levels	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.71)		.000**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.78)	.000**		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.58)	.000**	.000**		.399	.687	
4	10,000-99,999 (Ø = 3.93)	.000**	.000**	.402		1.000	
5	100,000+ (Ø = 4.00)	.000**	.000**	.762	1.000		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Ideal situations are defined to provide guidance for continuous improvement efforts	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.64)		.000**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.60)	.000**		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.47)	.000**	.000**		.161	.096	
4	10,000-99,999 (Ø = 3.85)	.000**	.000**	.163		.984	
5	100,000+ (Ø = 4.09)	.000**	.000**	.147	.989		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 27: Post hoc test results for the average use of 'continuous improvement' characteristics for different company sizes

Product variety management characteristic	Levene statistic	df1	df2	Sig.
There are clear goals for the use of off-the-shelf components within a product	20.705	4	203	.000
There are clear goals for the reuse of product parts among different modules, products and product families	17.438	4	203	.000
There are modular components with standardised interfaces	3.457	4	203	.009
There are common product platforms encompassing several product lines	4.804	4	203	.001

Appendix C 28: Results of Levene's test for the average use of 'product variety management' characteristics for different company sizes

Product variety management characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
There are clear goals for the use of off-the-shelf components within a product	-	-	#	#
There are clear goals for the reuse of product parts among different modules, products and product families	-	-	#	#
There are modular components with standardised interfaces	-	-	.000**	.000**
There are common product platforms encompassing several product lines	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Test couldn't be performed because at least one group has 0 variance

Appendix C 29: Results of significance tests for the average use of 'product variety management' characteristics for different company sizes

	There are clear goals for the use of off-the-shelf components within a product	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.14)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.33)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 4.00)				.271	.000**	
4	10,000-99,999 (Ø = 4.37)					.000**	
5	100,000+ (Ø = 5.00)						

* p < 0.05 ** p < 0.01

Appendix C 30: Post hoc test results for the average use of 'product variety management' characteristics for different company sizes (Part 1)

	There are clear goals for the reuse of product parts among different modules, products and product families	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.07)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.36)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.74)				.049*	.000**	
4	10,000-99,999 (Ø = 4.27)					.000**	
5	100,000+ (Ø = 5.00)						

* p < 0.05 ** p < 0.01

	There are modular components with standardised interfaces	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.29)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.65)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.58)				.211	.007**	
4	10,000-99,999 (Ø = 3.98)					.183	
5	100,000+ (Ø = 4.55)						

* p < 0.05 ** p < 0.01

	There are common product platforms encompassing several product lines	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.14)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.67)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.60)				.321	.017*	
4	10,000-99,999 (Ø = 3.90)					.178	
5	100,000+ (Ø = 4.45)						

* p < 0.05 ** p < 0.01

Appendix C 31: Post hoc test results for the average use of 'product variety management' characteristics for different company sizes (Part 2)

Supplier relationship and integration characteristic	Levene statistic	df1	df2	Sig.
Parts are evaluated according to their criticality before making outsourcing decisions	2.609	4	203	.037
A small number of high-capability suppliers are used for critical parts	1.346	4	203	.254
Critical suppliers are integrated in the concept definition phase	3.532	4	203	.008
Suppliers are mentored to improve their performance	0.871	4	203	.483

Appendix C 32: Results of Levene's test for the average use of 'supplier relationship and integration' characteristics for different company sizes

Supplier relationship and integration characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Parts are evaluated according to their criticality before making outsourcing decisions	-	-	.000**	.000**
A small number of high-capability suppliers are used for critical parts	2.676	.033*	-	-
Critical suppliers are integrated in the concept definition phase	-	-	.000**	.000**
Suppliers are mentored to improve their performance	17.360	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 33: Results of significance tests for the average use of 'supplier relationship and integration' characteristics for different company sizes

	Parts are evaluated according to their criticality before making outsourcing decisions	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.36)		.002**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.58)			.000**	.000**	.011*	
3	1,000-9,999 (Ø = 3.64)				.100	.645	
4	10,000-99,999 (Ø = 4.10)					1.000	
5	100,000+ (Ø = 4.18)						

* p < 0.05 ** p < 0.01

	A small number of high-capability suppliers are used for critical parts	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 3.00)		.996	.308	.249	.876	Gabriel
2	100-999 (Ø = 3.21)	.996		.202	.141	.953	
3	1,000-9,999 (Ø = 3.62)	.308	.202		1.000	1.000	
4	10,000-99,999 (Ø = 3.68)	.249	.141	1.000		1.000	
5	100,000+ (Ø = 3.55)	.876	.953	1.000	1.000		
		Hochberg's GT2					

* p < 0.05 ** p < 0.01

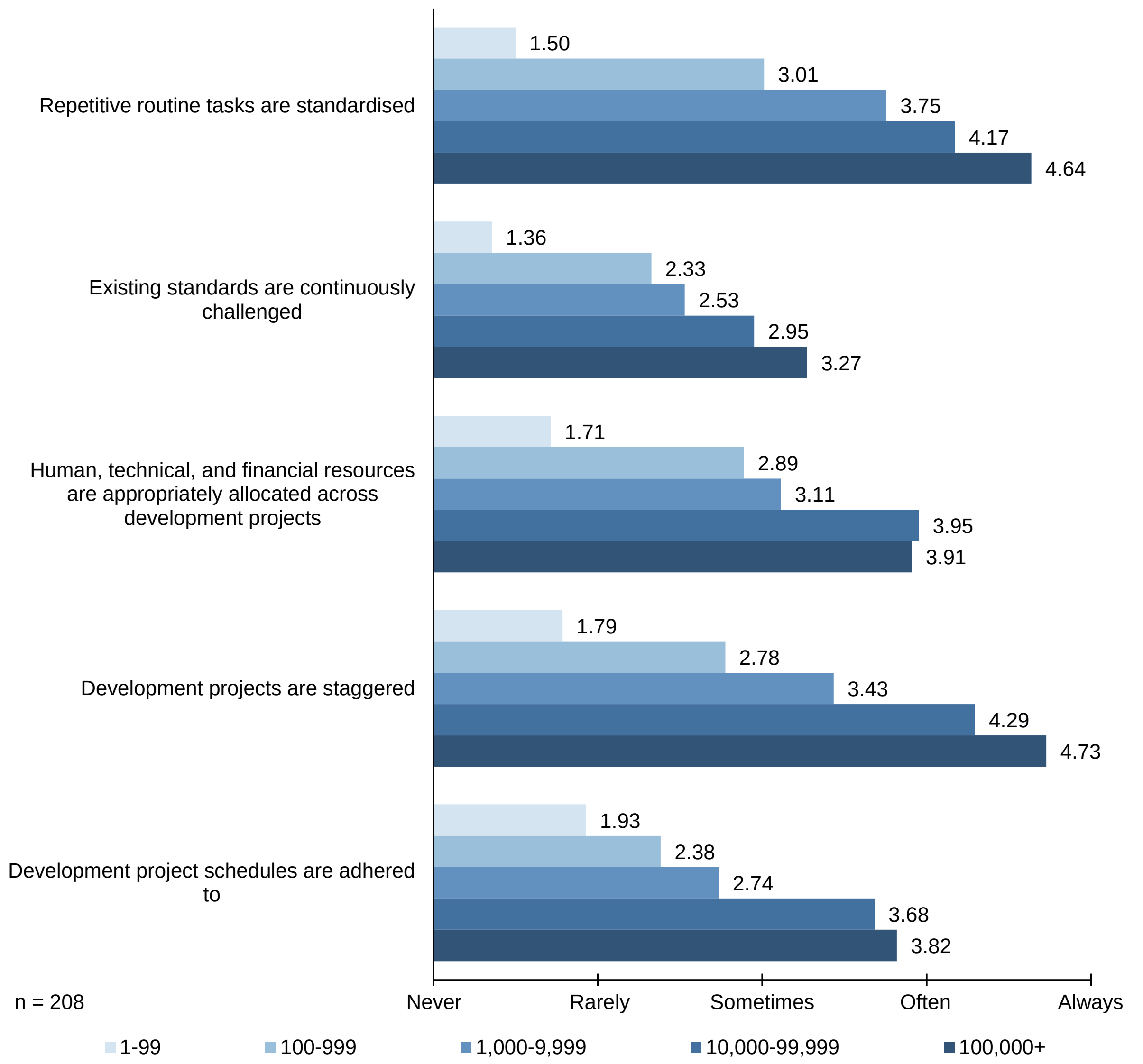
	Critical suppliers are integrated in the concept definition phase	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.64)		.285	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.16)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.25)				.094	.088	
4	10,000-99,999 (Ø = 3.73)					.958	
5	100,000+ (Ø = 3.91)						

* p < 0.05 ** p < 0.01

Appendix C 34: Post hoc test results for the average use of 'supplier relationship and integration' characteristics for different company sizes (Part 1)

	Suppliers are mentored to improve their performance	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.57)		.007**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.49)	.019*		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.40)	.000**	.000**		1.000	.866	
4	10,000-99,999 (Ø = 3.41)	.000**	.000**	1.000		.917	
5	100,000+ (Ø = 3.82)	.000**	.001**	.907	.938		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 35: Post hoc test results for the average use of 'supplier relationship and integration' characteristics for different company sizes (Part 2)



Appendix C 36: Use of 'process management' characteristics by company size

Process management characteristic	Levene statistic	df1	df2	Sig.
Repetitive routine tasks are standardised	3.073	4	203	.017
Existing standards are continuously challenged	1.073	4	203	.371
Human, technical, and financial resources are appropriately allocated across development projects	0.945	4	203	.439
Development projects are staggered	1.615	4	203	.172
Development project schedules are adhered to	0.743	4	203	.564

Appendix C 37: Results of Levene's test for the average use of 'process management' characteristics for different company sizes

Process management characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Repetitive routine tasks are standardised	-	-	.000**	.000**
Existing standards are continuously challenged	15.176	.000**	-	-
Human, technical, and financial resources are appropriately allocated across development projects	23.530	.000**	-	-
Development projects are staggered	41.369	.000**	-	-
Development project schedules are adhered to	27.443	.000**	-	-

* p < 0.05   ** p < 0.01

Appendix C 38: Results of significance tests for the average use of 'process management' characteristics for different company sizes

	Repetitive routine tasks are standardised	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.50)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 3.01)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.75)				.080	.010*	
4	10,000-99,999 (Ø = 4.17)					.336	
5	100,000+ (Ø = 4.64)						

* p < 0.05   ** p < 0.01

Appendix C 39: Post hoc test results for the average use of 'process management' characteristics for different company sizes (Part 1)

	Existing standards are continuously challenged	1	2	3	4	5
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)
1	1-99 (Ø = 1.36)		.000**	.000**	.000**	.000**
2	100-999 (Ø = 2.33)	.000**		.739	.000**	.000**
3	1,000-9,999 (Ø = 2.53)	.000**	.748		.083	.021*
4	10,000-99,999 (Ø = 2.95)	.000**	.000**	.084		.886
5	100,000+ (Ø = 3.27)	.000**	.002**	.038*	.913	

* p < 0.05 ** p < 0.01

Hochberg's GT2 (below diagonal); Gabriel (above diagonal)

	Human, technical, and financial resources are appropriately allocated across development projects	1	2	3	4	5
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)
1	1-99 (Ø = 1.71)		.000**	.000**	.000**	.000**
2	100-999 (Ø = 2.89)	.000**		.727	.000**	.000**
3	1,000-9,999 (Ø = 3.11)	.000**	.737		.000**	.028*
4	10,000-99,999 (Ø = 3.95)	.000**	.000**	.000**		1.000
5	100,000+ (Ø = 3.91)	.000**	.002**	.049*	1.000	

* p < 0.05 ** p < 0.01

Hochberg's GT2 (below diagonal); Gabriel (above diagonal)

	Development projects are staggered	1	2	3	4	5
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)
1	1-99 (Ø = 1.79)		.000**	.000**	.000**	.000**
2	100-999 (Ø = 2.78)	.001**		.000**	.000**	.000**
3	1,000-9,999 (Ø = 3.43)	.000**	.000**		.000**	.000**
4	10,000-99,999 (Ø = 4.29)	.000**	.000**	.000**		.706
5	100,000+ (Ø = 4.73)	.000**	.000**	.000**	.760	

* p < 0.05 ** p < 0.01

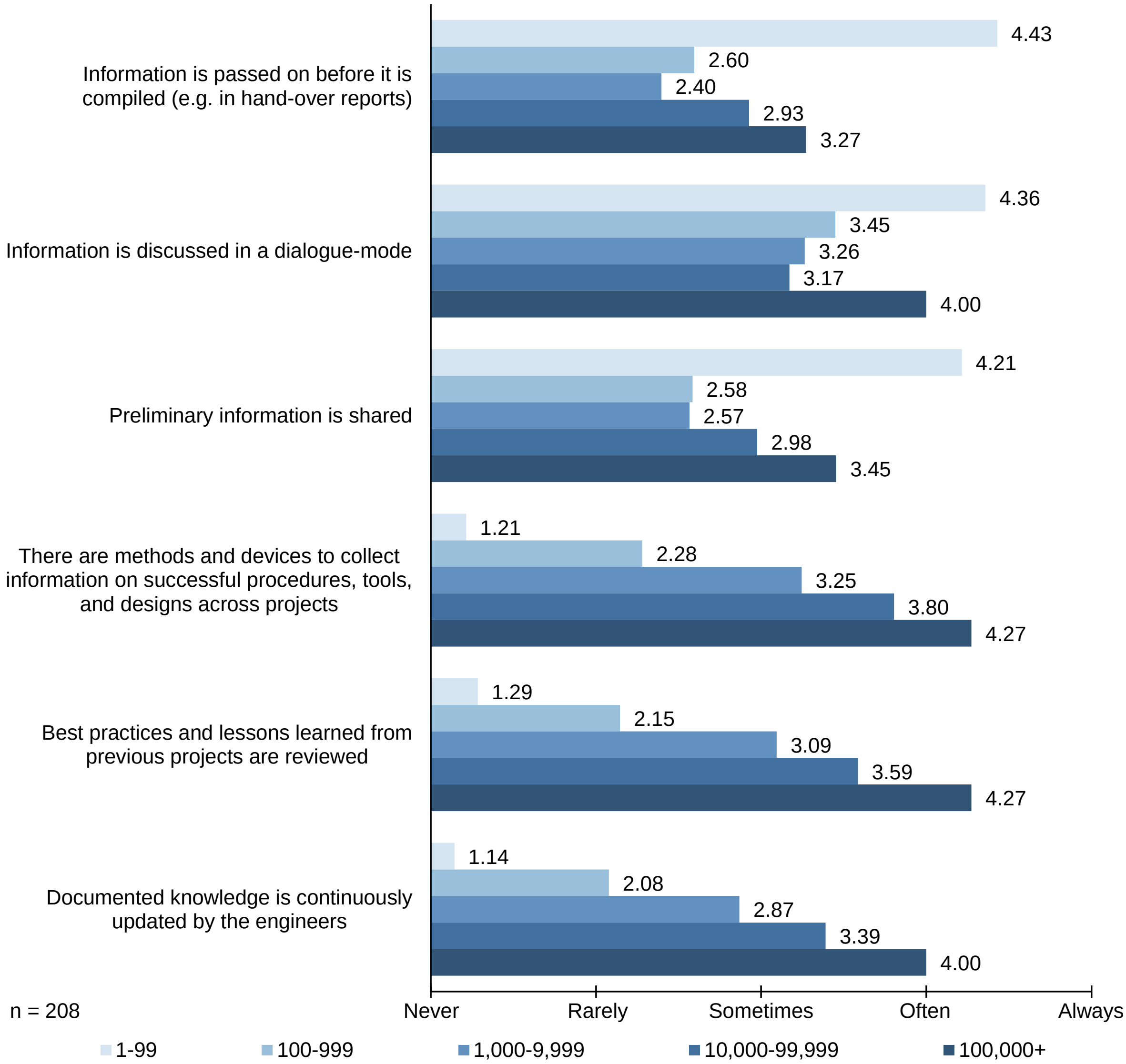
Hochberg's GT2 (below diagonal); Gabriel (above diagonal)

	Development project schedules are adhered to	1	2	3	4	5
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)
1	1-99 (Ø = 1.93)		.276	.005**	.000**	.000**
2	100-999 (Ø = 2.38)	.391		.100	.000**	.000**
3	1,000-9,999 (Ø = 2.74)	.009**	.106		.000**	.000**
4	10,000-99,999 (Ø = 3.68)	.000**	.000**	.000**		1.000
5	100,000+ (Ø = 3.82)	.000**	.000**	.001**	1.000	

* p < 0.05 ** p < 0.01

Hochberg's GT2 (below diagonal); Gabriel (above diagonal)

Appendix C 40: Post hoc test results for the average use of 'process management' characteristics for different company sizes (Part 2)



Appendix C 41: Use of 'communication and knowledge transfer' characteristics by company size

Communication and knowledge transfer characteristic	Levene statistic	df1	df2	Sig.
Information is passed on before it is compiled (e.g. in hand-over reports)	1.064	4	203	.376
Information is discussed in a dialogue-mode	0.637	4	203	.637
Preliminary information is shared	0.976	4	203	.422
There are methods and devices to collect information on successful procedures, tools, and designs across projects	1.957	4	203	.102
Best practices and lessons learned from previous projects are reviewed	3.646	4	203	.007
Documented knowledge is continuously updated by the engineers	4.459	4	203	.002

Appendix C 42: Results of Levene's test for the average use of 'communication and knowledge transfer' characteristics for different company sizes

Communication and knowledge transfer characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Information is passed on before it is compiled (e.g. in hand-over reports)	16.170	.000**	-	-
Information is discussed in a dialogue-mode	4.677	.001**	-	-
Preliminary information is shared	11.641	.000**	-	-
There are methods and devices to collect information on successful procedures, tools, and designs across projects	61.482	.000**	-	-
Best practices and lessons learned from previous projects are reviewed	-	-	.000**	.000**
Documented knowledge is continuously updated by the engineers	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Appendix C 43: Results of significance tests for the average use of 'communication and knowledge transfer' characteristics for different company sizes

	Information is passed on before it is compiled (e.g. in hand-over reports)	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 4.43)		.000**	.000**	.000**	.016*	Gabriel
2	100-999 (Ø = 2.60)	.000**		.889	.388	.092	
3	1,000-9,999 (Ø = 2.40)	.000**	.894		.048*	.019*	
4	10,000-99,999 (Ø = 2.93)	.000**	.413	.049*		.930	
5	100,000+ (Ø = 3.27)	.016*	.178	.036*	.948		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Information is discussed in a dialogue-mode	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 4.36)		.010*	.003**	.002**	.992	Gabriel
2	100-999 (Ø = 3.45)	.024*		.969	.788	.485	
3	1,000-9,999 (Ø = 3.26)	.005**	.971		1.000	.201	
4	10,000-99,999 (Ø = 3.17)	.003**	.806	1.000		.128	
5	100,000+ (Ø = 4.00)	.992	.630	.277	.170		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Preliminary information is shared	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 4.21)		.000**	.000**	.000**	.368	Gabriel
2	100-999 (Ø = 2.58)	.000**		1.000	.226	.015*	
3	1,000-9,999 (Ø = 2.57)	.000**	1.000		.309	.025*	
4	10,000-99,999 (Ø = 2.98)	.000**	.247	.312		.704	
5	100,000+ (Ø = 3.45)	.371	.040*	.046*	.758		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 44: Post hoc test results for the average use of 'communication and knowledge transfer' characteristics for different company sizes (Part 1)

	There are methods and devices to collect information on successful procedures, tools, and designs across projects	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.21)		.000**	.000**	.000**	.000**	Gabriel
2	100-999 (Ø = 2.28)	.000**		.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.25)	.000**	.000**		.003**	.000**	
4	10,000-99,999 (Ø = 3.80)	.000**	.000**	.003**		.408	
5	100,000+ (Ø = 4.27)	.000**	.000**	.000**	.477		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Best practices and lessons learned from previous projects are reviewed	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.29)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.15)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 3.09)				.101	.003**	
4	10,000-99,999 (Ø = 3.59)					.163	
5	100,000+ (Ø = 4.27)						

* p < 0.05 ** p < 0.01

	Documented knowledge is continuously updated by the engineers	1	2	3	4	5	
		1-99 (n = 14)	100-999 (n = 89)	1,000-9,999 (n = 53)	10,000-99,999 (n = 41)	100,000+ (n = 11)	
1	1-99 (Ø = 1.14)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.08)			.000**	.000**	.002**	
3	1,000-9,999 (Ø = 2.87)				.018*	.065	
4	10,000-99,999 (Ø = 3.39)					.516	
5	100,000+ (Ø = 4.00)						

* p < 0.05 ** p < 0.01

Appendix C 45: Post hoc test results for the average use of 'communication and knowledge transfer' characteristics for different company sizes (Part 2)

Set-based design characteristic	Levene statistic	df1	df2	Sig.
A large number of possible solutions for a design problem is considered early in the process	4.866	4	203	.001
Alternative solutions for a design problem are developed and tested simultaneously	8.405	4	203	.000
Decision are delayed until objective data allow the elimination of competing design solutions	2.987	4	203	.020
A concept for a design solution is not revised once it has been selected	3.423	4	203	.010

Appendix C 46: Results of Levene's test for the average use of 'set-based design' characteristics for different company sizes

Set-based design characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
A large number of possible solutions for a design problem is considered early in the process	-	-	.000**	.000**
Alternative solutions for a design problem are developed and tested simultaneously	-	-	.000**	.000**
Decision are delayed until objective data allow the elimination of competing design solutions	-	-	.000**	.000**
A concept for a design solution is not revised once it has been selected	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Appendix C 47: Results of significance tests for the average use of 'set-based design' characteristics for different company sizes

	A large number of possible solutions for a design problem is considered early in the process	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.21)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 2.55)			.000**	.000**	.094	
3	1,000-9,999 (Ø = 3.28)				.531	.945	
4	10,000-99,999 (Ø = 3.61)					1.000	
5	100,000+ (Ø = 3.55)						

* p < 0.05 ** p < 0.01

	Alternative solutions for a design problem are developed and tested simultaneously	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.07)		.000**	.000**	.000**	.002**	Games-Howell
2	100-999 (Ø = 2.13)			.000**	.003**	.082	
3	1,000-9,999 (Ø = 2.79)				.995	.679	
4	10,000-99,999 (Ø = 2.88)					.810	
5	100,000+ (Ø = 3.36)						

* p < 0.05 ** p < 0.01

Appendix C 48: Post hoc test results for the average use of 'set-based design' characteristics for different company sizes (Part 1)

	Decisions are delayed until objective data allow the elimination of competing design solutions	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 2.71)		.972	.987	.158	.001**	Games-Howell
2	100-999 (Ø = 2.58)			.531	.005**	.000**	
3	1,000-9,999 (Ø = 2.83)				.177	.001**	
4	10,000-99,999 (Ø = 3.34)					.087	
5	100,000+ (Ø = 4.09)						

* p < 0.05 ** p < 0.01

	A concept for a design solution is not revised once it has been selected	1 1-99 (n = 14)	2 100-999 (n = 89)	3 1,000-9,999 (n = 53)	4 10,000-99,999 (n = 41)	5 100,000+ (n = 11)	
1	1-99 (Ø = 1.21)		.000**	.000**	.000**	.000**	Games-Howell
2	100-999 (Ø = 1.93)			.000**	.000**	.000**	
3	1,000-9,999 (Ø = 2.72)				.063	.011*	
4	10,000-99,999 (Ø = 3.27)					.253	
5	100,000+ (Ø = 4.00)						

* p < 0.05 ** p < 0.01

Appendix C 49: Post hoc test results for the average use of 'set-based design' characteristics for different company sizes (Part 2)

			Company size	Decision are delayed until objective data allow the elimination of competing design solutions
Spearman's rho	Company size	Correlation Coefficient	1.000	.332**
		Sig. (2-tailed)		.000
		N	208	208
	Decision are delayed until objective data allow the elimination of competing design solutions	Correlation Coefficient	.332**	1.000
		Sig. (2-tailed)	.000	
		N	208	208

* p < 0.05 ** p < 0.01

Appendix C 50: Bivariate correlation results between a 'set-based design' characteristic and company size

Scale	Cronabch α	LPD Element	Corrected Item-Total Correlation
LPD	0.865	Strong Project Manager	.183
		Teams	.658
		Concurrent Engineering	.690
		Supplier Relationship and Integration	.635
		Set-based Design	.625
		Communication and Know ledge Transfer	.487
		Process Management	.738
		Product Variety Management	.729
		Continuous Improvement	.664

Appendix C 51: Reliability analysis results for the overall use of LPD

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval Low er	Upper
Strong Project Manager	Equal variances assumed	1.784	.183	-.561	201	.575	-.07225	.12868	-.32599	.18148
	Equal variances not assumed			-.571	193.412	.569	-.07225	.12649	-.32172	.17722
Teams	Equal variances assumed	11.332	.001	2.775	201	.006	.37495	.13513	.10849	.64141
	Equal variances not assumed			2.885	200.498	.004	.37495	.12998	.11865	.63125
Concurrent Engineering	Equal variances assumed	6.416	.012	3.546	201	.000	.57004	.16077	.25304	.88704
	Equal variances not assumed			3.647	197.953	.000	.57004	.15630	.26181	.87827
Supplier Relationship and Integration	Equal variances assumed	1.054	.306	2.675	201	.008	.36556	.13667	.09607	.63505
	Equal variances not assumed			2.713	191.872	.007	.36556	.13475	.09978	.63134
Set-based Design	Equal variances assumed	2.286	.132	2.833	201	.005	.33935	.11977	.10319	.57551
	Equal variances not assumed			2.792	172.791	.006	.33935	.12154	.09945	.57924
Communication and Know ledge Transfer	Equal variances assumed	2.582	.110	-.238	201	.812	-.02342	.09844	-.21753	.17069
	Equal variances not assumed			-.232	165.284	.817	-.02342	.10089	-.22262	.17577
Process Management	Equal variances assumed	3.034	.083	3.065	201	.002	.38147	.12445	.13608	.62687
	Equal variances not assumed			3.164	198.988	.002	.38147	.12058	.14370	.61925
Product Variety Management	Equal variances assumed	1.955	.164	4.656	201	.000	.80841	.17363	.46605	1.15078
	Equal variances not assumed			4.715	191.064	.000	.80841	.17144	.47025	1.14658
Continuous Improvement	Equal variances assumed	0.292	.589	2.914	201	.004	.38990	.13379	.12609	.65371
	Equal variances not assumed			2.956	191.966	.004	.38990	.13189	.12977	.65003

Appendix C 52: Independent t-test for average use of LPD elements and having a person responsible for LPD

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval Lower	Upper
Strong Project Manager	Equal variances assumed	0.014	.906	-1.051	199	.294	-.15153	.14414	-.43576	.13270
	Equal variances not assumed			-1.051	97.146	.296	-.15153	.14419	-.43770	.13463
Teams	Equal variances assumed	2.831	.094	-.163	199	.870	-.02503	.15315	-.32704	.27698
	Equal variances not assumed			-.176	114.061	.860	-.02503	.14200	-.30633	.25627
Concurrent Engineering	Equal variances assumed	1.159	.283	1.309	199	.192	.24050	.18374	-.12181	.60282
	Equal variances not assumed			1.360	105.081	.177	.24050	.17686	-.11017	.59118
Supplier Relationship and Integration	Equal variances assumed	13.037	.000	.199	199	.842	.03104	.15565	-.27590	.33798
	Equal variances not assumed			.235	140.932	.815	.03104	.13211	-.23012	.29220
Set-based Design	Equal variances assumed	19.661	.000	-1.487	199	.139	-.20146	.13550	-.46866	.06573
	Equal variances not assumed			-1.806	151.906	.073	-.20146	.11157	-.42190	.01897
Communication and Know ledge Transfer	Equal variances assumed	6.715	.010	-2.774	199	.006	-.30077	.10841	-.51455	-.08698
	Equal variances not assumed			-3.270	141.042	.001	-.30077	.09198	-.48261	-.11892
Process Management	Equal variances assumed	18.737	.000	-0.044	199	.965	-.00633	.14260	-.28752	.27487
	Equal variances not assumed			-0.055	156.979	.957	-.00633	.11585	-.23516	.22251
Product Variety Management	Equal variances assumed	6.339	.013	0.258	199	.796	.05286	.20466	-.35073	.45645
	Equal variances not assumed			0.283	118.498	.777	.05286	.18663	-.31670	.42242
Continuous Improvement	Equal variances assumed	3.021	.084	-0.769	199	.443	-.11666	.15171	-.41583	.18251
	Equal variances not assumed			-0.811	108.419	.419	-.11666	.14392	-.40193	.16860

Appendix C 53: Independent t-test for average use of LPD elements and employing external help

Strong project manager characteristic	Levene statistic	df1	df2	Sig.
Project manager leads the product development project from concept to market	4.586	4	203	.001
Project manager defines the product concept and advocates the customer value	1.656	4	203	.162
Project manager sets the project time frame and controls adherence to it	1.882	4	203	.115
Project manager has great technical know ledge	2.096	4	203	.083
Project manager chooses the technology and makes major component choices	2.054	4	203	.088

Appendix C 54: Results of Levene's test for the average use of 'strong project manager' characteristics for different company sizes

Strong project manager characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Project manager leads the product development project from concept to market	-	-	.007**	.004**
Project manager defines the product concept and advocates the customer value	4.953	.001**	-	-
Project manager sets the project time frame and controls adherence to it	3.038	.018*	-	-
Project manager has great technical knowledge	2.068	.086	-	-
Project manager chooses the technology and makes major component choices	2.171	.074	-	-

* p < 0.05 ** p < 0.01

Appendix C 55: Results of significance tests for the average use of 'strong project manager' characteristics for different company sizes

	Project manager leads the product development project from concept to market	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 3.33)		1.000	.134	.210	.014*	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.26)			.244	.287	.052	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.91)				1.000	.732	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.94)					.881	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.18)						

* p < 0.05 ** p < 0.01

	Project manager defines the product concept and advocates the customer value	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.59)		1.000	.684	.059	.001**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.70)	1.000		.988	.403	.037*	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.97)	.686	.991		.747	.062	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.39)	.063	.407	.765		.977	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.71)	.001**	.039*	.069	.977		
		Hochberg's GT2					

* p < 0.05 ** p < 0.01

Appendix C 56: Post hoc test results for the average use of 'strong project manager' characteristics for different company sizes (Part 1)

	Project manager sets the project time frame and controls adherence to it	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 3.69)		1.000	.589	.447	.036*
2	We do not have any goals but we are planning to develop some (Ø = 3.61)	1.000		.640	.516	.083
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 4.02)	.590	.681		1.000	.722
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 4.13)	.461	.520	1.000		.992
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.35)	.038*	.085	.738	.992	

Gabriel (upper-right triangle); Hochberg's GT2 (lower-left triangle)

* p < 0.05 ** p < 0.01

Appendix C 57: Post hoc test results for the average use of 'strong project manager' characteristics for different company sizes (Part 2)

Concurrent engineering characteristic	Levene statistic	df1	df2	Sig.
All involved functions are integrated into the concept definition phase of the development project	3.732	4	203	.006
There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	6.712	4	203	.000
There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	2.116	4	203	.080
Development and testing of production facilities is conducted in parallel to product development	0.674	4	203	.611

Appendix C 58: Results of Levene's test for the average use of 'concurrent engineering' characteristics for different company sizes

Concurrent engineering characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
All involved functions are integrated into the concept definition phase of the development project	12.025	.000**	-	-
There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	-	-	.000**	.000**
There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	-	-	.000**	.000**
Development and testing of production facilities is conducted in parallel to product development	16.923	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 59: Results of significance tests for the average use of 'concurrent engineering' characteristics for different company sizes

	All involved functions are integrated into the concept definition phase of the development project	1	2	3	4	5
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.44)		.010*	.000**	.002**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 3.39)	.012*		.983	1.000	.412
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.65)	.000**	.987		.986	.800
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.42)	.002**	1.000	.988		.367
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.00)	.000**	.418	.813	.367	

Gabriel

* p < 0.05 ** p < 0.01

Hochberg's GT2

	There are frequent review meetings with development, manufacturing, quality assurance, and purchasing	1	2	3	4	5
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.65)		.002**	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 3.74)			.698	.945	.392
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 4.05)				.979	.930
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.94)					.755
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.18)					

Games-Howell

* p < 0.05 ** p < 0.01

	There is a formalised process for evaluating design proposals regarding manufacturability and assembly compatibility	1	2	3	4	5
		(n = 54)	(n = 23)	(n = 66)	(n = 31)	(n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.17)		.188	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.87)			.122	.029*	.015*
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.61)				.789	.549
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.84)					.997
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.91)					

Games-Howell

* p < 0.05 ** p < 0.01

Appendix C 60: Post hoc test results for the average use of 'concurrent engineering' characteristics for different company sizes (Part 1)

	Development and testing of production facilities is conducted in parallel to product development	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 1.93)		.039*	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.78)	.047*		.129	.433	.079
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.48)	.000**	.157		1.000	.999
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.42)	.000**	.437	1.000		.997
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.65)	.000**	.082	.999	.997	

Gabriel

* p < 0.05 ** p < 0.01

Hochberg's GT2

Appendix C 61: Post hoc test results for the average use of 'concurrent engineering' characteristics for different company sizes (Part 2)

Teams characteristic	Levene statistic	df1	df2	Sig.
Development teams are made up by all involved functions, from marketing, to design, engineering, and production	4.293	4	203	.002
Development teams remain throughout the entire development project	2.645	4	203	.035
Team members are integrated to work alongside in the development team	2.427	4	203	.049
Team members have deep reaching technical knowledge	1.485	4	203	.208

Appendix C 62: Results of Levene's test for the average use of 'teams' characteristics for different company sizes

Teams characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Development teams are made up by all involved functions, from marketing, to design, engineering, and production	-	-	.000**	.000**
Development teams remain throughout the entire development project	-	-	.000**	.000**
Team members are integrated to work alongside in the development team	-	-	.000**	.000**
Team members have deep reaching technical knowledge	4.690	.001**	-	-

* p < 0.05 ** p < 0.01

Appendix C 63: Results of significance tests for the average use of 'teams' characteristics for different company sizes

	Development teams are made up by all involved functions, from marketing, to design, engineering, and production	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.44)		.017*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.39)			.996	.308	.042*	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.48)				.121	.002**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.94)					.718	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.21)						

* $p < 0.05$ ** $p < 0.01$

	Development teams remain throughout the entire development project	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.91)		.039*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.78)			.997	.733	.105	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.88)				.702	.023*	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.19)					.672	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.59)						

* $p < 0.05$ ** $p < 0.01$

	Team members are integrated to work alongside in the development team	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.30)		.127	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.96)			.244	.064	.006**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.45)				.719	.110	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 71)					.799	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.00)						

* $p < 0.05$ ** $p < 0.01$

Appendix C 64: Post hoc test results for the average use of 'teams' characteristics for different company sizes (Part 1)

	Team members have deep reaching technical knowledge	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 3.35)		.910	.244	.065	.001**
2	We do not have any goals but we are planning to develop some (Ø = 3.61)	.920		1.000	.950	.237
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.70)	.246	1.000		.983	.169
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.87)	.070	.951	.985		.936
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.12)	.001**	.243	.182	.936	

Gabriel

* p < 0.05 ** p < 0.01

Hochberg's GT2

Appendix C 65: Post hoc test results for the average use of 'teams' characteristics for different company sizes (Part 2)

Continuous improvement characteristic	Levene statistic	df1	df2	Sig.
Management encourages continuous and sustained improvement efforts	1.814	4	203	.127
Problems can be freely admitted	3.502	4	203	.009
There is freedom to experiment with new approaches	0.871	4	203	.482
Improvement efforts are encouraged on all levels	1.823	4	203	.126
Ideal situations are defined to provide guidance for continuous improvement efforts	1.593	4	203	.177

Appendix C 66: Results of Levene's test for the average use of 'continuous improvement' characteristics for different company sizes

Continuous improvement characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Management encourages continuous and sustained improvement efforts	29.908	.000**	-	-
Problems can be freely admitted	-	-	.000**	.000**
There is freedom to experiment with new approaches	20.315	.000**	-	-
Improvement efforts are encouraged on all levels	22.608	.000**	-	-
Ideal situations are defined to provide guidance for continuous improvement efforts	31.634	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 67: Results of significance tests for the average use of 'continuous improvement' characteristics for different company sizes

Management encourages continuous and sustained improvement efforts	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1 We do not have any goals and we are not planning to develop any (Ø = 2.67)		.021*	.000**	.000**	.000**	Gabriel
2 We do not have any goals but we are planning to develop some (Ø = 3.30)	.026*		.093	.003**	.000**	
3 We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.82)	.000**	.115		.444	.008**	
4 We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 4.16)	.000**	.003**	.468		.925	
5 We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.41)	.000**	.000**	.010*	.925		
* p < 0.05 ** p < 0.01	Hochberg's GT2					

Problems can be freely admitted	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1 We do not have any goals and we are not planning to develop any (Ø = 2.31)		.437	.000**	.000**	.000**	Games-Howell
2 We do not have any goals but we are planning to develop some (Ø = 2.83)			.529	.259	.003**	
3 We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.26)				.858	.001**	
4 We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.42)					.027*	
5 We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.00)						

* p < 0.05 ** p < 0.01

There is freedom to experiment with new approaches	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1 We do not have any goals and we are not planning to develop any (Ø = 2.46)		.005**	.000**	.000**	.000**	Gabriel
2 We do not have any goals but we are planning to develop some (Ø = 3.26)	.006**		1.000	.444	.004**	
3 We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.36)	.000**	1.000		.432	.001**	
4 We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.74)	.000**	.448	.457		.547	
5 We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.15)	.000**	.004**	.001**	.548		
* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 68: Post hoc test results for the average use of 'continuous improvement' characteristics for different company sizes (Part 1)

	Improvement efforts are encouraged on all levels	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.41)		.406	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.83)	.437		.161	.003**	.000**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.32)	.000**	.193		.320	.001**
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.71)	.000**	.003**	.343		.782
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.03)	.000**	.000**	.002**	.782	

Upper triangle: Gabriel; lower triangle: Hochberg's GT2

* p < 0.05 ** p < 0.01

	Ideal situations are defined to provide guidance for continuous improvement efforts	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.24)		.469	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.61)	.500		.012*	.000**	.000**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.23)	.000**	.017*		.478	.000**
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.55)	.000**	.000**	.503		.156
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.03)	.000**	.000**	.000**	.157	

Upper triangle: Gabriel; lower triangle: Hochberg's GT2

* p < 0.05 ** p < 0.01

Appendix C 69: Post hoc test results for the average use of 'continuous improvement' characteristics for different company sizes (Part 2)

Product variety management characteristic	Levene statistic	df1	df2	Sig.
There are clear goals for the use of off-the-shelf components within a product	4.326	4	203	.002
There are clear goals for the reuse of product parts among different modules, products and product families	4.297	4	203	.002
There are modular components with standardised interfaces	0.707	4	203	.588
There are common product platforms encompassing several product lines	1.888	4	203	.114

Appendix C 70: Results of Levene's test for the average use of 'product variety management' characteristics for different company sizes

Product variety management characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
There are clear goals for the use of off-the-shelf components within a product	-	-	.000**	.000**
There are clear goals for the reuse of product parts among different modules, products and product families	-	-	.000**	.000**
There are modular components with standardised interfaces	21.200	.000**	-	-
There are common product platforms encompassing several product lines	23.086	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 71: Results of significance tests for the average use of 'product variety management' characteristics for different company sizes

	There are clear goals for the use of off-the-shelf components within a product	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.67)		.026*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.83)			.307	.003**	.003**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.55)				.016*	.016*	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 4.32)					1.000	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.29)						

* p < 0.05 ** p < 0.01

	There are clear goals for the reuse of product parts among different modules, products and product families	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.70)		.090	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.61)			.051	.003**	.003**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.61)				.315	.336	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 4.03)					1.000	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.06)						

* p < 0.05 ** p < 0.01

Appendix C 72: Post hoc test results for the average use of 'product variety management' characteristics for different company sizes (Part 1)

	There are modular components with standardised interfaces	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
		Gabriel				
1	We do not have any goals and we are not planning to develop any (Ø = 2.17)		.099	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.83)	.115		.226	.011*	.001**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.38)	.000**	.264		.557	.070
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.77)	.000**	.012*	.581		.997
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.97)	.000**	.001**	.077	.997	
	* p < 0.05 ** p < 0.01	Hochberg's GT2				

	There are common product platforms encompassing several product lines	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
		Gabriel				
1	We do not have any goals and we are not planning to develop any (Ø = 2.19)		.066	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.83)	.078		.141	.010*	.000**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.38)	.000**	.170		.682	.081
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.71)	.000**	.010*	.703		.993
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.91)	.000**	.000**	.089	.993	
	* p < 0.05 ** p < 0.01	Hochberg's GT2				

Appendix C 73: Post hoc test results for the average use of 'product variety management' characteristics for different company sizes (Part 2)

Supplier relationship and integration characteristic	Levene statistic	df1	df2	Sig.
Parts are evaluated according to their criticality before making outsourcing decisions	2.396	4	203	.052
A small number of high-capability suppliers are used for critical parts	0.262	4	203	.902
Critical suppliers are integrated in the concept definition phase	2.689	4	203	.032
Suppliers are mentored to improve their performance	0.603	4	203	.661

Appendix C 74: Results of Levene's test for the average use of 'supplier relationship and integration' characteristics for different company sizes

Supplier relationship and integration characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Parts are evaluated according to their criticality before making outsourcing decisions	37.100	.000**	-	-
A small number of high-capability suppliers are used for critical parts	5.368	.000**	-	-
Critical suppliers are integrated in the concept definition phase	-	-	.000**	.000**
Suppliers are mentored to improve their performance	13.301	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 75: Results of significance tests for the average use of 'supplier relationship and integration' characteristics for different company sizes

	Parts are evaluated according to their criticality before making outsourcing decisions	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.02)		.274	.000**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.52)	.302		.000**	.000**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.45)	.000**	.001**		.592	.002**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.81)	.000**	.000**	.615		.622	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.21)	.000**	.000**	.003**	.622		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	A small number of high-capability suppliers are used for critical parts	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.91)		.191	.016*	.031*	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 3.48)	.215		1.000	1.000	.837	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.50)	.016*	1.000		1.000	.624	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.58)	.034*	1.000	1.000		.960	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.85)	.000**	.841	.642	.960		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

Appendix C 76: Post hoc test results for the average use of 'supplier relationship and integration' characteristics for different company sizes (Part 1)

	Critical suppliers are integrated in the concept definition phase	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.93)		.512	.000**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.39)	.543		.237	.020*	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.94)	.000**	.276		.715	.002**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.29)	.000**	.021*	.735		.511	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.76)	.000**	.000**	.003**	.512		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Suppliers are mentored to improve their performance	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.13)		.062	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.91)			.998	.890	.053	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.00)				.916	.006**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.19)					.195	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.74)						

* p < 0.05 ** p < 0.01

Appendix C 77: Post hoc test results for the average use of 'supplier relationship and integration' characteristics for different company sizes (Part 2)

Process management characteristic	Levene statistic	df1	df2	Sig.
Repetitive routine tasks are standardised	6.607	4	203	.000
Existing standards are continuously challenged	1.966	4	203	.101
Human, technical, and financial resources are appropriately allocated across development projects	3.344	4	203	.011
Development projects are staggered	5.361	4	203	.000
Development project schedules are adhered to	1.417	4	203	.230

Appendix C 78: Results of Levene's test for the average use of 'process management' characteristics for different company sizes

Process management characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Repetitive routine tasks are standardised	-	-	.000**	.000**
Existing standards are continuously challenged	11.007	.000**	-	-
Human, technical, and financial resources are appropriately allocated across development projects	-	-	.000**	.000**
Development projects are staggered	-	-	.000**	.000**
Development project schedules are adhered to	19.551	.000**	-	-

* p < 0.05 ** p < 0.01

Appendix C 79: Results of significance tests for the average use of 'process management' characteristics for different company sizes

	Repetitive routine tasks are standardised	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.37)		.012*	.000**	.000**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 3.22)			.214	.077	.000**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.67)				.787	.002**
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.87)					.270
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.29)					

Games-Howell

* p < 0.05 ** p < 0.01

	Existing standards are continuously challenged	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)
1	We do not have any goals and we are not planning to develop any (Ø = 2.06)		.889	.086	.001**	.000**
2	We do not have any goals but we are planning to develop some (Ø = 2.30)	.902		.998	.373	.001**
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.44)	.087	.999		.545	.000**
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 2.74)	.002**	.377	.569		.341
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.15)	.000**	.001**	.000**	.341	

Gabriel

* p < 0.05 ** p < 0.01

Hochberg's GT2

Appendix C 80: Post hoc test results for the average use of 'process management' characteristics for different company sizes (Part 1)

	Human, technical, and financial resources are appropriately allocated across development projects	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.41)		.067	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.04)			.998	.453	.002**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.11)				.254	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.45)					.047*	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.09)						

* p < 0.05 ** p < 0.01

	Development projects are staggered	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.37)		.039*	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 3.09)			.860	.043*	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.29)				.057	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.84)					.278	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.32)						

* p < 0.05 ** p < 0.01

	Development project schedules are adhered to	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.15)		.077	.005**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.70)	.091		1.000	.788	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.03)	.005**	1.000		.477	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.74)	.000**	.791	.502		.009**	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 2.77)	.000**	.000**	.000**	.009**		
		Hochberg's GT2					

* p < 0.05 ** p < 0.01

Appendix C 81: Post hoc test results for the average use of 'process management' characteristics for different company sizes (Part 2)

Communication and knowledge transfer characteristic	Levene statistic	df1	df2	Sig.
Information is passed on before it is compiled (e.g. in hand-over reports)	2.436	4	203	.048
Information is discussed in a dialogue-mode	2.516	4	203	.043
Preliminary information is shared	2.245	4	203	.066
There are methods and devices to collect information on successful procedures, tools, and designs across projects	2.926	4	203	.022
Best practices and lessons learned from previous projects are reviewed	0.150	4	203	.963
Documented knowledge is continuously updated by the engineers	4.414	4	203	.002

Appendix C 82: Results of Levene's test for the average use of 'communication and knowledge transfer' characteristics for different company sizes

Communication and knowledge transfer characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
Information is passed on before it is compiled (e.g. in hand-over reports)	-	-	.000**	.000**
Information is discussed in a dialogue-mode	-	-	.079	.081
Preliminary information is shared	4.858	.001**	-	-
There are methods and devices to collect information on successful procedures, tools, and designs across projects	-	-	.000**	.000**
Best practices and lessons learned from previous projects are reviewed	48.969	.000**	-	-
Documented knowledge is continuously updated by the engineers	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Appendix C 83: Results of significance tests for the average use of 'communication and knowledge transfer' characteristics for different company sizes

	Information is passed on before it is compiled (e.g. in hand-over reports)	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 3.13)		.510	.001**	.149	1.000	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.70)			.612	1.000	.457	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.35)				.397	.002**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 2.65)					.145	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.18)						

* p < 0.05 ** p < 0.01

	Preliminary information is shared	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.98)		.932	.041*	.996	.700	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.70)	.941		.971	1.000	.179	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.45)	.042*	.977		.644	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 2.81)	.996	1.000	.666		.314	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.32)	.708	.184	.001**	.314		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	There are methods and devices to collect information on successful procedures, tools, and designs across projects	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.74)		.006**	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.39)			.013*	.000**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.97)				.081	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.42)					.001**	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.24)						

* p < 0.05 ** p < 0.01

Appendix C 84: Post hoc test results for the average use of 'communication and knowledge transfer' characteristics for different company sizes (Part 1)

	Best practices and lessons learned from previous projects are reviewed	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.74)		.052	.000**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.30)	.062		.352	.000**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.70)	.000**	.396		.009**	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.29)	.000**	.000**	.011*		.001**	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 4.12)	.000**	.000**	.000**	.001**		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	Documented knowledge is continuously updated by the engineers	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.65)		.152	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 1.96)			.000**	.000**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.64)				.028*	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.13)					.004**	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.85)						

* p < 0.05 ** p < 0.01

Appendix C 85: Post hoc test results for the average use of 'communication and knowledge transfer' characteristics for different company sizes (Part 2)

Set-based design characteristic	Levene statistic	df1	df2	Sig.
A large number of possible solutions for a design problem is considered early in the process	2.340	4	203	.056
Alternative solutions for a design problem are developed and tested simultaneously	3.634	4	203	.007
Decision are delayed until objective data allow the elimination of competing design solutions	1.897	4	203	.112
A concept for a design solution is not revised once it has been selected	3.005	4	203	.019

Appendix C 86: Results of Levene's test for the average use of 'set-based design' characteristics for different company sizes

Set-based design characteristic	ANOVA		Robust tests of equality of means	
	F	Sig.	Welch's F	Brown-Forsythe F
A large number of possible solutions for a design problem is considered early in the process	24.581	.000**	-	-
Alternative solutions for a design problem are developed and tested simultaneously	-	-	.000**	.000**
Decision are delayed until objective data allow the elimination of competing design solutions	9.124	.000**	-	-
A concept for a design solution is not revised once it has been selected	-	-	.000**	.000**

* p < 0.05 ** p < 0.01

Appendix C 87: Results of significance tests for the average use of 'set-based design' characteristics for different company sizes

	A large number of possible solutions for a design problem is considered early in the process	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.98)		.015*	.000**	.000**	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.70)	.019*		.605	.042*	.000**	Gabriel
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 3.06)	.000**	.647		.500	.003**	Gabriel
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.42)	.000**	.043*	.525		.744	Gabriel
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.76)	.000**	.000**	.003**	.744		Gabriel
	* p < 0.05 ** p < 0.01	Hochberg's GT2	Hochberg's GT2	Hochberg's GT2	Hochberg's GT2	Hochberg's GT2	

	Alternative solutions for a design problem are developed and tested simultaneously	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.63)		.128	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.13)			.411	.006**	.000**	Games-Howell
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.50)				.077	.003**	Games-Howell
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 2.97)					.500	Games-Howell
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.35)						Games-Howell

* p < 0.05 ** p < 0.01

Appendix C 88: Post hoc test results for the average use of 'set-based design' characteristics for different company sizes (Part 1)

	Decision are delayed until objective data allow the elimination of competing design solutions	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 2.72)		.999	.997	.227	.000**	Gabriel
2	We do not have any goals but we are planning to develop some (Ø = 2.57)	.999		1.000	.145	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.59)	.997	1.000		.030*	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 3.19)	.238	.147	.035*		.417	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.65)	.000**	.000**	.000**	.417		
	* p < 0.05 ** p < 0.01	Hochberg's GT2					

	A concept for a design solution is not revised once it has been selected	1 (n = 54)	2 (n = 23)	3 (n = 66)	4 (n = 31)	5 (n = 34)	
1	We do not have any goals and we are not planning to develop any (Ø = 1.69)		.569	.000**	.000**	.000**	Games-Howell
2	We do not have any goals but we are planning to develop some (Ø = 2.00)			.199	.008**	.000**	
3	We have developed an overall strategy but we have not yet defined lower-level goals and suitable performance measurements (Ø = 2.45)				.240	.000**	
4	We have developed an overall strategy and measurable lower-level goals but we do not have suitable performance measurements yet (Ø = 2.90)					.095	
5	We have an overall strategy, measurable lower-level goals, and suitable performance measurements (Ø = 3.59)						

* p < 0.05 ** p < 0.01

Appendix C 89: Post hoc test results for the average use of 'set-based design' characteristics for different company sizes (Part 2)

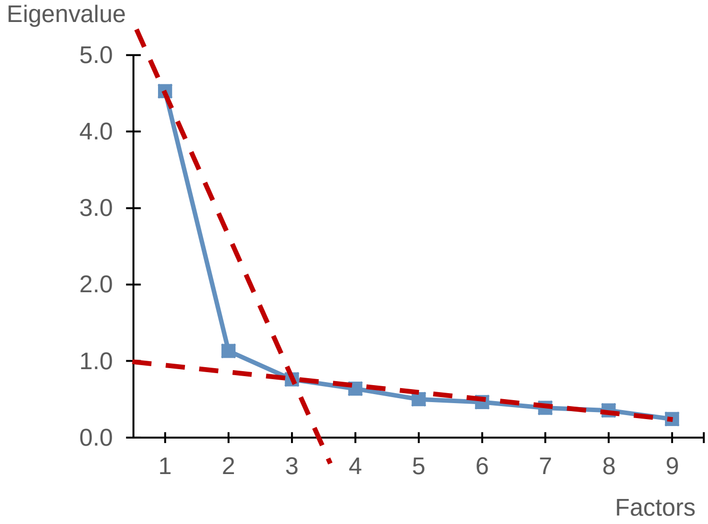
		Company size					Total
		1-99	100-999	1,000-9,999	10,000-99,999	100,000+	
Automotive	Count	9	58	29	18	3	117
	% within In which industrial sector does your company mainly operate?	7.7%	49.6%	24.8%	15.4%	2.6%	100.0%
	% within company size	64.3%	65.2%	54.7%	43.9%	27.3%	56.3%
	% of Total	4.3%	27.9%	13.9%	8.7%	1.4%	56.3%
Aerospace	Count	0	6	4	0	0	10
	% within In which industrial sector does your company mainly operate?	0.0%	60.0%	40.0%	0.0%	0.0%	100.0%
	% within company size	0.0%	6.7%	7.5%	0.0%	0.0%	4.8%
	% of Total	0.0%	2.9%	1.9%	0.0%	0.0%	4.8%
Chemicals	Count	0	6	2	0	0	8
	% within In which industrial sector does your company mainly operate?	0.0%	75.0%	25.0%	0.0%	0.0%	100.0%
	% within company size	0.0%	6.7%	3.8%	0.0%	0.0%	3.8%
	% of Total	0.0%	2.9%	1.0%	0.0%	0.0%	3.8%
Machinery, electrical, and transport equipment	Count	5	11	8	19	5	48
	% within In which industrial sector does your company mainly operate?	10.4%	22.9%	16.7%	39.6%	10.4%	100.0%
	% within company size	35.7%	12.4%	15.1%	46.3%	45.5%	23.1%
	% of Total	2.4%	5.3%	3.8%	9.1%	2.4%	23.1%
Mining and quarrying	Count	0	2	3	0	0	5
	% within In which industrial sector does your company mainly operate?	0.0%	40.0%	60.0%	0.0%	0.0%	100.0%
	% within company size	0.0%	2.2%	5.7%	0.0%	0.0%	2.4%
	% of Total	0.0%	1.0%	1.4%	0.0%	0.0%	2.4%
Other	Count	0	6	7	4	3	20
	% within In which industrial sector does your company mainly operate?	0.0%	30.0%	35.0%	20.0%	15.0%	100.0%
	% within company size	0.0%	6.7%	13.2%	9.8%	27.3%	9.6%
	% of Total	0.0%	2.9%	3.4%	1.9%	1.4%	9.6%
Total	Count	14	89	53	41	11	208
	% within In which industrial sector does your company mainly operate?	6.7%	42.8%	25.5%	19.7%	5.3%	100.0%
	% within company size	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
	% of Total	6.7%	42.8%	25.5%	19.7%	5.3%	100.0%

Appendix C 90: Frequencies of industrial sector across company size

	Strong Project Manager	Teams	Concurrent Engineering	Supplier Relationship and Integration	Set-based Design	Communication and Know ledge Transfer	Process Management	Product Variety Management	Continuous Improvement
Strong Project Manager	.629[a]	-.054	.160	-.061	.092	-.254	-.071	-.120	.038
Teams	-.054	.886[a]	-.386	-.113	.006	-.018	-.207	.052	-.150
Concurrent Engineering	.160	-.386	.846[a]	.048	-.006	.017	-.170	-.391	-.129
Supplier Relationship and Integration	-.061	-.113	.048	.925[a]	-.121	-.027	-.138	-.257	-.117
Set-based Design	.092	.006	-.006	-.121	.883[a]	-.327	-.072	-.274	-.093
Communication and Know ledge Transfer	-.254	-.018	.017	-.027	-.327	.808[a]	-.179	.139	-.161
Process Management	-.071	-.207	-.170	-.138	-.072	-.179	.927[a]	-.152	-.112
Product Variety Management	-.120	.052	-.391	-.257	-.274	.139	-.152	.854[a]	-.107
Continuous Improvement	.038	-.150	-.129	-.117	-.093	-.161	-.112	-.107	.942[a]

a. Measures of Sampling Adequacy (MSA)

Appendix C 91: Anti-image correlation matrix



Appendix C 92: Scree plot

	Ease of Implementation	Benefit of Implementation	LPD Use	Implementation Order	
Ease of Implementation	1	.845**	.586	-.593	Pearson's ρ
Benefit of Implementation	.845**	1	.881**	-.805**	
LPD Use	.586	.881**	1	-.774*	
Implementation Order	-.593	-.805**	-.774*	1	

* p < 0.05   ** p < 0.01

Appendix C 93: Correlation matrix of companies' experiences with average use and implementation order

Scale	Cronbach α	Characteristic	Corrected Item - Total Correlation
Communication	0.837	Information is passed on before it is compiled (e.g. in hand-over reports)	0.890
		Information is discussed in a dialogue-mode	0.756
		Preliminary information is shared	0.866
Knowledge Transfer	0.851	There are methods and devices to collect information on successful procedures, tools, and designs across projects	0.826
		Best practices and lessons learned from previous projects are reviewed	0.873
		Documented knowledge is continuously updated by the engineers	0.855

Appendix C 94: Reliability test results for 'communication' and 'knowledge transfer'