RISK-DRIVEN DESIGN – INTEGRATING RISK MANAGEMENT AS AN INTRINSIC PART OF PRODUCT DEVELOPMENT
Abstract

The dynamic nature of the market yields many challenges for the development of new products. To overcome potential process or product failures, a central part of the product development process includes the management and reduction of risk. This thesis investigates the integration of risk management as an emergent property of the product development approach itself. A recently published risk management framework called Risk-driven Design is used as a guiding concept for this research.

Risk and Risk Management (RM) are defined in the context of Product Development (PD). Eight existing RM frameworks in literature that are relevant to PD are reviewed and classified. In theory, Risk-driven Design (RdD) is the only framework that consists of solution-neutral principles and represents objectives or outcomes of successful RM instead of prescribing specific and external processes on how to manage risk. Based on a literature review, the respective RdD principles are validated and further developed. A collection of 85 classified and interrelated examples regarding design risks, corresponding mitigation actions, as well as risk related decisions are presented. Furthermore, characteristics of resilience are introduced.

PD frameworks are generally defined. Based on a comprehensive literature review, the extent to which common PD frameworks such as the Waterfall model, Spiral and Scrum development, Lean PD, Design for Six Sigma and several others address risk is analyzed and compared using the principles of RdD. The analysis shows that existing PD frameworks only partially address the four principles of RdD and that they have their specific strengths and weaknesses. Whereas the Waterfall model with its predictable sequential character, clear focus on structure and rigid design reviews constitutes the least responsive PD framework, Spiral and Scrum development are in contrast designed to better handle changes in customer needs. However, both latter PD approaches have limited PD project applicability. From the theoretical discussion, it is shown that Scrum development with Design for Six Sigma methods yield the most comprehensive risk management oriented PD approach.

In order to empirically validate and discuss the theoretical findings, a comprehensive survey among North American companies with 185 respondents was conducted. The results indicate that companies currently focus their RM effort too much on technological risks and too little on customer related risks. Additionally the understanding and perception of RM in PD is considerably different between project managers and PD engineers. The RM approach of several PD frameworks largely matches the theoretical findings. Moreover a first indication is given that addressing the principles of RdD positively influences the PD success.

The thesis concludes with a discussion on how to better integrate RM as an intrinsic part of PD. Based on the theoretical and empirical results, a conceptual framework is presented that companies can use as a guideline to choose the “base” PD framework that best fits the PD project characteristics, identify and benchmark the RM related performance and customize the PD process to include different risk identification, quantification and treatment actions using the principles of RdD.
ACKNOWLEDGEMENTS

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# Table of Contents

1 Introduction .................................................................................................................. 1  
1.1 Motivation .............................................................................................................. 1  
1.2 Research Goal and Approach .............................................................................. 2  
1.3 Thesis Organization ............................................................................................ 3  
2 General Context of Research .................................................................................. 5  
2.1 Risk Management in Product Development ....................................................... 5  
2.1.1 General Introduction to Risk Management .................................................. 5  
2.1.2 Definition of Risk and Risk Management .................................................... 6  
2.1.3 Goals and Benefits of Risk Management ..................................................... 7  
2.2 Product Development Frameworks ...................................................................... 10  
2.2.1 General Introduction to Product Development ............................................ 10  
2.2.2 Common Product Development Processes ............................................... 11  
2.2.3 Product Development Frameworks .............................................................. 13  
2.3 Research Communities ....................................................................................... 14  
2.4 Research Gap in Literature .................................................................................. 16  
2.5 Research Approach ............................................................................................. 17  
2.5.1 Literature Review .......................................................................................... 17  
2.5.2 Interviews ...................................................................................................... 18  
2.5.3 Survey ........................................................................................................... 19  
2.6 Summary of the Chapter ..................................................................................... 19  
3 Risk Management Frameworks .............................................................................. 21  
3.1 Research question and methodology ................................................................. 21  
3.2 Existing frameworks relevant to Product Development .................................... 21  
3.2.1 External Risk Management Process Frameworks ..................................... 22  
3.2.2 Risk Management as an Intrinsic Part of Product Development ............... 25  
3.3 Comparison and discussion .............................................................................. 26  
3.4 Summary of the Chapter ..................................................................................... 30  
4 Risk-driven Design ................................................................................................. 31  
4.1 Research question and methodology ................................................................. 31  
4.2 Uncertainty and Risks in the Context of Risk-driven Design ............................ 31
Table of Contents

4.3 Validation and further development ................................................................. 35
  4.3.1 Principle 1 - Creating Transparency regarding Design Risks ......................... 36
  4.3.2 Principle 2 – Making Risk-Driven Decision ................................................. 37
  4.3.3 Principle 3 – Minimizing Uncertainty in Design .......................................... 38
  4.3.4 Principle 4 – Creating Resilience in the Design System ............................... 39
  4.3.5 Mapping risk management processes to Risk-driven Design ................................ 40
4.4 Classified examples of the four Risk-driven Design principles ................................ 41
4.5 Summary of the chapter ..................................................................................... 48

5 Risk Management in Product Development Frameworks ........................................ 50
  5.1 Research questions and methodology ............................................................. 50
  5.2 Literature base of discussion ........................................................................... 50
  5.3 Product Development Processes ...................................................................... 53
    5.3.1 The Traditional Waterfall Model ................................................................. 53
    5.3.2 Spiral Development .................................................................................... 56
    5.3.3 The Scrum Methodology ........................................................................... 59
    5.3.4 Incremental delivery .................................................................................. 63
    5.3.5 Evolutionary Development ....................................................................... 66
  5.4 Product Development Principles ....................................................................... 68
    5.4.1 Design for Six Sigma ................................................................................ 68
    5.4.2 Lean Product Development ..................................................................... 72
  5.5 Comparison and Interpretation ......................................................................... 75
  5.6 Limitations and discussion .............................................................................. 78
  5.7 Summary of the chapter .................................................................................... 79

6 Survey on Risk Management in Product Development ........................................... 80
  6.1 Research questions and methodology ............................................................ 80
    6.2.1 Goals of the Survey .................................................................................. 80
    6.2.2 Development of the Survey ..................................................................... 83
    6.2.3 General Structure of the Survey ............................................................... 83
    6.2.4 Data Collection ....................................................................................... 85
  6.3 Contribution of this Thesis ............................................................................... 86
    6.3.1 Revision and Completion of Survey Questions ......................................... 86
<table>
<thead>
<tr>
<th>Section</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.2</td>
<td>Online Survey Infrastructure</td>
<td>87</td>
</tr>
<tr>
<td>6.3.3</td>
<td>Automated Benchmarking Tool</td>
<td>88</td>
</tr>
<tr>
<td>6.3.4</td>
<td>Descriptive Analysis of Survey Data</td>
<td>91</td>
</tr>
<tr>
<td>6.3.5</td>
<td>Exploratory Analysis of Survey Data</td>
<td>92</td>
</tr>
<tr>
<td>6.4</td>
<td>Findings of the Descriptive Analysis</td>
<td>94</td>
</tr>
<tr>
<td>6.4.1</td>
<td>Characteristics of the Organization of Study Participants</td>
<td>94</td>
</tr>
<tr>
<td>6.4.2</td>
<td>Characteristics of the Project of Study Participants</td>
<td>98</td>
</tr>
<tr>
<td>6.4.3</td>
<td>Use of Risk Management Process Frameworks</td>
<td>99</td>
</tr>
<tr>
<td>6.4.4</td>
<td>Use of Product Development Frameworks</td>
<td>100</td>
</tr>
<tr>
<td>6.5</td>
<td>Findings of the Exploratory Analysis</td>
<td>102</td>
</tr>
<tr>
<td>6.5.1</td>
<td>Overview of Applied and Aggregated Questions</td>
<td>103</td>
</tr>
<tr>
<td>6.5.2</td>
<td>Principle 1 - Creating Transparency regarding Design Risks</td>
<td>104</td>
</tr>
<tr>
<td>6.5.3</td>
<td>Principle 2 - Making Risk-driven Decisions</td>
<td>106</td>
</tr>
<tr>
<td>6.5.4</td>
<td>Principle 3 - Minimizing Uncertainty in Design</td>
<td>107</td>
</tr>
<tr>
<td>6.5.5</td>
<td>Principle 4 - Creating Resilience in the Design System</td>
<td>112</td>
</tr>
<tr>
<td>6.5.6</td>
<td>Risk Management Related Performance</td>
<td>114</td>
</tr>
<tr>
<td>6.5.7</td>
<td>Integral Findings Regarding the Principles of Risk-driven Design</td>
<td>116</td>
</tr>
<tr>
<td>6.6</td>
<td>Limitations of the Survey Results</td>
<td>120</td>
</tr>
<tr>
<td>6.7</td>
<td>Summary and Discussion of the Findings</td>
<td>120</td>
</tr>
<tr>
<td>7</td>
<td>Conclusion and Future Research</td>
<td>124</td>
</tr>
<tr>
<td>7.1</td>
<td>Conclusion</td>
<td>124</td>
</tr>
<tr>
<td>7.2</td>
<td>Future Research</td>
<td>127</td>
</tr>
<tr>
<td>8</td>
<td>References</td>
<td>129</td>
</tr>
<tr>
<td>10</td>
<td>Appendix B – Folder Structure of the Enclosed DVD-ROM</td>
<td>169</td>
</tr>
<tr>
<td>11</td>
<td>Appendix C – Glossary</td>
<td>170</td>
</tr>
</tbody>
</table>
## List of Terms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PD</td>
<td>Product Development</td>
</tr>
<tr>
<td>RM</td>
<td>Risk Management</td>
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<td>RdD</td>
<td>Risk-driven Design</td>
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<tr>
<td>RQ</td>
<td>Research Question</td>
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<td>ISO</td>
<td>International Organization for Standardization</td>
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<td>PDP</td>
<td>Product Development Process</td>
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<td>LAI</td>
<td>Lean Advancement Initiative</td>
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<tr>
<td>KFUPM</td>
<td>King Fahd University of Petroleum and Minerals</td>
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<tr>
<td>PMI</td>
<td>Project Management Institute</td>
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<tr>
<td>INCOSE</td>
<td>International Council on Systems Engineering</td>
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<tr>
<td>DoD</td>
<td>Department of Defense</td>
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<tr>
<td>PRINCE2</td>
<td>Projects in Controlled Environments</td>
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<tr>
<td>ID</td>
<td>Incremental delivery</td>
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<tr>
<td>ED</td>
<td>Evolutionary Development</td>
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<td>EP</td>
<td>Evolutionary Prototyping</td>
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<td>DISS</td>
<td>Design for Six Sigma</td>
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<tr>
<td>VOC</td>
<td>Voice of the Customer</td>
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<tr>
<td>SBCE</td>
<td>Set-based Concurrent Engineering</td>
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<td>GAO</td>
<td>Government Accountability Office</td>
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<tr>
<td>RiskSIG</td>
<td>Risk Management Special Interest Group</td>
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<tr>
<td>NDIA</td>
<td>National Defense Industrial Association</td>
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<tr>
<td>PM</td>
<td>Program Manager</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1-1: General Research Questions and Contributions of the Thesis ...........................................2
Figure 1-2: Structure of the Thesis ........................................................................................................3
Figure 2-1: Six levels of treatment of uncertainty in risk analysis (adapted from PATÉ-CORNELL 1996) .................................................................8
Figure 2-2: The generic product development process (adapted from ULRICH et al. 2008 & UNGER 2003) ..............................................................................12
Figure 2-3: Classified PD frameworks that are investigated in this thesis (proposal) ........13
Figure 2-4: Research communities of Risk Management related to Product Development .... 15
Figure 3-1: Risk Management Process, adapted from ISO 3100 (ISO 2009a) ....................... 25
Figure 3-2: The four principles of Risk-driven Design (OEHMEN et al. 2011) ..................... 26
Figure 4-1: Framework of risk as the effect of uncertainty on objectives in the context of Risk-driven Design ........................................................................................................... 34
Figure 4-2: The conventional and risk-based views of a PD system as a transformation process .................................................................35
Figure 4-3: Mapping risk management process elements to Risk-driven Design principles ...40
Figure 5-1: The traditional waterfall or staged PD-process (UNGER et al. 2009) ..................... 54
Figure 5-2: Spiral PD-process model (UNGER et al. 2009) ............................................................. 56
Figure 5-3: The Scrum Product Development Process (SCHWABEL 1995) ............................. 60
Figure 5-4: Incremental delivery (adapted from FORSBERG et al. 1995) ................................. 64
Figure 5-5: The Evolutionary Prototyping PD process (adapted from MCCONNELL 1996) ... 67
Figure 5-6: The flowchart of Design for Six Sigma (MAASS et al. 2010) .................................. 69
Figure 6-1: Survey Flow of the Different Respondent Groups .................................................... 88
Figure 6-2: Screenshot of Benchmarking Tool (1) - Example of Result Sheet ‘General Project’ ......................................................................................................................... 90
Figure 6-3: Screenshot of Benchmarking Tool (2) - Example of Data Source ‘Master-Methods v2’ ................................................................................................................... 90
Figure 6-4: Organization type and industry sectors of participating companies .................. 94
Figure 6-5: Yearly budget or revenue of participating companies .......................................... 95
Figure 6-6: Program level of participating companies .................................................................. 96
Figure 6-7: Role of survey participants during the program ...................................................... 96
Figure 6-8: Dedicated time and budget on RM activities of participating companies .......... 97
Figure 6-9: Main type of product of the PD project.................................................................98
Figure 6-10: Aggregated project profile of participating companies along uncertainty types.99
Figure 6-11: Use of risk management process frameworks in the project ............................100
Figure 6-12: Use of PD frameworks in the project ...............................................................101
Figure 6-13: Application background of PD frameworks ......................................................102
Figure 6-14: Profile of risk impact vs. frequency of occurrence .........................................105
Figure 6-15: Risk severity profile along uncertainty types ..................................................106
Figure 6-16: Use of risk evaluation actions in the PD project ............................................107
Figure 6-17: Profile of risk mitigation action effectiveness versus. frequency of use ..........108
Figure 6-18: Risk mitigation action intensity profile along uncertainty types .....................109
Figure 6-19: Risk Management Map - profile of risk severity versus mitigation action intensity ........................................................................................................................................110
Figure 6-20: Risk mitigation effectiveness profile of PD frameworks .................................112
Figure 6-21: Risk mitigation intensity profile regarding characteristics of resilience .........113
Figure 6-22: Resilience mitigation effectiveness (frequency of use) of PD frameworks .....114
Figure 6-23: Overall PD project success of participating companies .................................115
Figure 6-24: Agreement with statements regarding the role and perception of risk management (PM vs. RM) ..............................................................................................................116
Figure 6-25: Summary of addressing Principles of Risk-driven Design (High Performer vs. Low Performer) ..................................................................................................................117
Figure 6-26: Summary of all PD frameworks addressing Principles of Risk-driven Design 119
Figure 6-27: Conceptual framework for integrating RM into PD based on theoretical and empirical findings .................................................................122
Figure 9-1: Introductory pages of the survey .......................................................................147
Figure 9-2: Introductory pages of the survey structure .........................................................148
Figure 9-3: General Questions - Organization ......................................................................149
Figure 9-4: General Questions – Program/Project Part 1 .....................................................150
Figure 9-5: General Questions – Program/Project Part 1 .....................................................151
Figure 9-6: General Questions – Program/Project Part 2 .....................................................152
Figure 9-7: General Questions – Program/Project Part 2 .....................................................153
Figure 9-8: Questions on RM Process 1: Planning and Preparation ....................................154
Figure 9-9: Questions on RM Process 1: Planning and Preparation ....................................155
Figure 9-10: Questions on RM Process 2: Risks and Their Impact ......................................156
List of Figures

Figure 9-11: Questions on RM Process 2: Risks and Their Impact ........................................ 157
Figure 9-12: Questions on RM Process 3: Risk Analysis ..................................................... 158
Figure 9-13: Questions on RM Process 4: Risk Evaluation .................................................... 159
Figure 9-14: Questions on RM Process 5: Risk Mitigation ..................................................... 160
Figure 9-15: Questions on RM Process 5: Risk Mitigation ..................................................... 161
Figure 9-16: Questions on RM Process 5: Risk Mitigation ..................................................... 162
Figure 9-17: Questions on RM Process 6: Monitoring and Review ........................................ 163
Figure 9-18: Questions on RM Process 6: Monitoring and Review ........................................ 164
Figure 9-19: Questions on RM Performance ........................................................................... 165
Figure 9-20: Questions on RM Performance ........................................................................... 166
Figure 9-21: Option to receive survey results and general feedback ....................................... 167
Figure 9-22: Last page of the survey ...................................................................................... 168
List of Tables

Table 3-1: Overview of Existing Risk Management frameworks relevant to Product Development ................................................................. 29
Table 4-1: Examples of risks linked to the third principle of Risk-driven Design ................................................................. 44
Table 4-2: Examples of risk-related decisions ................................................................. 45
Table 4-3: Examples of risk mitigation actions linked to the first principle of Risk-driven Design ................................................................. 47
Table 4-4: Examples of characteristics of resilience linked to the first principle of Risk-driven Design ................................................................. 48
Table 5-1: Overview of reviewed PD framework literature ................................................................................................. 53
Table 5-2: Summary of the waterfall model risk management approach ......................................................................................... 56
Table 5-3: Summary of the spiral model risk management approach ................................................................................................. 59
Table 5-4: Summary of scrum risk management approach ............................................................................................................. 63
Table 5-5: Summary of incremental delivery risk management approach ................................................................................................. 66
Table 5-6: Summary of the evolutionary development risk management approach ................................................................................................. 68
Table 5-7: Summary of the DfSS risk management approach ............................................................................................................. 71
Table 5-8: The eleven components of Lean Product Development related to literature sources (HOPPMANN 2009) ................................................................................................. 72
Table 5-9: Summary of the Lean PD risk management approach ............................................................................................................. 75
Table 5-10: Overview of Extend of Risk Management of Different PD Frameworks ................................................................................................. 77
Table 6-1: Structure of the Survey on Risk Management Practices in Product Development ................................................................. 84
Table 6-2: Main Structure of the Automated Benchmarking Tool ............................................................................................................. 89
Table 6-3: Overview of Applied Survey Questions to the Descriptive Analysis ................................................................................................. 91
Table 6-4: Overview of Applied Survey Questions to the Exploratory Analysis ................................................................................................. 92
Table 6-5: Overview of applied and aggregated questions along types of uncertainty and RdD principles ................................................................................................. 103
1 Introduction

1.1 Motivation

Companies currently operate in very dynamic environments in which they are driven by competitive pressure to deliver their products faster, at cheaper prices and with better quality than their competitors (CHALUPNIK et al. 2009, ULRICH et al. 2008). The task of product development (PD) gets increasingly complex as it has to integrate preferences of a multitude of stakeholders from both inside and outside the organization to devise one overall optimal set of specifications (SOMMER et al. 2008, OEHMEN et al. 2010a). Thus, it requires knowledge spanning numerous disciplines, such as engineering, manufacturing, and marketing (AHMADI et al. 1999).

Although PD is valuable as a source of competitive advantage, it is a risky endeavor. The risks involved in the process of PD are significant as decisions that will strongly affect the product outcome must be made at a time of high uncertainty (FERDOWSI 2003). In this regard, many PD projects fail because of poor management of the design process and product development risk. As an example, the US Department of Defense is currently confronted with a cost overrun in development and acquisition projects of close to $300 billion, and deficient risk management is cited as one of the main underlying reasons (GAO 2009).

To address and overcome potential process or product failures, the literature acknowledges the management and reduction of risk as a central element of PD. Assuming that the objectives of PD projects is developing products that meet or exceed stakeholders’ expectations within budget and in a timely fashion, then any uncertainties that may cause delays, cost overruns, degradation in performance and/or misinterpreting stakeholder requirements are risks that need to be managed (BASSLER et al. 2011). Additional PD related risk exists due to the uncertainty regarding the stability of customer requirements (i.e. the customer utility functions). In this context, customers or stakeholders can change or extend requirements or their priority throughout the development process, resulting in significant changes in system specification, program execution or scope creep.

Risk management is the practice of identifying, evaluating and controlling risks to avoid or mitigate potential negative effects on the PD project (MEYER et al. 2001). It allows for considering both risk and reward in PD projects and contributes by increasing the quality of the PD processes (OEHMEN et al. 2010a). A recently published empirical study furthermore indicated that risk management strategies targeted at specific risk factors (i.e. technological, organizational and marketing) contribute both individually and interactively in affecting the performance of PD (MU et al. 2009). Hence, successful risk management greatly adds to the probability of project success (ROYER 2000).

However, in current practices risk management still tend to be treated as separate tasks rather than an integrated management approach (OEHMEN et al. 2010b). As such, various external risk management frameworks are developed that provide different prescriptive steps on how to manage risk such as the Department of Defense (DoD 2006), Project Management Institute
(PMI 2008a), NASA (NASA 2008) or the International Council on Systems Engineering (HASKINS et al. 2010). On the other side, risk management as an intrinsic part of PD is not investigated to a great extent in literature. Although an extensive array of different PD processes or principles exist (UNGER et al. 2009), there is currently no analytical comparison of PD frameworks’ inherent risk management capabilities that can help companies to find a suitable “base PD approach” to execute the PD project with a more effective intrinsic risk management.

Addressing this gap, one concept that advocates the integration of risk management processes and methods directly into the PD process is the recently published framework of Risk-driven Design (OEHMEN et al. 2011). This thesis builds upon the four underlying framework principles and investigates the integration of risk management into PD processes in more detail with both a theoretical and empirical research focus.

1.2 Research Goal and Approach

The overall goal of this thesis is to investigate how to better integrate risk management as an intrinsic part of product development. The recently published risk management framework Risk-driven Design is used as a guiding concept for this research.

The following Figure 1-1 provides an overview of the main research questions and the general research contributions of this thesis. It furthermore shows the chapters in which these questions are addressed.

![Figure 1-1: General Research Questions and Contributions of the Thesis](image-url)
In this context, the goals of this thesis are to address the following six research questions:

- (RQ1) What existing Risk Management frameworks are relevant for Product Development?
- (RQ2) How can the Risk-driven Design principles be validated and further developed?
- (RQ3) How do common Product Development Frameworks manage risks?
- (RQ4) What existing Risk Management frameworks are mostly used in industry?
- (RQ5) To what extent follows the industry the principles of Risk-driven Design?
- (RQ6) What is the Risk Management related performance of different Product Development Frameworks?

1.3 Thesis Organization

Addressing the goals described in the previous section, the following Figure 1-2 displays the structure of the thesis.

![Figure 1-2: Structure of the Thesis](image-url)
Introduction

In chapter 2 the general context for the discussion of the research domains of this thesis is laid out. It briefly introduces risk management in product development and emphasizes the corresponding goals and benefits. In addition, the general context of product development is narrowed down to the specific topic of product development frameworks. To associate the thesis with current research fields, existing research communities of risk management in product development are emphasized. At the end of the chapter, the research gap is formulated and the deployed research methodology is described.

Chapter 3 compares and discusses existing risk management frameworks that are relevant for product development based on a literature review. In this context, it classifies risk-driven design and describes its key benefits in regard to integrating risk management as an intrinsic part of product development.

Chapter 4 discusses the framework of risk-driven design in more detail. It validates and further develops the underlying four principles and presents a large collection of classified and linked examples of design risks, risk related decisions, risk mitigation actions and characteristics of resilience.

Chapter 5, as the last and biggest part of the theoretical research approach, analyzes and discusses the intrinsic risk management approach of different PD frameworks. The principles of risk-driven design are used as a guiding concept for this investigation. At the end of the chapter, a structured analytical comparison of the PD framework findings is presented.

Chapter 6 contains a comprehensive survey on risk management in product development to both deepen the knowledge of the current state of risk management practice in industry and to discuss the results of the literature-based chapters 3-5. In this regard, the context of the greater research project, the specific contributions of this thesis, the survey methodology, structure and sampling as well as the findings of both a descriptive and an in-depth exploratory analysis is described. At the end of the chapter, the findings of both theory and practice are discussed regarding how to better integrate risk management as an intrinsic part of product development.

Chapter 7 contains the final conclusion and the outlook for future research.
2 General Context of Research

2.1 Risk Management in Product Development

The following section provides a first overview of risk management related to product development. Based on a general introduction to risk management (Section 2.1.1), risk and risk management are generally defined and classified (Section 2.1.2). In addition, fundamental goals and corresponding benefits of risk management in product development are described in Section 2.1.3. Building upon the findings of this introductory section, Section 4.2 more specifically illustrates the concept of uncertainty and risk in the context of Risk-driven Design.

2.1.1 General Introduction to Risk Management

Besides its origin in the financial sector, risk management (RM) has become very popular in various fields of engineering (WAGNER 2007). It is comprehensively applied in areas such as product development (UNGER et al. 2009, OEHMEN et al. 2010a, SMITH et al. 2002), supply chain management (OEHMEN 2009, ZIEGENBEIN 2007), software development (HALL 1998, BOEHM 1989, BOEHM 1991), project management (PMI 2008a, CHAPMAN et al. 1997) or systems engineering (HASKINS et al. 2010, McMANUS et al. 2006).

In the field of Product Development (PD), risk management plays a crucial role as risk is intrinsic or prevalent in every PD project in every industry (KWAK et al. 2005, UNGER et al. 2009). OEHMEN et al. (2010b) even underline the similarity of risk management and PD activities. The authors argue that if risk management is interpreted as the structured identification and reduction of uncertainty, all PD activities that aim at minimizing uncertainty can be seen as risk treatment measures such as knowledge management, quality management, review processes or early supplier or customer integration. However, in current practices these processes still tend to be treated as separate tasks rather than an integrated management approach (OEHMEN et al. 2010b).

The general purpose of RM is to improve project performance with a systematic identification, assessment and management of PD-related risk (CHAPMAN et al. 1997). It contributes directly to project and product success by identifying and quantifying the actual risk state, enabling risk-based decision making, risk minimization and building a resilient design system (BASSLER et al. 2011). RM also allows considering both risk and reward in PD projects and increases the quality of the PD processes (OEHMEN et al. 2010a). From the Lean Product Development perspective, it is an important tool to explicitly create customer value by reducing uncertainty in PD projects which improves the affordability of the product (BROWNING et al. 2003). Although rarely considered pleasant in business, UNGER (2003) emphasizes that taking risk is frequently essential for PD success. Managing and therefore balancing risks and potential rewards is one of the most enduring themes of engineering and program management (ANSELL et al. 1992, MACCRIMMON et al. 1988, FOSTER et al. 2001).
2.1.2 Definition of Risk and Risk Management

Existing literature suggests various definitions and categorizations of risks. MEYER et al. (2001) define risk in regard to project management as an “uncertain factor – positive or negative – that can significantly affect achievable performance” (p.61). As such, the authors emphasize that risk management is the practice of identifying, evaluating and controlling those factors to avoid or mitigate potential negative effects (MEYER et al. 2001). BROWNING et al. (2003) define risk associated with technical product performance as the “uncertainty that a product design will satisfy technical requirements and the consequences thereof” (p.445).

In the context of product development, UNGER (2003) defines risk as the “exposure to danger or loss” (p.21). He describes four generic and interrelated types of risk and emphasizes that a successful PD process should be able to manage or mitigate them:

- **Technical**: Risk whether a new product is technologically feasible and will perform as expected. This risk type is related to design specifications that are distinct and valid but difficult to achieve.
- **Schedule**: Risk whether a new product can be developed within the originally planned time.
- **Budget**: Risk whether a new product can be developed with the available financial resources.
- **Market**: Risk whether a new product accurately addresses changing customer requirements and product positioning with respect to dynamic market competitions. This risk type arises when the market needs are not met, assuming that the technical product specification has been satisfied (SMITH et al. 1991).

Besides the stated risk definitions of researchers, various government organizations and professional associations introduced different classifications of risk and risk management. In this regard, the Department of Defense defines risk as a “measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints” (DoD 2006, p.1). The Project Management Institute outlines risk as an “uncertain event or condition that, if it occurs, has an effect on at least one project objective” (PMI 2008b, p.275). In the context of systems engineering, the International Council on Systems Engineering (INCOSE) defines risk as “events that if they occur can influence the ability of the project team to achieve project objectives and jeopardize the successful completeness of the project” (HASKINS et al. 2010, p.218). Further definitions of risk of different organizations and associations can be seen in Table 3-1.

This thesis follows the ISO 31000 definition of risk as the “effect of uncertainty on objectives” (ISO 2009a, p.1). Thus, if PD objectives are understood as meeting or exceeding internal or external stakeholders expectations within schedule and budget, any events that cause delays, quality deviations, cost overruns or misinterpretation of customer requirements are risks that have to be managed (BASSLER et al. 2011).
Additional PD related risks exist due to the uncertainty regarding the stability of customer requirements (i.e. the customer utility functions). In this context, customers or stakeholders can change or extend requirements or their priority throughout the PD process, resulting in significant changes in system specification, program execution or scope creep.

As the definition implicates, risk is closely tied to uncertainty. Uncertainty is a prerequisite to risk and is often viewed as a natural basis over which initiatives may be taken. Risk usually applies to the critical action rather than the context and tends to be more quantifiable (UNGER 2003, BEN-HAIM 2001). A common and basic quantification method of risk is the product of probability of risk occurrence and the severity of its consequences in the PD project (McMANUS et al. 2006). A more sophisticated view of risk analysis is described by OEHMEN et al. (2011). The authors emphasize risk as probability-distributed input factors leading to probability-distributed achievements of objectives. Risks can therefore be analyzed in various ways such as (OEHMEN et al. 2011):

- The probability of failure to achieve a specific target
- The maximum possible deviation from an objective for a project
- A probability-weighted deviation from an objective, either as a point estimate of single impact and probability pair or as the integration of a probability-distributed objective function
- The variance from a mean value for achieving an objective

As already stated in the previous section, risk management is an important tool to mitigate risks by creating transparency regarding the risk state and enabling management attention to either minimize the likelihood of risk occurrence or reduce the potential risk severity of consequences in the PD project. Existing literature strongly emphasizes the process characteristics of risk management and recommends comprehensive sequential frameworks to cope with risks. In this context and as described above, various government organizations and professional associations suggest different definitions of risk management that are presented in Table 3-1.

Similar to the classification of risk, this thesis follows the ISO 31000 definition of risk management as “coordinated activities to direct and control an organization with regard to risk” (ISO 2009a, p.2).

### 2.1.3 Goals and Benefits of Risk Management

In general, the goal of risk management is to explicitly and proactively address risk in a structured approach in order to minimize the associated losses (OEHMEN 2005). In the case of product development managers therefore need to (MU et al. 2009, p.171):

- Identify and control the risk factors within time and resource limits of the project
- Take actions to reduce the likelihood of a bad outcome
- Minimize adverse impact
Most notably, the process of identification and control of risks is considered to be a significantly important aspect of the overall risk management effectiveness (OGC 2009). ROYER (2000) accentuates that unrecognized, unmanaged or unmitigated risks are among the primary causes of project failures. In this regard, PATÉ-CORNELL (1996) presents a prominent analytical approach in the treatment of uncertainties in risk analysis consisting of six different sophistication levels (see Figure 2-1). The author emphasizes that structured information in the assessment of risks can be “envisioned depending on the alternatives of the decision, on the management rule that one intends to apply, on the magnitude of the outcomes, and on the probabilities of these outcomes” (PATÉ-CORNELL 1996, p. 98). Thus, risk management needs to identify and assess risks using the following six levels of treatment:

**Figure 2-1: Six levels of treatment of uncertainty in risk analysis (adapted from PATÉ-CORNELL 1996)**
• **Level 0 – Hazard detection and failure modes’ identification:** This level merely involves the identification of a potential hazard or of the different ways in which a system can fail, without attempting to assess the risk in any quantitative manner.

• **Level 1 – ‘Worst-case’ approach:** The first level does not involve any notion of probability but is based on the accumulation of worst-case assumptions and only yields the potential maximum loss level.

• **Level 2 – quasi worst cases and plausible upper bounds:** The second level attempts to acquire an evaluation of the worst possible conditions that can be ‘reasonably’ predicted when there is some uncertainty as to what the worst case might be, or when the worst case is so unlikely that it is meaningless (e.g. Maximum Credible Earthquake used in building codes).

• **Level 3 – best estimates and central values:** The third level relies on a ‘best estimate’ and/or on a central value (e.g. the mean, the median, or the mode) of the outcome (e.g. loss) distribution, generally through ‘best estimates’ of the different variables (e.g. assessment of health risks)

• **Level 4 – probabilistic risk assessment, single risk curve:** The fourth level relies on the probabilistic risk analysis process (also defined as quantitative risk assessment or probabilistic safety assessment in literature) which can be performed to obtain a distribution of the probabilities of the different system states based on best estimates of the models and parameter values. The effects of all uncertainties are aggregated into one distinctive risk curve.

• **Level 5 – probabilistic risk analysis, multiple risk curves:** The fifth and last level allows the display of uncertainties about fundamental hypotheses by multiple risk curves. This can be done by statistical treatment of existing data or by asking a group of experts to provide an assessment of risk based on their evaluation of the distribution of parameter values given this model.

The PD project can benefit in several ways if risk is managed properly. Among other factors, this includes (OEHMEN 2005):

• Less firefighting
• Crisis prevention
• Reduction of surprise problems in late development phases
• Avoidance of reoccurrence of known problems
• Explicit addressing of root cause
• Retaining of best practice solutions and organizational learning
As already stated in the motivations of this thesis (see Section 1.1), Mu et al. (2009) furthermore argue that risk management strategies targeted at specific risk factors (i.e. technological, organizational and marketing) contribute both individually and interactively in affecting the performance of PD. As such, the authors emphasize that if companies effectively manage risks associated with PD by increasing their stock of knowledge, then risk and uncertainty “will be a source not merely of threats, but of opportunities” (p.176).

2.2 Product Development Frameworks

This section narrows the general context of product development down to the specific topic of product development frameworks in order to better understand the theoretical risk management capability analysis in Chapter 5. Thus, the following Section 2.2.1 provides an overview of the fundamental basics and current challenges of PD in order to establish a common language for the reader. In addition, common processes or actions that are included in PD efforts are underlined (Section 2.2.2). To cope with the various PD tasks and uncertainties, the literature provides different PD frameworks that are introduced and classified in the following Section 2.2.3.

2.2.1 General Introduction to Product Development

The ability to repeatedly develop successful products is crucial to maintaining a competitive position in the market (Griffin et al. 1996). As such, companies need to identify the customer needs and rapidly create products that meet this demand at low development and product cost. Product development plays an important role in this endeavor since it is the process in which most of the product’s life cycle costs are determined (Browning et al. 2003). In this thesis product development (PD) is defined as the “set of activities beginning with the perception of the market opportunity and ending in the production, sale and delivery of a product” (Ulrich et al. 2008, p.2). Therefore PD involves the full spectrum of activities including marketing, design, management and several others (Browning et al. 2003).

Unlike manufacturing, the goal of PD is not to frequently execute distinctive tasks in the exact same way, but to generate information that hasn’t been exactly generated before (Schuh et al. 2007). This information has to be transformed into precise product specifications that must conform to the customer or market needs. PD is therefore a problem-solving and knowledge-accumulation process which adds value by creating useful information that reduces uncertainty (Browning et al. 2003). In order to assess the performance of a PD effort, Ulrich et al. (2008) emphasize five dimensions that are related to profit: product quality, product cost, development time, development costs and development capability. The authors underline that high performance along these PD metrics “should ultimately lead to economic success” (p.3).

However, in order to achieve and sustain high performance, there are many difficulties that have to be managed in the task of PD. One of the main challenge arises from the complexity of integrating technical feasibility with the preferences of various stakeholders from both inside and outside the organization to elaborate one overall optimal set of specifications.
Therefore PD is an interdisciplinary task requiring various contributors and clearly managed operational and organizational structures (ULRICH et al. 2008, WAGNER 2007). Since companies currently focus more on their core competencies, the degree of internal value creation decreases which intensifies the necessity of partners along the value chain. This aspect however leads to additional sources of uncertainties that can affect the overall PD objectives (OEHMEN et al. 2010a). In this regard, existing literature provides various examples of risks in PD that led to alternating degrees of failures of the PD process and the product in the market such as:

- The PD project cost and schedule overrun of the Boeing 787 Dreamliner (TANG et al. 2009)
- The large scale budget overrun of 45% in major PD projects of the Department of Defense, which results in projected additional costs of $296 billion for the largest 96 systems that are currently being developed (GAO 2010)
- The Newton Message Pad introduced by Apple in 1993, which suffered from risks related to product quality, performance and the associated product prize (BAYUS et al. 1997)

As already stated in the previous section, risk management in PD is an imperative tool to identify, assess and minimize the risks that companies face (see Section 2.1.3). Thus, existing literature sources recognize product development frameworks as risk management structures since they provide an organized approach for managing uncertainty in PD (UNGER 2003).

### 2.2.2 Common Product Development Processes

Most product development efforts involve a series of common actions or tasks. Executing them in an organized manner constitutes a product development process (PDP) (UNGER 2003). As such, a PDP is defined as a “sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product” (ULRICH et al. 2008, p.14). Due to the dynamic nature of the market and the resulting challenges in the development of new products, the literature provides many different PDPs that attempt to mitigate uncertainties in the development processes in different ways. Although every PDP is not uniform, there are comparable elements or steps in every approach (ULRICH et al. 2008, UNGER 2003, UNGER et al. 2009) (see Figure 2-2):
• **Product Planning** – The first introductory step includes the assessment of technology development, market objectives as well as the selection and design of the product concept.

• **Concept development** – In the next phase, companies need to identify the needs of the customer or the target market and generate and evaluate alternative product concepts. UNGER (2003) emphasizes that this phase furthermore involves choosing from an array of PD processes with different types of schedules, patterns and feedback iterations in order to determine how to proceed with the overall PD process.

• **System-Level Design** – The system-level design phase includes the definition of upper-level design of the overall product and the system architecture. The output of this phase usually includes a generic layout of the product including an initial setting of product specification without great attention on individual modules or features.

• **Detail Design** – This phase is the actual ‘main’ part of the development process and includes the mathematical or engineering design of mechanical components or the actual coding of software.

• **Integration and Test** – This step primarily involves the validation and verification of both the detailed and system-level design to confirm the behavior and feasibility of the product with detailed prototyping and simulations. Depending on the chosen PD process, this phase can be one before the last in which success is common or a regular part of a frequently-occurring iteration cycle, in which case the information from both successful and unsuccessful tests are used as feedback for product modifications (UNGER 2003).

• **Release** – The last PD step mainly includes marketing, production ramp-up and several other issues such as financing or maintenance contracts. After the release of the product, the company has no expectancy of further testing it. Any received feedback from the product is either used for future product versions or goes towards fixes or maintenance in case of trouble or recalls (UNGER 2003).
All of the stated PDP can be arranged or advanced in different ways. For instance, firms in the pharmaceutical industry need additional steps and requirements regarding clinical tests and pretrial approvals. The PD tasks can also strongly vary depending on reviews and information feedback within the company which leads to shortened, repeated, skipped, reordered or reorganized PD processes. In this regard, companies frequently face the difficult challenge of designing or choosing a PD framework that best addresses their specific risk situation in the PD project (UNGER 2003, UNGER et al. 2009).

2.2.3 Product Development Frameworks

The general purpose of PD frameworks is to guide the process of product development from the task to achieving a solution with a structured management approach (WAGNER 2007, UNGER 2003). In this thesis, ‘PD framework or PD approach’ is the umbrella term for both PD process frameworks and PD principles.

It should be noted, that all of the reviewed PD approaches explicitly focus on engineered software as well as hardware products and are frequently used by companies in these respective industry sectors (see Section 6.4.4).

As can be seen in Figure 2-3, the following seven PD frameworks are further investigated in this thesis:

- The Traditional Waterfall Model
- Spiral Development
- The Scrum Methodology
- Incremental Delivery
- Design for Six Sigma
- Lean Product Development
- Evolutionary Development
Past research in the area of PD related risk management both in software and hardware development (e.g. McCONNELL 1996, UNGER 2003, UNGER et al. 2009, FERDOWSI 2003) focused on most of these models. Furthermore various discussions with industry practitioners confirmed the important role of the stated PD frameworks and showed that they are comprehensively used in current industry practices.

The PD frameworks in this thesis are grouped along two criterions. The first criterion refers to the actual framework type. As already stated above, this thesis investigates both PD process frameworks and PD principles. PD process frameworks are the actual base PD approach of the project and involve a common and generic series of actions, steps or stages to manage PD risks (UNGER 2003). They all follow at least some of the processes which are described in the previous Section 2.2.2. On the other hand, PD principles provide useful methods and philosophies for the development process and are defined as supportive or integrated parts of the PD process (BASSLER et al. 2011). For an easier distinction between the two PD framework types, this thesis uses the term “PD processes” for PD process frameworks and “PD principles” for those that consist of different principles.

The second proposed criterion denotes the character of the PD frameworks and classifies them into prescriptive and descriptive PD approaches (SCACCHI 2002). Prescriptive PD frameworks, such as the waterfall model, spiral development, the scrum methodology or design for six sigma explicitly prescribes how a new product should be developed. Thus, the frameworks are not only used as guidelines to organize and structure the different PD activities but also to explicitly articulate in which exact order the actions have to be executed. In addition and most importantly, prescriptive frameworks are already empirically grounded. On the other hand, descriptive frameworks, such as incremental delivery, evolutionary development and lean product development, characterize how particular PD systems are actually developed in specific settings. Although these frameworks can also be used as guidelines for PD, they are not yet comprehensively generalized through systematic comparative analysis (SCACCHI 2002).

2.3 Research Communities

Risk management can either be treated as a separate process to the product development process or as an emergent property or intrinsic part of the development approach itself (BASSLER et al. 2011). Existing research can be grouped along these two stated risk management perspectives into four different communities (see Figure 2-4).
The first research community focuses on analyzing specific risk management capabilities of different PD processes. It therefore considers risk management as an intrinsic part of PD with a limited research scope on specific methods or aspects. As such, MACCORMACK et al. (2001b) examine the characteristics of an effective development process. The authors conclude that PD approaches supporting a more flexible development process are associated with better-performing projects as they are able to reduce risks by generating and responding to new information for longer proportion of a development cycle. McCONNELL (1996) offers a brief and balanced comparison of different PD frameworks but limits its research on very few high-level and theoretical risk management capabilities. Assuming that PD activities can be interpreted as risk treatment measures (see Section 2.1.1), various authors and organizations emphasize different best-practices regarding the proper execution of PD tasks (e.g. ULRICH et al. 2008, HASKINS et al. 2010, PMI 2008a, NASA 2008, DoD 2006).

The second research group focuses on dedicated and external risk management processes which are structured in several phases such as risk identification, risk analysis, risk evaluation, risk treatment or monitoring and review (ISO 2009a, SMITH et al. 2002). However, this community limits its research scope on specific risk management methods that can be used within a process step. A comprehensive literature review has shown that various methods exist to identify, quantify and monitor risks but there are shortcomings regarding risk treatment or mitigation, as well as the overall integration of the risk management process with the PDP (OEHMER et al. 2010a). In this regard, prominent methods for risk identification include Brainstorming and Delphi surveys (SMITH et al. 2002, BROWNING 1999), Quality Function Deployment (QFD) (MAASS et al. 2010, REICH et al. 2008, LEUNG et al. 2008), Life Cycle Cost Analysis (MARKESET 2003) or Failures Mode and Effect Analysis (FMEA) (SEGISMUNDO et al. 2008, KMENTA et al. 1999).

The third and fourth research communities also focus on risk management either as an intrinsic part or as a prescribing and external process of PD. However, instead of investigating specific methods or metrics, the research scope relies on holistic risk management frameworks.
This thesis is largely related to research community three as it introduces and classifies (see Section 3.2), validates and further develops (see Chapter 4), as well as applies (see Chapter 5) the framework of risk-driven design (OEHMEN et al. 2011). In addition, parts of this thesis are also related to research group four, as prominent and widely-used risk management process frameworks (see Section 6.4.3) are introduced, compared and discussed in Chapter 3.

2.4 Research Gap in Literature

To underline the different literature gaps that are relevant for this research, the following section is structured along the main research questions of this thesis (see Section 1.2). It is furthermore laid out in which chapters these gaps are addressed and what research method is used.

- (RQ1) What existing Risk Management frameworks are relevant for Product Development?

Whereas a significant body of existing literature emphasize various methods or measures to identify or analyze risks, no literature source could be identified that provides a detailed analysis and comparison of external RM process frameworks as well as frameworks that emphasize RM as an intrinsic part of PD. This literature gap is addressed with a literature review in Chapter 3.

- (RQ2) How can the Risk-driven Design principles be validated and further developed?

Several examples of risk management process frameworks are described to a great extent by various authors and organizations (e.g. HASKINS et al. 2010, NASA 2008, ISO 2009a). However, very few literature sources investigate risk management as an intrinsic part of the PD approach. The framework of risk-driven design published by OEHMEN et al. (2011) constitutes an example of this research community (see Section 2.3) but is not yet comprehensively validated. Furthermore OEHMEN et al. (2010a) emphasizes that examples of specific design risks and real life applications of RM processes are hardly described in literature. Chapter 4 addresses these literature gaps with both a literature review and interviews with risk practitioners in industry.

- (RQ3) How do common Product Development Frameworks manage risk?

As already stated in Section 2.2.1, existing literature recognize product development frameworks as risk management structures since they provide an organized approach for managing uncertainty in PD. In this context, very few literature sources provide a structured comparison of different PDPs in their approach to managing risks (UNGER 2003, UNGER et al. 2009 FERDOWSI 2003). However, all of these authors use very broad and high-level risk categories regarding their analysis and comparison. Chapter 5 addresses this literature gap with a comprehensive literature review as well as interviews and contributes a structured and more detailed analysis and comparison of the risk management approaches of common PD frameworks.
(RQ4) What existing Risk Management frameworks are mostly used in industry?

(RQ5) To what extent follows industry the principles of Risk-driven Design?

(RQ6) What is the Risk Management related performance of different Product Development Frameworks?

Research question four, five and six all refer and correspond to the theoretical research questions that have already been discussed above (see Figure 1-1). In general, no literature source could be identified that empirically validates the current state of practice regarding both risk management process frameworks and risk management as an intrinsic part of PD from a holistic point of view. Case studies are generally rare and industry involvement primarily takes the form of application examples to demonstrate the general feasibility of their specific risk management approach. Furthermore no clear picture exists regarding industry requirements on a risk management process in PD (OEHMEN et al. 2010a). Therefore, chapter 6 addresses this literature gap with preliminary results of a comprehensive survey on risk management in PD that was conducted at MIT’s Lean Advancement Initiative and King Fahd University of Petroleum and Minerals (KFUPM)-MIT Center for Clean Water and Energy during the research stay of the author.

2.5 Research Approach

This section highlights the research approach of this thesis that aims at addressing the different literature gaps and corresponding research questions described above. As such, three different research methodologies were used and combined: (1) literature review, (2) interviews with practitioners in industry and (3) survey on risk management practices in PD.

2.5.1 Literature Review

All theoretical investigations in this thesis are largely based on a literature review on various research topics such as risk management related to different areas (e.g. product development, supply chain management, strategic management, project and program management, operations management) but also risk management process frameworks, best-practices in product design and development, general software development, agile software development, design for six sigma, lean product development, numerous descriptive and prescriptive product development process frameworks, product development performance measurement, psychological studies on perceived risk under uncertainty, psychological studies on decision-making under uncertainty, general uncertainty management in product development, case study and survey research.

To identify the most useful books and papers in regard to these research topics, detailed forward and backward searches were conducted based on keywords, references and authors. The main sources for the literature review included:

- Google Books: Search engine and database which includes a large array of books of all kinds.
• Google Scholar: Search engine for scholarly literature across a large selection of publishing formats and disciplines.
• MIT Barker and Dewey Libraries
• Springer Link: Online platform which includes numerous academic papers and books of the publishing company Springer.
• WorldCat: Search engine which is connected to the databases of all university and public libraries in the United States.
• Amazon.com: A large database for books including customer reviews, which were used for prioritization of the literature.

### 2.5.2 Interviews

Several interview sessions were conducted with employees of three major companies in the aerospace and defense industry as well as one consultancy. To ensure high accuracy and expressiveness of the shown presentations in the meetings as well as to design the interview questions in a proper way, literature on case study research was reviewed (Eisenhardt 1989, Cunningham 1997, Stake 1995, Gerring 2007).

These interviews had two main objectives in regard to both the theoretical and empirical research approach:

- **Goal regarding theoretical research**: Obtain feedback about the theoretical investigations and findings to sharpen and adjust the research effort in regard to current industry practices.
- **Goal regarding empirical research**: Obtain information on how to adjust, restructure, rephrase or rearrange the survey questions to better address the needs of the industry.

Addressing the first objective, two interviews were held with a major defense contractor. The first meeting took place at the office of the company and involved two employees. One employee was related to project risk management and the other held the title of “Director of Six Sigma”. The second interview included a telephone conference with an employee who is an expert in the field of “Design for Six Sigma”. Both of these interview sessions served to gaining insightful feedback regarding both the general concept of Risk-driven Design (see Section 4.3) and the theoretical analysis of the risk management approach of different PD frameworks (see Chapter 5).

Addressing the second objective, many interviews were held with a technology consulting firm that is specialized on risk management and two major companies in the aerospace industry. All of these interviews were part of a bigger research project that is conducted at MIT and KFUPM and helped to develop and adjust the infrastructure as well as the questions of the survey which is described in the next section and in Section 6.2.2.
2.5.3 Survey

In order to empirically validate the theoretical research findings and to shed more light into the current state of practice on risk management in PD, two general methods of data collection are available – case studies and surveys (HOPPMANN 2009):

- **Case studies** are typically deployed to study a particular phenomenon within a small sample in order to investigate an object of interest in very high detail. They are beneficial if the aspects influencing the behavior of a system are unknown and need to be identified in the progression of the research.

- **Surveys** offer the potential for quick response return (FOWLER 2009) and yield results that are more generalizable than the findings gained by case studies. They are generally used as to collect data among a large sample size.

In the context of this thesis, both described methods for data collection would contribute to literature, since holistic risk management frameworks in PD are hardly empirically investigated yet (see Section 2.4). Furthermore the framework of Risk-driven Design and the related focuses on risk management as an intrinsic part of PD constitutes an emerging research community in literature (see Section 2.3). As such, every new empirical insight regarding the risk-driven design framework would contribute identifying a better integration of risk management in PD processes.

Since a very comprehensive survey on risk management practices in product development was conducted at MIT’s Lean Advancement Initiative and the KFUPM-MIT Center for Clean Water and Energy during the research stay of the author, it was decided to collaborate on this survey. Therefore it was out of the scope of this thesis to develop survey questions from scratch. However, the main part of the empirical research approach included a preliminary descriptive and exploratory analysis of the survey data. Thus, literature on survey research was reviewed to obtain beneficial information on quantitative data analysis (FOWLER 2009, TuftE et al. 1983, MILES et al. 1994, FREEMAN et al. 2005).

To differentiate between the greater research project at MIT/ KFUPM and the main research focus of this thesis, Section 6.2 provides a detailed overview of the general context, goals and structure of the survey as well as the development of the survey questions. Section 6.3 underlines the general contributions of this thesis to the survey design and the methodology of the descriptive and exploratory analysis of the survey data.

2.6 Summary of the Chapter

This chapter can be divided into three main parts and aimed at presenting and classifying the general context of this thesis.

First, a common language for the reader was established regarding the different research topics of the thesis. Therefore, risk and risk management in product development was generally introduced and defined. In addition, the main goals and benefits of risk management were pointed out. Since product development frameworks can be interpreted as risk
management structures, the general context of product development was narrowed down to the specific topic of PD frameworks. Seven common PD frameworks that are relevant for further investigations in this thesis were introduced and a classification of the PD frameworks along two dimensions was proposed. These comprise the type of the PD framework including PD processes and PD principles as well as the character of PD frameworks including prescriptive and descriptive PD framework types.

Secondly, four existing research communities of RM related to PD were presented along two dimensions in order to integrate the thesis into the current branch of research. The first dimension describes the type of integration of RM in PD and distinguishes between RM as an external process of PD and RM as an intrinsic part of PD. The second dimension describes the research scope of RM in PD and differentiates between specific methods or measures within one process and holistic process frameworks. This thesis refers to the research communities that focus on integral frameworks regarding both risk management as an intrinsic and external part of PD.

Thirdly, the current research gaps in literature regarding risk management in PD were formulated. In order to address these gaps, the research approach of this thesis which involved different research methodologies were described. These include a comprehensive literature review, several interviews with industry practitioners and a survey on risk management practices in PD.
3 Risk Management Frameworks

As has been discussed in Section 2.3, this thesis follows the research communities that focus on holistic risk management frameworks. This chapter therefore investigates risk management frameworks in more detail. Section 3.1 indicates the main research question, the deployed research methodology and the research contribution.

Section 3.2 describes both existing external risk management frameworks relevant for PD (Section 3.2.1) and frameworks that accentuate risk management as an intrinsic part of PD (Section 3.2.2).

Finally Section 3.3 compares and discusses all frameworks in regard to their definition of risk and risk management, the structure of included steps or actions and the general scope of each framework. Furthermore the general key benefits of Risk-driven Design are outlined in regard to integrating risk management as an intrinsic part of PD.

3.1 Research question and methodology

As already stated in Section 2.4, this chapter addresses the first main research question of the thesis with a literature review:

- (RQ1) What existing Risk Management frameworks are relevant for Product Development?

In this regard, a new structured comparison of various popular risk management frameworks that are related to PD is contributed to research. Moreover, the role and key benefits of the recently published risk-driven design framework compared to the other RM frameworks is discussed.

3.2 Existing frameworks relevant to Product Development

Over the years, several government organizations and professional associations developed RM processes and models to guide their RM efforts. In this chapter, eight different RM frameworks relevant to PD are reviewed and described (see Table 3-1). The first six approaches are widely used in industry (see Section 6.4.3) and consider risk management as external and prescribing RM processes that consist of several sequential steps. As such, they follow the fourth risk management research community (see Section 2.3). The reviewed RM process frameworks can be broadly classified into three categories:

- RM processes developed by various government organizations such as NASA (NASA 2008), and Department of Defense (DoD 2006).
RM processes developed by professional societies such as the Project Management Institute (PMI 2008a), International Council on Systems Engineering (HASKINS et al. 2010) and Projects in Controlled Environments (PRINCE2) (OGC 2009).


The last two reviewed frameworks suggest risk management as an intrinsic part of the PD process. They provide both principles that represent objectives of successful risk management and metrics that are useful in distinguishing the risk management approach of PD processes. Therefore they are related to the third risk management research community (see Section 2.3).

3.2.1 External Risk Management Process Frameworks

Government organizations

Risk management at NASA includes two complementary processes (NASA 2008): Risk-Informed Decision Making (RIDM) and Continuous Risk Management (CRM). RIDM and CRM processes are integrated into a coherent framework to foster proactive risk management: “to better inform decision making through improved use of risk information, and then to more effectively manage implementation risks using the CRM process, which is focused on the baseline performance requirements emerging from the RIDM process” (NASA 2008, p.1). Setting the context and defining objectives is executed at the level of the RIDM. Proactive risk management applies to programs, projects, and institutional or mission support offices. NASA uses a specific process for the management of risks associated with the implementation of designs, plans, and processes. The steps of the CRM framework involve – Communicate Document, Identify, Analyze, Plan, Track and Control (NASA 2008).

The Department of Defense (DoD) developed RM processes to address risks on its acquisitions programs (DoD 2006). RM is viewed as a key element to acquisition program success. The RM Guide for DoD Acquisition document has been developed to assist all parties involved in an acquisition program in effectively managing program risks during the entire acquisition process, including sustainment. The DoD RM process is a continuous effort that has to be conducted throughout the life cycle of a system. It is described as an organized methodology for continuously identifying and measuring the unknowns; developing mitigation options; selecting, planning, and implementing appropriate risk mitigations; and tracking the implementation to ensure successful risk reduction (DoD 2006).

Professional societies

The Project Management Institute Handbook (PMI 2008a) contains a chapter entitled Project Risk Management. According to the section, the objectives of project risk management are to increase the probability and impact of positive events, and decrease the probability and impact of negative events in the project. The suggested project RM processes consist of the following six steps: Plan risk management, identify risks, perform qualitative risk analysis, perform quantitative risk analysis, plan risk responses, monitor and control risks. These processes are
fully integrated with different phases and other project processes. Project RM ensures that projects can be carried out within budget and schedule constraints by making it possible to plan responses for identified risks (PMI 2008a).

PRINCE2 (PRojects IN Controlled Environments) is a process-based method for effective project management (OGC 2009). PRINCE2 is extensively used by the UK Government and widely used in the private sector, both in the UK and internationally. The risk management process framework consists of five steps: Communicate, Identify both regarding context and risks, Assess, Plan and Implement (OGC 2009).

The International Council on Systems Engineering (INCOSE) divides RM into two branches (HASKINS et al. 2010). Project risk management (PRM) includes the management of technical risks and task performance uncertainties associated with any development or production project, in order to meet performance, cost, and schedule objectives. Environmental risk management (ERM) comprises the management of environmental, health and safety risks associated with the production, operation and disposal of systems, in order to minimize adverse impacts and assure sustainability of these systems. The Risk management process framework consists of five sequential process steps: Planning, Identification, Assessment, Analysis, and Mitigation (HASKINS et al. 2010).

ISO 31000 Risk Management Standard

In November 2009, the International Standard ISO 31000 “Risk Management – Principles and guidelines” has been published (ISO 2009a). This is the only globally standard recognized. It is general and comprehensive in order that it can be customized to different applications. It is also designed to integrate different RM processes at different levels. The standard itself is accompanied by two documents, a definition of risk management terminology (ISO 2009b), as well as an overview of commonly used risk management methods (ISO 2009c). The standard consists of three parts that are shortly described in this subchapter:

- Risk management principles
- Risk management implementation framework
- Risk management process

Risk management principles

On a strategic level, the risk management principles formulate the goals that an organization should seek in order to develop a highly effective risk management system (ISO 2009a):

- Risk management creates and protects value.
- Risk management is an integral part of all organizational processes.
- Risk management is part of decision making.
- Risk management explicitly addresses uncertainty.
- Risk management is systematic, structured and timely.
Risk management is based on the best available information.
Risk management is tailored.
Risk management takes human and cultural factors into account.
Risk management is transparent and inclusive.
Risk management is dynamic, iterative and responsive to change.
Risk management facilitates continual improvement of the organization.

Risk management implementation framework
The risk management implementation framework provides the foundations for embedding the risk management processes on different levels of the organization. It consists of five parts (ISO 2009a):

- **Mandate and commitment**: Ensuring strong and sustained management support.
- **Design of framework for managing risk**: Understanding the internal and external context of the organization, establishing a risk management policy, creating accountability, integration of risk management with other organizational processes, definition of resource allocation, and establishing internal and external communication channels.
- **Implementing risk management**: Implementing the framework as well as the risk management processes.
- **Monitoring and review of the framework**: Ensure effectiveness and support provided to the organization.
- **Continual improvement of the framework**: Taking action based on identified weaknesses and opportunities for improvement of the risk management framework

Risk management processes
The third and last part of the ISO 31000 is the actual risk management process. It describes a generic process for risk management “to ensure that risk is managed effectively, efficiently and coherently across an organization” (ISO 2009a). The risk management process is comprised of seven process steps: Communication & Consultation, Establishing Context, Risk Identification, Risk Analysis, Risk Evaluation, Risk Treatment and Monitoring & Review (see Figure 3-1).
3.2.2 Risk Management as an Intrinsic Part of Product Development

The framework of Risk-Driven Design

Very recently, OEHMEN et al. (2011) published a framework consisting of four principles that represent objectives or outcomes of successful risk management (see Figure 3-2). The authors advocate the integration of RM methods and practices directly into the design process. As such, the framework of Risk-driven Design takes a different view of managing risk. Conventionally, researchers predominantly focus on separate RM processes and suggest installing them as an add-on to existing PD processes (see Section 3.2.1). OEHMEN et al. (2011) emphasize that when the design process is driven by the intention to manage risk, uncertainties and their effect on the objectives are identified and quantified. Decision making
then focuses on risks, usually the most critical first. This is done by reducing the level of uncertainty as much as reasonable and then creating a resilient PD system that can absorb the residual uncertainty to achieve the objectives within the target range.

Since the Risk-driven Design framework is a central part of this thesis, a detailed description, theoretical validation and further development of each principle can be found in the following Chapter 4.

Comparison of intrinsic Risk Management in Product Development Processes

UNGER (2003) investigates the relationship between PD processes and risk management in order to help companies improve their PD process design. He discusses the dimensions of “iterations” (from narrow iterations within a phase to comprehensive, cross-phase iterations) and “review” (from rigid reviews that are frequent with fixed requirements to less frequent flexible reviews with soft requirements) to contrast several PD frameworks in terms of their intrinsic management of risks. To empirically validate the theoretical findings the author conducted ten case studies and concluded that the proposed metrics are useful in distinguishing PD processes and their different risk management approach and that companies can tailor their PD process designs to suit their own unique risk profile (UNGER 2003, UNGER et al. 2009).

3.3 Comparison and discussion

Table 3-1 illustrates the eight RM frameworks that are reviewed in this chapter. In addition to bibliographic information, this overview also indicates the respective definition of risk and risk management, the quantity of pages as well as the scope of each framework.
In general, all approaches show differing definitions of risk and risk management (see Section 2.1.2). Moreover the scope of each RM framework also partly differs, as they all have a varying background and context (e.g. commercial, military, academic or universal standard). It has been shown in the previous section that risk management can either be treated as a separate process to the PD process or as an intrinsic or integrated part of the development approach.

By comparing the RM process frameworks it becomes apparent that all separate process steps are very similar and well addressed and synthesized by the ISO 31000 (ISO 2009a). The RM standard provides a useful framework with a balanced number of steps that promote the application of this approach to various settings. Since its publication in 2009 it became both praise and critics. Examples of the praise include most notably, that it unifies vocabulary and process steps, lists all-important RM processes and provides guidance and sets forth important principles. On the other side criticism comprises the unclear and not very meaningful definitions, the impossible compliance and that it leads to illogical decisions if followed (LEITCH 2010, PURDY 2010). Yet, no reviewed RM process framework is explicitly customized to the specific application of risk management in PD. However, OEHMEN et al. (2010a) emphasize that the ISO 31000 standard is a “promising candidate to serve as a reference model for PD” (p.6).

On a more general perspective, there is a significant research stream addressing RM process frameworks. However, RM as an intrinsic part of PD is only investigated in a minor degree in literature (see Section 2.4). This is surprising as several authors explicitly recommend that RM should take a comprehensive and integrated approach in PD (MU et al. 2009). SMITH (2007) accentuates that especially in fast changing projects, RM must move “beyond simply being integrated to being intrinsic” (p.191). Every activity in project management should primarily aim at managing risk (SMITH 2007). BROWNING (1999a) furthermore emphasizes that effective RM requires holistic and continuous monitoring of project risks and effective control mechanism for identifying and reacting to process instabilities. Without a systems view, many RM activities serve only to push schedule risk into another category such as cost or performance risk (BROWNING 1999a).

This thesis therefore follows the research community that focuses on RM as an intrinsic part of PD (see Section 2.3). As such, UNGER (2003) introduces metrics to compare the RM approach of several PD processes but just uses very broad risk categories. He furthermore even concludes that additional knowledge about the specific risks, rather than broad risk classifications might provide greater insights regarding the risk profile of the different PD processes (UNGER 2003). RdD represents the only RM framework that consists of solution-neutral principles and does not only consider uncertainty or risk sources but also risk related decisions and characteristics of resilience. However, since this RM framework is just recently published, the four principles are not yet validated to a greater extent, both in theory and in practice. This aspect leads to the second and fifth research questions of this thesis which are partly addressed in the following Chapter 4.

- **(RQ2)** How can the Risk-driven principles be validated and developed further?
- **(RQ5)** To what extend is the industry following the principles of Risk-driven Design?
<table>
<thead>
<tr>
<th>Author</th>
<th>Definition Risk</th>
<th>Definition RM</th>
<th>Type and activities</th>
<th>Pages</th>
<th>Scope of RM approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 2009a</td>
<td>Risk is defined as the effect of uncertainty on objectives (p.1)</td>
<td>Risk management are coordinated activities to direct and control an organization with regard to risk (p.2)</td>
<td>Dedicated RM-processes: • Communication &amp; Consultation • Establishing Context • Risk Identification • Risk Analysis • Risk Evaluation • Risk Treatment • Monitoring &amp; Review</td>
<td>p. 1-21</td>
<td>22 pages</td>
</tr>
<tr>
<td>PMI 2008</td>
<td>Risk is an uncertain event or condition that, if it occurs, has an effect on at least one project objective (p.275)</td>
<td>Project Risk Management includes the processes of conducting risk management planning, identification, analysis, response planning, and monitoring and control on a project. (p.273)</td>
<td>Dedicated RM-processes: • Plan Risk Management • Identify Risks • Qualitative Risk Analysis • Quantitative Risk Analysis • Plan Risk Responses • Monitor and Control Risks</td>
<td>p. 273-312</td>
<td>40 pages</td>
</tr>
<tr>
<td>DoD 2006</td>
<td>Risk is a measure of future uncertainties in achieving program performance goals and objectives within defined cost, schedule and performance constraints. (p.1)</td>
<td>Risk management is the overarching process that encompasses identification, analysis, mitigation planning, mitigation plan implementation, and tracking. (p.1)</td>
<td>Dedicated RM-processes: • Risk identification • Risk Analysis • Risk Mitigation Planning • Risk Mitigation Plan implementation • Risk Tracking</td>
<td>p. 1-30</td>
<td>32 pages</td>
</tr>
<tr>
<td>NASA 2008</td>
<td>In the context of mission execution, risk is the potential for performance shortfalls (p. 3)</td>
<td>Risk management is a set of activities aimed at achieving success by proactively risk-informing the selection of decision alternatives and then managing the implementation risks associated with the selected alternative. (p.1)</td>
<td>Dedicated RM-processes: • Communicate Document • Identify • Analyze • Plan • Track • Control</td>
<td>p. 1-10</td>
<td>11 pages</td>
</tr>
</tbody>
</table>
### Table 3.1: Overview of Existing Risk Management Frameworks relevant to Product Development

<table>
<thead>
<tr>
<th>Author</th>
<th>Definition Risk</th>
<th>Definition RM</th>
<th>Type and activities</th>
<th>Pages</th>
<th>Scope of RM approach</th>
</tr>
</thead>
</table>
| INCOSE (HASKINS et al. 2010) | Risks are events, that if they occur can influence the ability of the project team to achieve project objectives and jeopardize the successful completion of the project (p.218) | Risk management is a disciplined approach to dealing with uncertainty that is present throughout the entire systems life cycle (p.214) | Dedicated RM-processes:  
- Plan RM  
- Manage the Risk profile  
- Analyze Risks  
- Treat Risks  
- Monitor Risks  
- Evaluate RM Process | p.213-226 14 pages | Scope is on RM as a continuous process for systematically addressing risk throughout the life cycle of a system, product or service (p.213) |
| PRINCE2 (OGC 2009) | Risk is an uncertain event which, should it occur, will have an effect on the achievement of objectives (p.77) | Risk management refers to the systematic application of principles, approach and processes to the tasks of identifying and assessing risks and then planning and implementing risk responses. (p.77) | Dedicated RM-processes:  
- Communicate  
- Identify  
- Assess  
- Plan  
- Implement | p.77-88 11 pages | Scope is on RM-process as a continual activity, performed throughout the life of the project. |
| OEHMEN et al. 2011 | Risks are defined as the quantified impact of uncertainties on the objectives of the PD project (p.1) | No concrete definition of RM given, but advocates the integration of RM-methods and processes directly into the product design process | Intrinsic RM-framework consisting of four principles:  
- Creating Transparency regarding Design Risks  
- Making Risk-Driven Decisions  
- Minimizing Uncertainty in Design  
- Creating Resilience in the Design System | p.1-10 11 pages | Scope of RM approach is on reducing and managing uncertainties as an intrinsic part of Product Design |
| UNGER et al. 2009  
UNGGER 2003 | Risk is defined as exposure to danger or loss (p.383) | Not explicitly defined | Comparison of intrinsic Risk management in PDP via:  
- Design iterations and integration  
- Design reviews | p. 383-400 8 pages | Scope of approach is on comparing Product Development Processes (PDP) as RM structures |
3.4 Summary of the Chapter

This chapter reviewed and classified eight existing Risk Management frameworks that are relevant for Product Development. From a general point of view, it has been shown that Risk Management is either treated as a dedicated and separate process to existing PD processes or as an intrinsic part of the PD approach itself.

Taking a more in-depth perspective, all current RM approaches differ regarding their definition of risk, risk management and their specific scope. No reviewed RM process framework, such as the ISO 31000 RM standard (ISO 2009a), the PMI Project Risk Management (PMI 2008a), the DoD Risk Management guide (DoD 2006) and several more, is explicitly customized to the specific application of RM in PD. However, all prescribing RM process steps are very similar and well synthesized by the actual ISO 31000 RM standard. In this regard and based on a literature review OEHMEN et al. (2010a) accentuate that no comprehensive case studies on the application of risk management in product development exist in practice. Addressing this research gap and the corresponding fourth research question of this thesis (see Section 2.4), chapter 6 empirically investigates the application status of the six reviewed RM process frameworks in industry.

Following the frameworks that treat risk management as an intrinsic part of the PD process, Risk-driven Design is the only approach that consists of four principles which represent outcomes of successful risk management. It not only considers broad risk categories but specific risk sources, risk related decision making and also characteristics of a resilient design system. As such, it constitutes a very sophisticated framework that advocates the direct integration of RM methods and activities into PD. Hence, the next chapter 4 investigates the principles of Risk-driven Design to a greater extent and validates and further develops the framework based on a comprehensive literature review and various interviews with industry practitioners.
4 Risk-driven Design

As has been discussed in Section 3.3, the framework of Risk-driven Design constitutes a promising guidance for integrating RM as an intrinsic part of PD. Building upon the previous findings this chapter addresses and validates the four principles of Risk-driven Design in more detail.

Section 4.1 points out the main research question, the deployed research methodology and the research contributions. Section 4.2 describes the definition and interrelation of uncertainty and risks in the context of Risk-driven Design. The holistic framework structure is discussed in more detail in Section 4.3. Moreover, each of the four principles of Risk-driven Design is validated and a mapping of conventional risk management process steps to the four principles is presented.

Section 4.4 finally introduces a collection of 85 classified and linked examples of risks, risk related decisions and characteristics of resilience that are related to each of the four principles of Risk-driven Design.

4.1 Research question and methodology

As stated in Section 2.4, this chapter addresses the second research question of the thesis with a comprehensive literature review:

- (RQ 2) How can the Risk-driven Design principles be validated and further developed?

It therefore not only contributes a theoretical validation of the recently published Risk-driven Design framework with additional literature sources, but also populates the four principles with a new comprehensive list of classified and interrelated examples that serve both as a starting point for future investigations and to further investigate the concept of Risk-driven Design from an empirical point of view.

4.2 Uncertainty and Risks in the Context of Risk-driven Design

Uncertainty is an inevitable characteristic of most PD projects and can negatively or positively influence the proper functioning and market success of any new or modified product (De Weck et al. 2007, Meyer et al. 2001). It is defined as a persons’ perceived inability to completely understand how the external environment of a project may evolve and whether subsequent activities taken may be successful (Bstielr 2005). Since one primary goal of product designers is to generate information and to reduce uncertainty by transforming inaccurate into explicit information (Sommer et al. 2008), they are often challenged to make decisions when not all important data is available (Song et al. 2001). Moreover, Simon (1997) emphasizes that decision making is always subject to uncertainty, as it is hindered by
three factors: imperfect availability of knowledge, limited cognitive capacity and limited time to reach a decision. This so-called theory of bounded rationality can be extended to organizations, as there will be always significant uncertainty in any team or group due to the practical impossibility of evenly sharing all relevant information (RADNER 2000).

Existing literature recognizes two approaches on coping with uncertainty in PD: Reducing and managing uncertainty (SCHMITT et al. 2011). Reducing uncertainty accentuates comprehensive forecasting and risk-reduction efforts that focus on acquiring information about sources of uncertainty and the future so as to increase the probability that the firm makes correct choices from the beginning (THOMKE et al. 1998). Although uncertainty can be reduced to some extent, every PD project will still be facing a residual amount of uncertainty that must be dealt with (OEHMEN et al. 2011). Due to volatile customer preferences, shifting markets or technological developments, specifications of product designs are changing, which makes it difficult to proactively plan the knowledge that will be most useful to solve unexpected problems (SCHMITT et al. 2011, MACCORMACK et al. 2001b, EISENHARDT et al. 1995). Managing uncertainty therefore emphasizes both the ability to flexibly respond to unexpected events and to absorb process deviations so that project outcomes remain within the target range, e.g. through built-in buffers (CHALUPNIK et al. 2009, OEHMEN et al. 2011). The two aspects of coping with uncertainty are explicitly addressed by Risk-driven Design, as it focuses both on exploring and reducing uncertainty (principle one and three) as well as establishing a resilient design system to manage residual uncertainty throughout the PD process (principle four).

Many authors attempt to classify and describe different types of uncertainty in PD. MCMANUS et al. (2006) define uncertainty as “things that are not known or known only imprecisely” (p.3) and present a framework that considers uncertainty from the perspective of the system architect or designer. They classify it into lack of knowledge, lack of definition, statistically variables, known unknowns and unknown unknowns. MEYER et al. (2001) distinguish project uncertainty profiles that comprise four types: variation, foreseen uncertainty, unforeseen uncertainty and chaos. They advocate an uncertainty-based management approach that orients more towards flexibility and learning and less towards extensive planning and forecasting. DE WECK et al. (2007) and CHALUPNIK et al. (2009) differentiate regarding the origin of the uncertainty, e.g. factors endogenous to the PD process (technology and process execution) and exogenous factors (process environment: market, user, culture). Other perspectives and classifications of uncertainty related to PD can be found e.g. in THUNNISSEN (2003), CHOI (2006), MACCORMACK (2000), WILLIAMS (1999), BSTIELER (2005) or KEIZER ET AL. (2005). The framework of Risk-driven Design published by OEHMEN et al. (2011) follows the uncertainty taxonomy of DE WECK et al. (2007) and classifies uncertainty regarding its origin as technology, company-internal, customer requirements, supplier and market uncertainty (see Figure 4-1 and Figure 4-2). A detailed description of each uncertainty type is provided in the following Section 4.3.1.

Following the ISO 31000 definition of risk as “the effect of uncertainty on objectives” (ISO 2009a), risks can be understood as the quantified impact of uncertainties on the objectives of the PD project (see Chapter 2.1.2). As risks are functions of both the uncertainty of input factors and their impact on PD objectives, a number of risk taxonomies are possible. They can be structured along the input factors (e.g. technology risks, customer requirements risk,
company-internal process risks), or along their corresponding objectives that they impact (e.g. cost risk, schedule risk, performance risk, market risk). A more sophisticated approach is to link risks in a complex causal network (e.g. technology uncertainty leading to schedule slip leading to cost overrun) (OEHMEN et al. 2011). BROWNING (1999a) investigated comprehensive causal frameworks of factors contributing schedule, technology, performance and market uncertainty in system product development to discuss distributions of their possible outcomes.

As already stated in the last Section 3.2.2, this thesis focuses on risk management as an intrinsic part of PD. In this regard, UNGER (2003) analyzed different PD processes concerning their risk management approach. However, he classified and defined risks along the output factors (technical, schedule, budget and market risks) of a PD system. Concerning the comparison of risk in the PD processes, this risk taxonomy can be inaccurate for two reasons. First, all of the stated risks are highly interrelated and therefore not clearly overlap free (e.g. see BROWNING 1999a) for a complex causal risk network). Secondly, since all risks predominantly focus on output deviations of the PD system, the actual root cause of the respective risk is not explicitly considered. For instance, schedule risk can occur due to many reasons along the input factors of the PD system, such as immature technology, supplier failures or insufficient skills of the workforce.

The framework of Risk-driven Design addresses risks in product design along uncertainties regarding the input factors of the PD system. Several interviews with different managers and risk practitioners in industry confirmed a better understanding of PD related risks when discussing them along the input factors. A further developed illustrative framework of the classification of risk in the context of Risk-driven Design (RdD) can be seen in Figure 4-1. It shows the five classified types of uncertainty sources (technology, company-internal, customer requirement, supplier and market uncertainty) and their respective influence on PD objectives and the utility functions (see Section 4.3.1). Furthermore the level of control of each uncertainty source is defined ranging from high level (e.g. company internal processes) to low level of control (e.g. environmental aspects such as political regulations or social trends).
The link between the different types of uncertainty sources and the corresponding PD objective or utility function can be described as follows. Technology and company-internal uncertainty factors primarily affect internal PD performance risks of the company (e.g. the dependency on a technology that is still under development lengthens the schedule which increases the probability of a project cost overrun). From the supply chain perspective, supplier uncertainty or customer requirement uncertainty can result to risks in both the customer utility functions and internal PD performance (e.g. customers change or extend requirements or their priority that results in significant changes in system specification and in the customer utility function regarding quality.). Finally, environmental factors such as demographical change can strongly affect the customer utility functions regarding time, cost and quality. In this regard, utility functions translate specific values of objective achievement into an overall utility contribution. A meaningful example of a “risk value method” that links the distribution of performance outcomes in PD projects with the customer utility function can be found in BROWNING et al. (2003).

In summary, all six aspects shown above, i.e. both the achieved PD performance objectives and the utility functions regarding the customer/stakeholder requirements consequently affect or influence the overall customer satisfaction.
4.3 Validation and further development

The previous section showed that Risk-driven Design is a promising framework to integrate RM as an intrinsic part of PD, as it firstly focuses on risks along the input, rather than the output factors of a PD system and secondly comprises both aspects of coping with uncertainties in PD. To shed more light into the holistic structure of it, Figure 4-2 illustrates the differences between a conventional efficiency-driven and the risk-based view of a PD system as a transformation process.

The emphasis of conventional PD systems is on increasing the efficiency of the design process that is minimizing the amount or quality of input factors while maximizing the output. Relevant characteristics of the output include the trade-off between different objectives such as time, cost, quality and the customer satisfaction or utility function (GRIFFIN et al. 1996, OEHMEN et al. 2011). A number of PD approaches aim at improving the trade-off among the input factors both in terms of efficiency to reach a higher overall “average” among the objectives, as well as in terms of explicitly increasing one of the objectives at the expense of the others e.g. Target Costing, Value Engineering or Design for X. However, in most techniques the input factors are generally treated as static foreseeable point estimates or known uncertainty (OEHMEN et al. 2011).
The Risk-based view on a PD system highlights a different management approach of the design process than the conventional efficiency-driven design. As already stated in Section 3.2.2, uncertainty regarding the input factors and their effect on the objectives are identified and quantified. Based upon this transparency, decision making focuses on risks, usually the most critical first by both reducing the level of uncertainty as much as reasonable and then creating a resilient PD system that can absorb unexpected events or residual uncertainty (OEHMEN et al. 2011). The risk-based management view therefore focuses more on effectively executing the PD process, i.e. doing the right activities, jobs or processes to meet the overall customer satisfaction through transparency regarding risks and subsequent risk-driven decision making in the PD project. These observations underlie the four principles of Risk-Driven Design that are theoretically validated and further developed in the following sections.

4.3.1 Principle 1 - Creating Transparency regarding Design Risks

DE WECK et al. (2007) accentuate that traditional practice in design and marketing is to generate a most likely “forecast” for future demand. Products are then optimized for this expected future. However, forecasts are almost always wrong by either overestimating demand, or by underestimating it. By ignoring uncertainty and relying only on past averages or best guesses, systems become inflexible and once the true nature of demand reveal itself, necessary changes become slow and prohibitively expensive to make (DE WECK et al. 2007).

The first principle of Risk-driven Design (RdD) therefore aims at identifying knowable uncertainty in order to create transparency regarding design risks. As such, five uncertainty types i.e. risk sources are considered in the RdD framework. Most notably, the following list is primarily adapted from OEHMEN et al. (2011) and aims at providing a common “language” or understanding of the RdD framework structure. It is furthermore necessarily incomplete as uncertainty can affect every element of product design:

- **Technology uncertainty:** Technology uncertainty affects an array of product outcomes. For instance, technology maturity influences the performance reliability under field conditions. System integration readiness affects overall system performance and reliability. MU et al. (2009) emphasize that perceived technological risks (as an effect of technology uncertainty) refer to a firm’s inability to completely understand or accurately predict aspects of technological environments as it relates to PD projects.

- **Company-internal uncertainties:** Uncertainty exists regarding the effectiveness of new development processes (e.g. ability of review processes to catch errors). It also arises in communication processes regarding both the scope (completeness) as well as the quality (correctness) of communicated information, which is related to uncertainty in the coordination of work among individuals or groups. Uncertainty surrounding the capabilities has a significant effect on cost, schedule and performance.
- **Customer requirements uncertainties**: Uncertainties both regarding the stability of customer requirements (i.e. customers’ uncertainty regarding their needs) and their clarity (i.e. quality of understanding of the requirements by the organization) have significant impact on the project performance.

- **Supplier uncertainties**: Suppliers execute significant parts of the value creation in all life cycle phases. Therefore uncertainties regarding supplier performance during the development process can cause performance, schedule as well as cost risks.

- **Market uncertainty**: Environmental factors, such as demographical changes (e.g. aging population) or social trends (e.g. concerns regarding the safety of nuclear reactors or global warming), as well as actions by competitors (e.g. new technology introduction or pricing strategy) can significantly alter target specifications.

Since the primary research question of this chapter is how to further develop and validate the four principles of RdD, a comprehensive collection of detailed examples regarding each type of uncertainty is presented in Table 4-1.

After uncertainty is identified, the next step is to quantify it. As already stated in Section 2.1.2, this can be done to different degrees, ranging from purely verbal descriptions of uncertainties without the possibility for quantification to sophisticated continuous probability distributions (PATÉ-CORNELL 1996). However, all descriptions of uncertainty are only as reliable as the input data they are based on, whether it is expert opinions, simulation models, or historic data with limited applicability (OEHMEN et al. 2011).

### 4.3.2 Principle 2 – Making Risk-Driven Decision

Having transparency regarding the different risks in a PD project yields several benefits for subsequent decision making processes. However, before alluding to examples regarding the second principle of RdD, it is important to understand why transparency regarding risks can help to overcome naive decision making under uncertainty.

MULLINS et al. (1999) conducted several psychological experiments to examine factors that account for the variability in the risk-taking behavior of marketing managers and their respective decision making process under uncertainty. As a result, the authors found out that decision-makers tend to choose generally lower risk product modifications or improvements over riskier. Both the hazard and uncertainty dimension drive the overall risk perceptions. Moreover, four aspects are important conclusions of their study. First, procedures or activities that provide appropriate screens and reviews of a decision under uncertainty are needed to protect the company against the impulses of a swashbuckling risk taker or an overly conservative risk averter. Secondly, performance goals and aspirations affect the levels of risk decision-makers are willing to undertake when making potentially risky decisions. Third, decision makers lack the ability to ignore the sunk cost of prior decisions in making subsequent ones. Risky choice behavior of decision-makers is therefore strongly influenced by the impact on financial resources caused of prior decisions. Fourth, the decision-maker is willing to take on more risk, when the responsibility for decision outcomes is attributed to elements within his or her control (MULLINS et al. 1999).
KRUEGER et al. (1994) also confirmed that individual or personal factors strongly affect the risk-taking behavior. The authors explored in an experimental study how decision makers’ beliefs about their decision making skills and abilities change their risk taking and their perceptions of the presence of threats and opportunities in the decision they make. The research findings indicate that managers who perceive that their company has a lot of strengths and few weaknesses will see more opportunities and fewer threats in a SWOT analysis. The contrasting results were found for managers who recognize many weaknesses and few strengths of their firm. As such, the first group will make and prefer more high-risk high-return decisions, whereas the second will take fewer risks such as choosing the status quo over a riskier strategy. The authors accentuate that the perceived self-efficacy influences the perception of opportunity and threat. In summary, they strongly recommend that an established static transparency about the respective situation helps to choose or make a decision on a neutral base (KRUEGER et al. 1994).

Another important finding concerning the research area of managers risk-taking tendencies can be found in MARCH et al. (1987). The authors emphasize that individuals generally do not trust, do not understand or simply do not often use precise probability estimates as a basis for decision making. As such, possible project outcomes or risks with very low probabilities seem to be ignored regardless of their potential significance or severity. Managers normally have a strong normative reaction to risk and risk taking in terms of that they care predominantly about their personal reputation for risk taking. However, a primary problem results in developing and maintaining a managerial reputation for taking “good” (i.e. ultimately successful) risks and avoiding “bad” (i.e. ultimately unsuccessful) risks, in the face of uncertainties about which are which (MARCH et al. 1987).

In summary transparency and quantification regarding design risks can serve as an important basis for decision making and does not only provide static information about the possible opportunity or threat, but also helps to overcome individual differences in the risk taking behavior of managers in their PD decisions. In the context of RdD, examples of different risk related decisions relevant for PD can be found in Table 4-2.

4.3.3 Principle 3 – Minimizing Uncertainty in Design

As discussed in Section 4.2, managers have two contrasting options to cope with uncertainty: Reducing the uncertainty underlying risks and therefore underlying causes, or managing uncertainty by for example creating a resilient PD system that is able to achieve its objectives given a range of input factors. The third principle of RdD addresses the first stated factor and emphasizes minimizing uncertainty in Design.

OEHMEN et al. (2011) accentuate that the reduction of the overall risk exposure of a project can be used as an important key performance indicator to incentivize reducing significant risks as early as possible in the design process, instead of succumbing to postpone dealing with them for a long time, which might then lead to unexpected deviations from objectives (e.g. cost or schedule overrun in late phases of the PD project). In this regard, Table 4-3 presents a collection of important examples of methods and activities that aim at reducing uncertainty along the input factors of the PD system.
4.3.4 Principle 4 – Creating Resilience in the Design System

The last principle of RdD addresses the factor of managing uncertainty. In general, some uncertainties in PD can be reduced easily and cost efficient especially when they are under direct control of the company. However, uncertainty that is related to the external environment or due to bounded rationality (see Section 4.2) can just partly be influenced at all. As such, managing uncertainty can be broken down into agility, i.e. the ability to respond effectively and flexibly to unexpected events and robustness, i.e. the mechanism to absorb process deviations so that project outcomes remain within the target range of objectives, e.g. through built-in buffers (OEHMEN et al. 2011, CHALUPNIK et al. 2009).

Many authors emphasize development flexibility as a powerful approach for controlling risks or managing uncertainty. SCHMITT et al. (2011) extensively reviewed the current literature on development flexibility and synthesized two important aspects that describe a flexible PD system: The capability of deploying a range of technologies and designing a broad range of products as well as the ability of moving from one state to another incurring less cost, time, organizational disruption or loss of performance (SCHMITT et al. 2011). From a more general perspective, THOMKE et al. (1998) emphasize that a company is forced to invest in the more difficult risk management strategy of accurately forecasting a potentially unknowable future when it does not consider flexibility in PD. As a result, the authors present three approaches on how to increase development flexibility. In the context of dealing with unknowable uncertainty, MEYER et al. (2001) also suggest to move beyond traditional risk management and adopt roles and techniques that are less oriented towards forecasting and more towards flexibility in PD. Therefore development flexibility plays an important role in effectively dealing with unexpected events or unknowable uncertainty.

Agility or responsiveness, as one part of the fourth principle of RdD, addresses this aspect and is defined as the ability of the PD system to deliver stable performance under varying circumstances. This includes four aspects, that are adapted from OEHMEN et al. (2011) and further developed with the stated flexibility characteristics of SCHMITT et al. (2011): Swiftness, the ability to detect errors quickly and plan and take corrective action; cost efficiency, the ability to accommodate changes at low cost; versatility, the ability of the PD system to process unexpected challenges, for example due to a broadly skilled workforce and knowledge capability, the ability to deploy a range of technologies and design a broad range of products in order to use this broad scope of knowledge stock to adapt to different customer needs (see Table 4-4).

On the other hand, the robustness of a PD system can be increased by buffers. OEHMEN et al. (2011) emphasize two categories of buffers in the context of RdD: Those that are based on main objectives (e.g. financial, schedule or performance buffer) and lower-level buffer (e.g. holding excess capacities or a large stock of knowledge with a broad quantity of ideas). The authors conclude that transparency regarding project risk situation forms the basis for making a business case in favor of establishing critical buffers, and against excess buffers. However, while creating a responsive PD system aligns well with an efficiency-driven management approach such as Lean Product Development, the emphasis on creating critical buffers is contradictory to it (OEHMEN et al. 2011, KRAFCIK 1988). All validated and further developed aspects and examples of the fourth principle of RdD are consolidated in Table 4-4.
4.3.5 Mapping risk management processes to Risk-driven Design

It has been shown in Sections 3.2 and 3.3 that the different steps of all reviewed risk management process frameworks are very similar and well synthesized in the ISO 31000 risk management standard (ISO 2009a). This section builds upon these findings and demonstrates the link between the ISO (2009a) process stages and the RdD framework. As such, Figure 4-3 shows a possible mapping of five risk management process elements to the corresponding principles. Since the steps communication and consultation as well as establishing the context primarily focus on the organization of and coordination within the risk management process, they are not further considered in this investigation.

The risk management process elements risk identification, risk analysis and monitoring and review relate to the first principle of RdD. The step risk identification consists of identifying uncertainties, areas of impact and associated events with their respective causes and effects. The goal of this step is to create a comprehensive list of risks based on uncertainties that have a large influence on successfully achieving the objectives. The risk analysis step develops a deeper understanding of the causal structure behind the uncertainties and their effect on the objective and quantifies the previously identified risks. In the monitoring and review phase, the identified risks are observed to ensure that their quantification is still accurate, as well as emerging risks are identified.

The process element risk evaluation can be linked to the second principle of RdD as it addresses the comparison and prioritization of risks as well as decision making regarding which risks must generally be treated.

Risk treatment, as the last step of the RM framework in Figure 4-3, relates to the reduction of uncertainty and to the creation of resilience. Risk treatment activities fall into two aspects: Reducing the probability of occurrence, i.e. reducing uncertainty and the impact of risks as well as assessing the cost-benefit ratio of different treatment options in order to select the best option.
4.4 Classified examples of the four Risk-driven Design principles

The literature provides several different taxonomies of uncertainties or corresponding risks that are related to PD (see Section 4.2). However, a specific and classified collection of different practical examples could not be identified. OEHMEN et al. (2010a) confirmed this finding in their comprehensive literature review on risk management in product design with a special focus on the ISO 31000 risk management standard. They emphasize that all RM process steps show varying degrees of deficiencies. Whereas some process elements such as risk identification or risk evaluation are addressed to a great extent, the topic of risk treatment is, despite its importance, only marginally considered in literature. In this regard, examples or particular discussions of alternative treatment options are generally missing (OEHMEN et al. 2010a).

The following Table 4-1, Table 4-2, Table 4-3 and Table 4-4 address this literature gap and provide several classified examples of risks, risk related decisions, risk mitigation actions and characteristics of resilience that are related to each of the four principles of RdD. The detailed examples of these RdD practices are based on two main sources: (a) the content that was developed for the survey based on interviews with an industry focus group (see section 6.2.2) and (b) an additional literature review (both types of sources are given in each table).

Additionally, the PD risk examples of the first principle are linked to the corresponding mitigation examples of the third and fourth principle. The alignment along types of uncertainty including bibliographic information can serve as a starting point for future research. If no literature source is explicitly documented, then the actual risk or uncertainty type constitutes a possible umbrella term or placeholder for upcoming investigations.

In summary, the newly investigated collection of examples provided an additional basis for parts of the survey questions in Chapter 6 to empirically address the fifth main research question of this thesis:

- (RQ5) To what extent follows industry the principles of Risk-driven Design?

As already stated, it should be noted that this thesis only addresses parts of a bigger research project that is conducted at the Lean Advancement Initiative at MIT and the KFUPM-MIT Center for Clean Water and Clean Energy. Therefore, Section 6.2 and 6.3 both outline the context of the main research project and the specific contributions of this thesis regarding the development of the survey questions.

Based upon the theoretical findings of this chapter, the RdD framework is used as a guiding concept to analyze the intrinsic risk management approach of different PD frameworks in order to address the third main research question of this thesis in the next Chapter 5.

- (RQ3) How do common Product Development frameworks manage risks?
The principles of Risk-driven Design

### Principle 1: Creating Transparency regarding Design Risks

<table>
<thead>
<tr>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industry focus group</td>
<td>28.1</td>
</tr>
</tbody>
</table>

#### Technology uncertainty (under field conditions)

<table>
<thead>
<tr>
<th>1.</th>
<th>Simulation and testing planning and execution</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Test plan (component and system level) schedule unrealistic, incomplete or lacking dependencies</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>28.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2.</th>
<th>Component-level technology readiness / technology maturity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Technology readiness level (component-level) too low to meet objectives</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>29.1; 29.2</td>
</tr>
</tbody>
</table>

| 2.2 | Development of a kind of component that is brand new to the organization takes longer than expected |
| McConnell 1996 | 51 |

| 2.3 | Dependency on a technology that is still under development lengthens the schedule |
| McConnell 1996 | 51 |

<table>
<thead>
<tr>
<th>3.</th>
<th>System-level readiness / system integration maturity (performance and reliability of integrated system)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>System-level integration readiness level too low to meet objectives</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>30.1; 30.2; 30.3; 49.1</td>
</tr>
</tbody>
</table>

| 3.2 | Error-prone modules require more testing, design, and implementation work than expected |
| McConnell 1996 | 51 |

| 3.3 | Requirements for interfacing with other systems, other complex systems, or other systems that are not under the team’s control result in unforeseen design, implementation, and testing |
| McConnell 1996 | 51 |

| 3.4 | Operation in an unfamiliar or unproved hardware/software environment causes unforeseen problems |
| McConnell 1996 | 51 |

<table>
<thead>
<tr>
<th>4.</th>
<th>Production system readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Production readiness level for the entire system too low to meet delivery objectives</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>31.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5.</th>
<th>Operations, service and support system readiness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Service readiness level for the system too low to effectively support operations and maintenance</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>31.1</td>
</tr>
</tbody>
</table>

### Company-internal uncertainty

<table>
<thead>
<tr>
<th>6.</th>
<th>PD Process efficiency and quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Uncertain capabilities and productivity in engineering</td>
</tr>
<tr>
<td>6.1.1</td>
<td>Product development / systems engineering processes ineffective (e.g. stage gate model, engineering change processes, design reviews)</td>
</tr>
<tr>
<td>Industry focus group</td>
<td>32.1</td>
</tr>
</tbody>
</table>

| 6.1.2 | Management and development process was unstable; time was wasted by frequent deviations from or changing process standard |
| Industry focus group | 32.2 |

<p>| 6.2 | Ability of review process to catch errors |
| Oehmen et al. 2011 | 49.2 |</p>
<table>
<thead>
<tr>
<th>Principle 1: Creating Transparency regarding Design Risks</th>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Company-internal uncertainty</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.2.1. Management places more emphasis on heroics than</td>
<td></td>
<td></td>
</tr>
<tr>
<td>accurate status reporting which undercuts its ability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>to detect and correct problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Project management efficiency and quality</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.1. Uncertainty regarding project progress</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.1.1. Progress monitoring and management (e.g. Earned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Value Management) insufficient to create transparency</td>
<td></td>
<td>35.2.1</td>
</tr>
<tr>
<td>regarding cost, schedule or performance status.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2. Unrealistic objectives / estimates</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.2.1. Unrealistic objectives regarding cost, schedule</td>
<td></td>
<td>35.1.1</td>
</tr>
<tr>
<td>or performance are set, e.g. due to insufficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>feasibility analyses, pressure to fit objectives into</td>
<td></td>
<td></td>
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<tr>
<td>existing guidelines or ignoring known risks.</td>
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<td></td>
</tr>
<tr>
<td>7.2.2. Schedule, resources, and product definition</td>
<td></td>
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<tr>
<td>have all been dictated by the customer or upper</td>
<td></td>
<td></td>
</tr>
<tr>
<td>management and are not in balance.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3. Uncertainty regarding financial resources</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3.1. Resources are re-allocated or become available</td>
<td></td>
<td>33.2; 44.1</td>
</tr>
<tr>
<td>(e.g. budget, manpower, facilities or government-</td>
<td></td>
<td>50; 52;</td>
</tr>
<tr>
<td>furnished equipment)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.3.2. Project lacks an effective top-management</td>
<td></td>
<td></td>
</tr>
<tr>
<td>sponsor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4. Change management and process improvement</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.4.1. Insufficient change management or improvement</td>
<td></td>
<td>34.1; 34.2</td>
</tr>
<tr>
<td>processes (e.g. Lean management, Six Sigma) to</td>
<td></td>
<td></td>
</tr>
<tr>
<td>continuously increase the efficiency of the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>project/program execution</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. Planning and forecasting uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. Manpower and skills uncertainty: Uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>surrounding the qualification and ability of</td>
<td></td>
<td></td>
</tr>
<tr>
<td>employees for specific tasks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.1. Insufficient skills or intellectual capital</td>
<td></td>
<td>34.4.1; 49.4</td>
</tr>
<tr>
<td>leading to problems in leading or executing the</td>
<td></td>
<td></td>
</tr>
<tr>
<td>program/project as planned</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. Process integration and communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.1. Cross-organizational integration &amp; communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with suppliers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.1.1. Lack of cross-organizational integration &amp;</td>
<td></td>
<td>37.2.1; 37.2</td>
</tr>
<tr>
<td>communication with suppliers</td>
<td></td>
<td>2; 37.1</td>
</tr>
<tr>
<td>10.2. Cross-organizational integration &amp; communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>with customers</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.2.1. Lack of cross-organizational integration &amp;</td>
<td></td>
<td>41.1; 41.2.1</td>
</tr>
<tr>
<td>communication with customers / government</td>
<td></td>
<td>3; 41.3.1</td>
</tr>
</tbody>
</table>
### Principle 1: Creating Transparency regarding Design Risks

<table>
<thead>
<tr>
<th>Company-internal uncertainty</th>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.3. Cross-functional integration &amp; communication within the organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.3.1. Lack of cross-functional and cross-project integration &amp; communication within the organization</td>
<td>Industry focus group</td>
<td>33.1</td>
</tr>
<tr>
<td>10.3.2. Poor relationship between developers and management slow decision making and follow through</td>
<td>McCONNELL 1996</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Supplier uncertainty</th>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>11. Incentive alignment</td>
<td>Industry focus group</td>
<td>37.2.1; 37.2.2; 41.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Customer requirements uncertainty</th>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>15. Level of understanding of customer requirements by the project team</td>
<td>Industry focus group</td>
<td>41.2.1; 41.3.1</td>
</tr>
<tr>
<td>15.1. Customer/stakeholder requirements are poorly understood, negatively impacting project management and performance</td>
<td>Industry focus group</td>
<td>41.2.1; 41.3.1</td>
</tr>
<tr>
<td>16. Level of certainty of customer with own requirements</td>
<td>Industry focus group</td>
<td>41.3.1; 41.1; 47.1; 49.3; 52</td>
</tr>
<tr>
<td>16.1. Customers/stakeholders change or extend requirements or their priority, resulting in significant changes in system specification, program execution or scope creep</td>
<td>Industry focus group</td>
<td>41.3.1; 41.1; 47.1; 49.3; 52</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Market uncertainty</th>
<th>Source</th>
<th>Principle 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Actions of competitors (e.g. pricing strategy or new technology introduction)</td>
<td>Industry focus group</td>
<td>45.1</td>
</tr>
<tr>
<td>17.1. Activities of competitors disrupt project/program execution (e.g. aggressive pricing, new technology introduction)</td>
<td>Industry focus group</td>
<td>45.1</td>
</tr>
<tr>
<td>18. Political, social, legal, regulatory developments</td>
<td>Industry focus group</td>
<td>44.1</td>
</tr>
<tr>
<td>18.1. Insufficient management of compliance leads to issues with regulatory policies</td>
<td>Industry focus group</td>
<td>44.1</td>
</tr>
<tr>
<td>18.2. Product depends on government regulations which change unexpectedly</td>
<td>McCONNELL 1996</td>
<td></td>
</tr>
<tr>
<td>19. Environmental influences</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>19.1. Demographic factors (e.g. aging population)</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>19.2. Social trends (e.g. concerns regarding global warming)</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
</tbody>
</table>

Table 4-1: Examples of risks linked to the third principle of Risk-driven Design
### Principle 2: Making Risk-driven Decisions

<table>
<thead>
<tr>
<th></th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>20. Make go/no-go decisions based on risk assessment</td>
<td>Industry focus group</td>
</tr>
<tr>
<td>21. Resources are allocated to reduce largest risks as early as possible</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>22. Risk assessments are used to set more 'realistic' or 'achievable' objectives</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>23. Forecasts and projections (e.g. cost, schedule, performance) are adjusted based on risk assessment</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>24. The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>25. Decisions are made based on risk-benefit trade-offs, e.g. larger risks are only acceptable for significant expected benefits</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>26. Risk-benefit trade-offs are used systematically to favor 'low risk - high benefit' options and eliminate 'high risk - low benefit' options</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
<tr>
<td>27. Contracts are derived from detailed cost risk assessments</td>
<td>Industry focus group; OEHMEN et al. 2011</td>
</tr>
</tbody>
</table>

### Principle 3: Minimizing Uncertainty in Design

<table>
<thead>
<tr>
<th>Technology uncertainty</th>
<th>Source</th>
<th>Principle 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>28. Technology readiness assessment (component, system, production, sustainment)</td>
<td>Industry focus group</td>
<td>1.1</td>
</tr>
<tr>
<td>28.1. Increased testing and prototyping</td>
<td>Industry focus group</td>
<td>2.1</td>
</tr>
<tr>
<td>28.2. Breakout of technology development / validation into separate projects</td>
<td>OEHMEN et al. 2011</td>
<td>2.1</td>
</tr>
<tr>
<td>28.3. Dedicated technology scouting projects</td>
<td>OEHMEN et al. 2011</td>
<td>2.1</td>
</tr>
<tr>
<td>29. Investing into component design</td>
<td>Industry focus group</td>
<td>3.1</td>
</tr>
<tr>
<td>29.1. Engineering with redundancy or safety margins</td>
<td>Industry focus group</td>
<td>4.1</td>
</tr>
<tr>
<td>29.2. Reuse existing components or off-the-shelf components</td>
<td>Industry focus group</td>
<td>5.1</td>
</tr>
<tr>
<td>30. Investing into system design</td>
<td>Industry focus group</td>
<td>3.1</td>
</tr>
<tr>
<td>30.1. Develop flexible product architecture (e.g. modular platform)</td>
<td>Industry focus group</td>
<td>3.1</td>
</tr>
<tr>
<td>30.2. Strict configuration control to manage and minimize complexity and uncertainty</td>
<td>Industry focus group</td>
<td>3.1</td>
</tr>
<tr>
<td>30.3. Pursue several engineering solutions in parallel (e.g. set-based design)</td>
<td>Industry focus group</td>
<td>3.1</td>
</tr>
<tr>
<td>31. Investing into manufacturability and serviceability</td>
<td>Industry focus group</td>
<td>4.1; 5.1</td>
</tr>
<tr>
<td>31.1. Focus on design for manufacturing and / or design for service</td>
<td>Industry focus group</td>
<td>4.1; 5.1</td>
</tr>
</tbody>
</table>

*Table 4-2: Examples of risk-related decisions*
<table>
<thead>
<tr>
<th>Principle 3: Minimizing Uncertainty in Design</th>
<th>Source</th>
<th>Principle 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Company-internal uncertainty</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32. Process standardization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>32.1. Adaptation of PD process to match specific project requirements</td>
<td>Industry focus group</td>
<td>6.1.1</td>
</tr>
<tr>
<td>32.2. Define “standard work” or “standard processes” to increase process reliability</td>
<td>Industry focus group</td>
<td>6.1.2</td>
</tr>
<tr>
<td>32.3. Clear communication guidelines</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>32.4. Standardized interfaces that clearly define information needs and responsibilities;</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td><strong>33. Process integration (internally)</strong></td>
<td></td>
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</tr>
<tr>
<td>33.1. Organizational-internal integration, e.g. process harmonization and data integration</td>
<td>Industry focus group</td>
<td>10.3.1</td>
</tr>
<tr>
<td>33.2. Active internal lobbying towards top management to promote project / program</td>
<td>Industry focus group</td>
<td>7.3.1</td>
</tr>
<tr>
<td><strong>34. Continuous Improvement</strong></td>
<td></td>
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</tr>
<tr>
<td>34.1. Self-assessments and implementation of best practices (e.g. through Six Sigma, Kaizen)</td>
<td>Industry focus group</td>
<td>7.4.1</td>
</tr>
<tr>
<td>34.2. Improved engineering change process to speed up changes</td>
<td>Industry focus group</td>
<td>7.4.1</td>
</tr>
<tr>
<td>34.3. Quality management and control to uncover uncertainties early</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>34.4. Structured project staffing, training &amp; learning</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>34.4.1. Implement training program or specialist career path to increase skill level</td>
<td>Industry focus group</td>
<td>9.1</td>
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<tr>
<td><strong>35. Creating transparency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.1. Transparent planning assumptions, integrated view of uncertainties underlying assumptions</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
<tr>
<td>35.1.1. Detailed cost, schedule and performance simulations and trade-off studies</td>
<td>Industry focus group</td>
<td>7.2.1</td>
</tr>
<tr>
<td><strong>35.2. Process performance transparency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35.2.1. More detailed design reviews, increased process monitoring</td>
<td>Industry focus group</td>
<td>7.1.1</td>
</tr>
<tr>
<td><strong>Supplier uncertainty</strong></td>
<td></td>
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<tr>
<td>36. Process standardization</td>
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<tr>
<td>37. Supplier integration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>37.1. Supplier / enterprise integration and management, e.g. process harmonization and data integration</td>
<td>Industry focus group</td>
<td>10.1.1; 14.1</td>
</tr>
</tbody>
</table>
### Principle 3: Minimizing Uncertainty in Design

<table>
<thead>
<tr>
<th>Supplier uncertainty</th>
<th>Source</th>
<th>Principle 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>37.2. Aligning incentives</td>
<td>Industry focus group</td>
<td>11.1; 10.1.1</td>
</tr>
<tr>
<td>37.2.1. Contractual sharing of overrun cost with suppliers</td>
<td>Industry focus group</td>
<td>11.1; 10.1.1</td>
</tr>
<tr>
<td>37.2.2. Cost-Plus Contracts</td>
<td>Industry focus group</td>
<td>11.1; 10.1.1</td>
</tr>
<tr>
<td>37.3. Reward long-term relationships</td>
<td>OEHMEN et al. 2011</td>
<td></td>
</tr>
</tbody>
</table>

38. Continuous improvement

38.1. Supplier training | OEHMEN et al. 2011 |

39. Transparency in the supply chain

40. Process standardization

41. Customer integration

<table>
<thead>
<tr>
<th>41.1. Contractual sharing of overrun cost with customer</th>
<th>Industry focus group</th>
<th>10.2.1; 11.1; 16.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>41.2. Active, continuing customer involvement</td>
<td>Industry focus group</td>
<td>10.2.1; 15.1</td>
</tr>
<tr>
<td>41.2.1. Customer / government integration, e.g. reporting, feedback, voice of customer</td>
<td>Industry focus group</td>
<td>10.2.1; 15.1</td>
</tr>
<tr>
<td>41.3. Guiding customer through trade-off analyses</td>
<td>Industry focus group</td>
<td>10.2.1; 15.1; 16.1</td>
</tr>
<tr>
<td>41.3.1. Enhanced exploration of customer requirements to help customer understand what their needs are and make tradeoffs (e.g. MATE or other tradeoff simulations and calculations)</td>
<td>Industry focus group</td>
<td>10.2.1; 15.1; 16.1</td>
</tr>
</tbody>
</table>

42. Continuous improvement

43. Transparency

### Market uncertainty

44. Lobby politicians

| 44.1. Active lobbying with key stakeholders outside of direct customer / contractor relationship, e.g. competitor, regulatory or oversight agencies | Industry focus group | 7.3.1; 18.1 |

45. Monitor competitors

| 45.1. Monitor activities of competitors (e.g. technology disclosures, bidding strategy, product launches, market entries, analysis of existing products, etc.) | Industry focus group | 17.1 |

46. Monitor environmental influences (assess as uncertain factor)

*Table 4-3: Examples of risk mitigation actions linked to the first principle of Risk-driven Design*
### Principle 4: Creating Resilience in the Design System

<table>
<thead>
<tr>
<th>Source</th>
<th>Principle 1</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Responsive Design System</strong></td>
<td></td>
</tr>
<tr>
<td>47. “Resilient” customer</td>
<td></td>
</tr>
<tr>
<td>47.1. Management (and re-negotiation if necessary) of requirements</td>
<td>Industry focus group</td>
</tr>
<tr>
<td>48. Resilient supply chain (Principle 4)</td>
<td></td>
</tr>
<tr>
<td>49. Creating resilient design system (Principle 4)</td>
<td></td>
</tr>
<tr>
<td>49.1. Cost efficiency: accommodate changes at low cost (aligned incentives, modular product structure)</td>
<td>OEHMEN et al. 2011</td>
</tr>
<tr>
<td>49.2. Swiftness: Detect errors and deviations (early warning system); quickly take corrective actions (e.g. un-bureaucratic change management)</td>
<td>OEHMEN et al. 2011</td>
</tr>
<tr>
<td>49.3. Flexibility: Ability to change / adapt objectives (e.g. regular customer / stakeholder interaction and consultation)</td>
<td>OEHMEN et al. 2011</td>
</tr>
<tr>
<td>49.4. Versatility: Ability to handle unexpected tasks (broadly skilled workforce, adaptable processes)</td>
<td>OEHMEN et al. 2011</td>
</tr>
<tr>
<td>49.5. Knowledge capability: Capability to deploy a range of technologies and design a broad range of products; Use broad scope of knowledge stock to adapt to different customer needs</td>
<td>SCHMITT et al. 2011</td>
</tr>
<tr>
<td><strong>Critical Buffer</strong></td>
<td></td>
</tr>
<tr>
<td>50. Financial reserves</td>
<td>Industry focus group</td>
</tr>
<tr>
<td>51. Schedule reserves</td>
<td>Industry focus group</td>
</tr>
<tr>
<td>52. Holding excess resources (e.g. manpower, inventory or facilities)</td>
<td>Industry focus group</td>
</tr>
</tbody>
</table>

*Table 4-4: Examples of characteristics of resilience linked to the first principle of Risk-driven Design*

### 4.5 Summary of the chapter

The generic concept of Risk-driven Design (RdD), introduced in Section 3.2.2, is validated and further developed in this chapter. In this regard, uncertainty and risk in PD are defined and a new illustrative causal network of uncertainty and risk in PD is developed. As risks are functions of both the uncertainty of input factors and their impact on PD objectives, the literature acknowledges several different risk taxonomies. RdD classifies risks along uncertainties regarding the input factors of the PD system, i.e. technology, company-internal, customer requirements, supplier and market uncertainty.

It has been shown, that reducing as well as managing uncertainty are fundamental approaches to cope with uncertainty in PD. These aspects are both addressed by RdD. The first principle includes exploring and quantifying knowable uncertainty. Based upon this established transparency, the second principle focuses on risk-driven decisions. In this context, many
authors in the research area of decision making under uncertainty confirm the importance of static risk transparency since the human perception of risk and uncertainty are strongly influenced by various personal factors. The third and fourth principle of RdD addresses reducing the level of uncertainty as much as reasonable and creating a resilient PD system that can absorb residual uncertainty. The latter aspect includes the ability to effectively as well as flexibly respond to unexpected events and the creation of buffers that increase the robustness of the PD system.

From a more general point of view, the differences between conventional efficiency-driven and risk-driven PD systems are highlighted. Furthermore all four principles of RdD are mapped to the ISO 31000 risk management process elements to demonstrate a possible knowledge link between the two risk management research communities (see Section 2.3).

As a main result of this chapter, a comprehensive collection of 85 interlinked practical examples regarding each principle is presented. This list includes possible design risk sources, corresponding mitigation actions, risk related decision making processes as well as characteristics of resilience. These examples are used for parts of the survey questions in Chapter 6 in order to empirically analyze the extent to which companies follow the principles of RdD.

Based upon the theoretical findings of this chapter, RdD is furthermore used as a guiding framework to analyze the intrinsic risk management approach of different PD frameworks in the next Chapter 5.
5 Risk Management in Product Development Frameworks

Section 2.2 narrowed the field of Product Development down to the specific domain of PD frameworks. In this regard it has been explained that PD approaches can be recognized as risk management structures since they provide an organized approach for managing uncertainty in PD. This chapter investigates the intrinsic risk management approach of PD frameworks in more detail. In this context, Risk-driven Design (RdD) is used as a guiding concept for this analysis.

Similar to the previous chapter, Section 5.1 gives a brief overview of the addressed research question, the deployed research methodology and the contributions to research. Section 5.2 outlines the literature sources that have been included in the discussion of the PD framework analysis. The following Sections 5.3 and 5.4 comprehensively analyze and discuss the extent of intrinsic risk management of PD process frameworks and PD principles respectively. Section 5.5 interprets the findings and presents a structured comparison of the PD frameworks along the principles of RdD. Section 5.6 points out the limitations of the research approach and discusses the benefits of the theoretical results for industry and research.

It should generally be noted that an early version of the comparison of PD frameworks along the principles of RdD is published in BASSLER et al. (2011).

5.1 Research questions and methodology

As has been discussed in Section 2.4, this chapter addresses the third main research question of this thesis with a comprehensive literature review and interviews with practitioners in industry.

- (RQ3) How do common Product Development Frameworks manage risk?

As a result, it contributes a new structured analysis and comparison of the intrinsic risk management approaches of popular PD frameworks that are guided by the principles of RdD.

5.2 Literature base of discussion

This thesis focuses on both prescriptive and descriptive PD processes as well as PD principles (see Section 2.2.3). However, the understanding of descriptive PD frameworks might be incomplete because they are limited on observations in industry and are not yet generalized into a distinctive prescriptive approach. Many authors for example discuss Lean Product Development based on the single practice of Toyota but with a respective different research scope. This might lead to different definitions and interpretations of Lean PD principles. The following Table 5-1 therefore provides an overview of literature sources that have been included in the discussion of the RM approach of the different PD frameworks. It also distinguishes the levels to which each literature source is taken into account and emphasizes the actual main reference source for each framework.
<table>
<thead>
<tr>
<th>Literature</th>
<th>PD-Process Framework</th>
<th>PD-Principle</th>
<th>Research Scope</th>
</tr>
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<tr>
<td></td>
<td>Traditional Waterfall model</td>
<td>Spiral development</td>
<td>Evolutionary development</td>
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<tr>
<td>Comprehensive scope</td>
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</tr>
<tr>
<td>UNGER et al. 2009</td>
<td>x</td>
<td>x</td>
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<tr>
<td>UNGER 2003</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>McCONNELL 1996</td>
<td>x</td>
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<td>x</td>
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<td>FERDOWSI 2003</td>
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<td>SCACCHI 2002</td>
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<tr>
<td>BIAZZO 2009</td>
<td>x</td>
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<tr>
<td>ZHANG et al. 2010</td>
<td>x</td>
<td>x</td>
<td>x</td>
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<tr>
<td>SMITH et al. 1992</td>
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</tr>
<tr>
<td>COOPER 2001</td>
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<td></td>
<td></td>
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<tr>
<td>COOPER 1990</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COOPER et al. 1986</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>KHALIFA et al. 2000</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUIMARÃES et al. 2005</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spiral development</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOEHM 1988</td>
<td>x</td>
<td></td>
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<tr>
<td>BOEHM et al. 2000</td>
<td>x</td>
<td></td>
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<tr>
<td>BOEHM et al. 1994</td>
<td>x</td>
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<tr>
<td>CHAO et al. 2006</td>
<td>x</td>
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<td>Evolutionary development</td>
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<tr>
<td>HASKINS et al. 2010</td>
<td>x</td>
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<td>GILB 1985</td>
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<td>GILB et al. 1988</td>
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<td>DAVIS et al. 2002</td>
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</table>
### Risk Management in Product Development Frameworks

#### Literature

<table>
<thead>
<tr>
<th>PD-Process Framework</th>
<th>PD-Principle</th>
<th>Research Scope</th>
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<td>Traditional model</td>
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<td>GRAHAM 1989</td>
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<td>LIKER et al. 1996</td>
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<td>SMITH 2007</td>
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</table>
5.3 Product Development Processes

5.3.1 The Traditional Waterfall Model

General overview of the Traditional Waterfall Model

The traditional waterfall model, also discussed as stage-gate (COOPER et al. 1986), phase development (SMITH et al. 1992), or life cycle (GUIMARÃES et al. 2005, ULRICH et al. 2008) by various authors is one of the most widely used type of PD process and has been dominant in US industry for almost 30 years (UNGER 2003). It follows a linear progression of product development steps that are designed to gather information needed for the next stage or decision point (FERDOWSI 2003, COOPER 2001, p.130) (see Figure 5-1). As a consequence, the output of one stage is simultaneously the input of the next stage (GUIMARÃES et al. 2005).

Every phase of activity is rigorously reviewed at a stage-gate or milestone that determines whether the PD-process can advance to the next phase. Otherwise it has to iterate within the current phase until all performance requirements are accomplished (McCONNELL 1996), (KHALIFA et al. 2000). In general, waterfall processes recommend that each phase be completed before starting on the next phase, so the working system in its entirety is delivered at the end of the whole development process (GRAHAM 1992). BIAZZO (2009) emphasizes the clear separation between concept development and implementation (detail design and production ramp-up) as a main distinguishing aspect of waterfall models.
There is a substantial literature stream that discusses advantages and disadvantages of the waterfall process both theoretically and empirically (KHALIFA et al. 2000, SMITH et al. 1992, UNGER et al. 2009, BOEHM et al. 2009, BOEHM 1988). Most notably, the main advantages of the staged process include that it imposes structure on development by reaching sharp product definitions and specifications early in PD, without necessarily demanding specific processes on how to reach the desired state (UNGER 2003). Additionally budget, schedule and resources might be more predictable due to the rigid nature of the process (FERDOWSI 2003).

However, the main disadvantages arise from the difficulty of fully specifying product and customer requirements at the beginning of the project, especially in a highly dynamic or hypercompetitive markets (UNGER et al. 2009, McCONNELL 1996). Many authors, such as BIAZZO (2009), UNGER et al. (2009) or KALYANARAM et al. (1997) furthermore discuss inflexibility in adapting to change as another significant disadvantage of the waterfall process. They accentuate that the waterfall model requires stable product specifications during the entire product realization phase.

The literature provides several additional modified phased development models that follow or are built upon the traditional Waterfall model such as:

- The V-model for system engineering (HASKINS et al. 2010)
- Design to Budget/Schedule (UNGER 2003)
- Department of Defense Acquisition System (DoD 2008)
- Overlapping and parallel waterfalls (FERDOWSI 2003)
- The next-generation Stage-Gate model (COOPER 2008)
The waterfall model risk management approach

Due to its sequential character, the traditional waterfall model mainly focuses on reducing uncertainties in system integration and understanding customer requirements with comprehensive up-front planning. The product functionality and performance is agreed prior to the start of the project and specifications. Narrow iterations within, and rigorous quality reviews after each phase make sure to meet actual performance requirements, i.e. manage technical risks. Every gate consists of a set of checklist deliverables against which the project is judged (COOPER 2001). Uncertainty regarding how the project team understands customer requirements is reduced with extensive market screens and evaluations at the beginning of the process e.g. review of opportunity and market attractiveness, product advantages or strategic alignments (COOPER 1990).

The gate or milestone to detailed design is the last point at which the project can be terminated before entering significant financial spending (COOPER 2001). The uncertainty regarding the stability of customer requirements throughout the PDP is not directly addressed in the waterfall model, which can lead to unplanned and costly cross-phase iterations. Failure can furthermore result if early specifications and assumptions are proven wrong by subsequent market research, detailed design or prototyping (UNGER 2003). Company-internal and organizational uncertainties are reduced due to the clear structured activity and process guideline that facilitate managerial control (UNGER et al. 2009). Each stage consists of a set of planned activities, numerous milestones and periodic reviews and do not require significant management attention (COOPER 1990).

Decisions at every gate are mainly based on detailed performance checklists and scoring models that serve as quality-control checkpoints. The first, most parts of the second and especially the fourth principle of Risk-driven design is not addressed in the Waterfall process. As stated in the previous subchapter, some authors describe the waterfall model as the opposite of a flexible or agile PD (BIAZZO 2009, UNGER et al. 2009) and as “unresponsive to dynamic environments, such as budget, cuts, new technology insertion, and changing user needs” (FERDOWSI 2003, p.49). In addition some types of uncertainty are not considered, such as suppliers, market or competitors, which might lead to high risks or missed opportunities. The waterfall model therefore performs well when product cycles have stable product definitions, the product uses well-understood technologies and the project is dominated by quality requirements. In these cases the PDP helps to find errors in the early stages of a project when costs of changes are low (UNGER 2003). It is also desirable in those programs that require formal reviews that signify the completion of specific phases and which frequently form the basis for progress payments.

The following Table 5-2 summarizes the Risk management approach of the waterfall model in the context of RdD.
The Traditional Waterfall Model

**Principle 1: Creating Transparency regarding Design Risks**
- Not addressed, no identification or quantifications of uncertainties or risks in the process

**Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties**
- Checklist and scoring model after each stage to check if quality requirements are met
- Preceding each stage is go or no-go decision point

**Principle 3: Minimizing uncertainty in Design**
- System integration uncertainties are reduced with narrow iterations within and rigorous quality reviews after each phase
- Customer uncertainties are reduced with heavy up-front market screens, evaluation and interpretation of customer needs
- Company-internal uncertainties are reduced with clear structured and detailed action plans

**Principle 4: Creating Resilience in the Design System**
- Not addressed

| Table 5-2: Summary of the waterfall model risk management approach |

5.3.2 Spiral Development

**General overview of the Spiral Development Model**

The spiral model is a PD process that has found particular application in the software industry (UNGER et al. 2009, MCCONNELL 1996, BOEHM et al. 2000, GUIMARÃES et al. 2005, CHAO et al. 2006) and was originally proposed by BOEHM 1988). It recognizes the repetitive nature and stepwise refinement in PD and provides a risk-reduction approach by planning a series of iterations that span several phases of product development (UNGER et al. 2009) (see Figure 5-2).

\[Figure 5-2:~Spiral~PD-process~model~(UNGER~et~al.~2009)\]
The basic concept of the spiral model is to start on a small project scale, explore risks, develop a plan to handle the risks and commit to an approach for the next cross-phase iteration (McConnell 1996). It therefore helps to screen and evaluate risks early, before major costs are incurred (Boehm 1988). Each cycle considers the main spiral elements (Boehm et al. 2000, Guimarães et al. 2005):

- Determination of stakeholder objectives, product alternatives and limitations
- Evaluation of alternatives and analysis of risks that are related to decisions of the previous stage.
- Actual product development, validation and verification phase
- Evaluation of cycle and planning for the next possible spiral

As a project spirals outwards, each loop brings it closer to completion, while each movement away from the center reflects additional costs. Considering minimal uncertainty, a simple spiral process with only one cross-phase iteration would closely be similar to a stage-gate or waterfall process (Unger 2003).

The main advantages of the PDP include the continuous stakeholder feedback throughout the project and the reduction of burdensome and expensive rework (Unger et al. 2009, McConnell 1996). Guimarães et al. (2005) emphasize the strong basis in risk analysis and risk-driven development planning as one of the major innovations of the spiral model. From a practical point of view, Chao et al. (2006) points out that “the spiral development model features cyclic concurrent engineering, risk-driven determination of process and product, growing a system via risk-driven experimentation and elaboration, and lowering development cost by early elimination of nonviable alternatives and rework avoidance.” (p. 10).

Several authors argue that high complexity and the significant required management attention are main disadvantages of the spiral model (Unger et al. 2009, Ferdowski 2003, McConnell 1996). The spiral process itself must be highly customized to each individual development project, which limits its re-usability across projects (Zhang et al. 2010). Hence, it is a very detailed approach that forces specific decisions on issues and costs. This attention to detail also limits the domain to which the spiral cycle is applicable. The costs of such explicit documentation are necessarily not warranted under all PD conditions. Chao et al. (2006) furthermore emphasize significant training time to understand the model properly. Even Boehm et al. (1994) acknowledge difficulties in the first spiral step of determining objectives, alternatives and constraints due to the lack of explicit process guidance.

**The spiral model risk management approach**

Unlike the waterfall model (see Section 5.3.1), in which functionality and specifications of the product are agreed upon at the start of the project, the spiral model begins with more difficult and poorly understood product components and incorporate easier components over time. Each cycle includes an initial assessment of continued risks for the upcoming cycle, and concludes with a review to establish validity of continued cross-phase iterations. The uncertainty of new and immature technology is therefore reduced with continuous stakeholder integration and risk management: The PD process identifies, assesses and evaluates risk early
in the cycle when costs of change are relatively low. With repeating regular steps, including concept development, system level design, detailed design, integration and testing, it furthermore provides a method for iteratively developing the product, while the project definition is still proceeding over time (see Figure 5-2).

The spiral model is very well suited to reduce uncertainties regarding the stability of customer requirements. Due to considerations and commitments of critical stakeholders (e.g. users, customers, developer and maintainer) in every cycle, the long-term iterations can lead to flexible product adjustments to customer needs even in later phases of the PD process. However, the quality or quality of understanding customer requirements by the project team is just weakly addressed in the spiral process. Additionally, it should be noted that spiral development is very complex and therefore also just partly reduces company-internal uncertainties. Compared with the waterfall model, there is no clear guideline structure and no definitive total plan. Furthermore risk calculations are difficult in subsequent cycles and strongly rely on existing risk management expertise (BOEHM et al. 2000). It requires significant management overhead and developer sophistication. UNGER (2003) describes difficulties in defining objective and verifiable milestones that indicate the readiness to execute another iteration. These factors can lead to significant delays in manufacturing and long lead times. The spiral model is therefore appropriate for complex projects with “unstable” or poorly understood customer and/or performance requirements. In this context, it provides a method for iteratively developing the product, while program or project definition is still proceeding.

Many authors describe the spiral PD process as a risk-driven approach (BOEHM et al. 2000, BOEHM 1988, FORSBERG et al. 2005, McCONNELL 1996). Decisions about the degree of performance details of each product, as well as the level of effort to be devoted to each activity within the cycles, are determined based on technology or performance risks (BOEHM et al. 2000). However, the associated probability of success of each activity is not considered in the decision making process. The spiral PDP includes go or no-go reviews based on stakeholder commitments. The main criteria, after which each cycle is judged, include whether the specific architecture of the product is supporting operational concepts, realize prototype results or satisfy the stakeholder requirements (BOEHM et al. 2000). However, compared with the waterfall model, these review procedure is much less rigid (UNGER 2003).

Due to its nature of cross-phase iterations with comprehensive risk evaluations in the beginning and the integration of stakeholder commitments and reviews throughout each cycle, the spiral model can detect and correct errors fast and flexible in the process and can adjust objectives with low costs of change even in later phases of the development process. Future increments always depend on feedback from users and technology maturation. If implemented in appropriate projects, the spiral model allows more process flexibility and therefore fosters better responsiveness in PD.
The theoretical aspects are supported by the findings of Unger (2003). In his comparison of PD risk management approaches in ten industry case studies, he ascertained that the spiral process was more widespread than anticipated and also appeared in less expected companies (e.g. software firms with high quality requirements like critical flight control or network solutions). He concludes that this aspect represents a business trend towards introducing greater flexibility to PD (Unger 2003, p.159). Table 5-3 summarizes the key findings of this Section.

### The Spiral Model

#### Principle 1: Creating Transparency regarding Design Risks
- Quantifying risks is weakly addressed due to the initial assessment of continued risks

#### Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties
- Risk considerations are used to determine level of effort to be devoted to activities and to determine degree of performance details of the product
- Less rigid go or no-go decisions after stakeholder commitments

#### Principle 3: Minimizing uncertainty in Design
- Technology uncertainty is reduced with cross-phase iterations and integrated risk management in the PD-process
- Uncertainty due to the stability of customer needs is reduced with excessive stakeholder integration and commitment throughout the development process
- Company-internal uncertainties are weakly reduced due to the complex process execution, the significant management overhead and the high developer sophistication

#### Principle 4: Creating Resilience in the Design System
- Cross-phase iteration and stakeholder commitments allows fast and flexible error detection
- Adjust objectives with low costs of change even in later phases
- Critical buffers are not addressed in the spiral model

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<tr>
<th>Table 5-3: Summary of the spiral model risk management approach</th>
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### 5.3.3 The Scrum Methodology

#### General Overview of the Scrum Methodology

Studies have shown that traditional plan-driven software development methodologies are actually not often used in practice, because, among other things, they are too mechanistic to be applied in detail (Abrahamsson et al. 2002). Agile development attempts to provide a new paradigm shift in the field of software engineering and was “officially” originated with the publication of the agile manifesto by Beck et al. (2001). It claims to place more emphasis on people, interaction, working software, customer collaboration, and change, rather than on processes, tools, contracts and plans (Abrahamsson et al. 2002). The development team should solitary concentrate on the product functions needed at first, delivering them fast, gathering feedback by customers and reacting to received information.
ABRAHAMSSON et al. (2002) characterize Agile Development methods as:

- **Incremental** - Small software releases, with rapid cycles
- **Cooperative** - Customer and developers working constantly together with close communication
- **Straightforward** - The method itself is easy to learn and to modify, and also well documented
- **Adaptive** – Ability to make last moment changes

In recent years, many authors have developed different agile software development methods such as Extreme Programming (BECK 2000), Scrum (SCHWABER 1995; SCHWABER et al. 2002), Crystal family of methodologies (COCKBURN 2007), Feature Driven Development (PALMER et al. 2002), Dynamic Systems Development Method (STAPLETON 1997), Adaptive Software Development (HIGHSMITH 2000) or the Rational Unified Process (KRUCHTEN 2000). An in-depth analysis of all stated methods is out of the scope of this thesis. However, interested readers can find a detailed literature review, analysis and interpretation in ABRAHAMSSON et al. (2002) and BOEHM et al. (2003).

This thesis follows the Scrum method that was originally proposed by SCHWABER (1995). Scrum is defined as an empirical approach that is applying ideas of industrial process control theory to systems development, resulting in an approach that “reintroduces ideas of flexibility, adaptability and productivity” (SCHWABER et al. 2002 104). The main emphasis of Scrum is on iterations in the so-called “sprint-phase”, in which the self-organized development team considers the available technology, evaluates its own skills and capabilities and finally collectively determines how to provide the functionality of the product (SCHWABER et al. 2002). The main differences between Scrum and traditional plan-driven development models (e.g. waterfall model) is that Scrum assumes that analysis, design and development processes are unpredictable due to rapidly changing customer needs. It therefore uses control mechanism to manage this unpredictability and the related risk. Figure 5-3 provides an overview of the structure of the Scrum methodology.

---

*Figure 5-3: The Scrum Product Development Process (SCHWABER 1995)*
In this regard, the following phases are included in the Scrum PD framework (ABRAHAMSSON et al. 2002):

- The **Planning & System Architecture phase** includes the definition and high level design of the system being developed based on current items in the Product Backlog. It furthermore considers the definition of the project team, tools and other resources, as well as risk assessment and controlling measures. The Product Backlog consists of high-level product functionality requirements and is maintained and continuously updated throughout the entire project.

- The actual **Development phase** (agile part of the Scrum approach) is treated as a black box where unpredictable situations are expected. The so-called “Sprints” phase is an empirical, iterative cycle where functionality is enhanced to produce new increments of the product. External controls such as risk management are used to avoid chaos, while simultaneously maximizing flexibility (SCHWABER 1995). Rather than only taking environmental and technical variables into account at the start of the development project, Scrum aims at controlling them continuously in order to be able to flexibly adapt to changes.

- The **Closure phase** is entered when an agreement has been made that environmental variables such as requirements or deliverables are completed. The system is finally ready for release and starts preparation for system integration, testing and documentation.

Next to the described development phases, Scrum considers three pre-defined roles with distinctive responsibilities in the development process (ABRAHAMSSON et al. 2002):

- **The Scrum Master** is responsible for ensuring that the project is executed according to the practices, values and rules of Scrum and that it is progressed as planned. He or she interacts with the project team, the customer and the management and ensures that the development team can work as productively as possible during the project.

- **The Product Owner** is officially responsible for the project as well as managing and controlling the Product Backlog (i.e. requirements list). He or she makes final decisions of the tasks related to the product, participates in estimating the development effort and turns the issues in the Backlog into features to be developed.

- **Scrum Team** is the actual self-organized project team that can decide on the necessary activities in order to achieve the goals of each Sprint. It is involved in e.g. effort estimation, creating Sprint Backlog, reviewing the product Backlog list and suggesting interruptions that need to be removed from the project.

BOEHM et al. (2003) accentuate that Agile Development is generally appropriate for small projects, with a low amount of integration and no rigid process standards. It is furthermore suited for turbulent environments with significant changes, like the rapidly growing and volatile internet software industry or the emerging mobile application market (ABRAHAMSSON et al. 2002).
Scrum risk management approach

The first RdD principle is weakly addressed by Scrum. Risks that affect the success of the project both are continuously assessed and used as a primary control variable throughout the Scrum process. Additionally, adequate risk responses are evaluated and implemented after every sprint iteration (Schwaber 1995).

Decisions in the development phase are primarily made based on quality reviews, but also on risk assessments and respective mitigation actions. However, Schwaber (1995) does not explicitly describe methods or procedures that address risk assessment processes in more detail.

New technology uncertainty is reduced with the clear focus on iterative and incremental development. Every sprint enhances new functionality to the product, is continuously considering the available technology and modifies its approach daily as it encounters new complexities e.g. immature technology. Company-internal uncertainties are strongly reduced due to the focus on small, self-organizing development teams and review meetings that are held between the project team and the Product Owner or Scrum Master both on a daily basis (Daily Scrum) and in frequent intervals (Sprint planning meeting). Frequent management activities aim at consistently identifying any deficiencies or impediments in the development process (Abrahamsson et al. 2002). Although Boehm et al. (2003) describe process complexity as a weakness of Scrum, the clear distinction between development and management, is an innovative factor that helps the groups to focus on their pre-defined responsibility and thus leading to a better process flow.

The uncertainty of customer stability or changing customer needs is very well addressed in Scrum due to its clear focus on flexibility and continuous incorporation and assessment of customer needs in the actual development or sprint phase. The quality of understanding customer needs is reduced due to the pre-defined responsibility of the Scrum Master. He or she gathers customer needs and translates it into the Product Backlog requirement list. By continuously interacting with the project team, the Scrum process ensures that all development effort is concentrating on the most important customer requirements.

Unlike other PD frameworks Scrum furthermore weakly addresses market uncertainties. The gathering process of product requirements are originated from “customer, sales and marketing divisions, customer support or software developers” (Abrahamsson et al. 2002, p.29). Due to its flexibility and the frequent adjustments in the Sprint phase, the uncertainty of system integration is just weakly addressed in Scrum. Abrahamsson et al. (2002) state that Scrum details in how to manage Sprints, but lacks in describing the integration and acceptance phases in more detail. Also due to the clear focus on incremental development of product functionality, the technical integration planning can be difficult.

The characteristics of a responsive design system in the context of RdD are very well addressed by Scrum. It is responsive to both initial and additional requirements discovered during the ongoing development. Additionally it enables to quickly change project and deliverables at any point in time with a relatively low cost of change. Table 5-4 summarizes the key findings of the scrum development risk management approach.
The Scrum PD Framework

**Principle 1: Creating Transparency regarding Design Risks**
- Exploring uncertainties and quantification of risks weakly addressed due to the continuous assessment of risks that are used as primary control variables throughout the Scrum PDP
- Risk responses are evaluated and implemented after every sprint iteration

**Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties**
- Decisions in PDP are primarily made based on quality reviews, but also on risk assessment and respective mitigation actions.

**Principle 3: Minimizing uncertainty in Design**
- New component technology uncertainty is addressed with enhancing new functionality to the product in each sprint while concurrently considering and modifying available technology
- Company-internal uncertainty is reduced due to the focus on small, self-organizing development teams and consistent review meetings that assure an efficient PDP flow
- Uncertainty due to customer requirements is reduced due to Scrum Master, who is responsible for gathering and managing customer requirements
- Stability of customer requirements is addressed due to its clear focus on process flexibility and continuous incorporation and assessment of customer needs in the Sprint phase.

**Principle 4: Creating Resilience in the Design System**
- Characteristics of Responsive Design System are well addressed by Scrum (low cost of change and ability of quickly change project and deliverables)
- Critical buffers are not addressed

| Table 5-4: Summary of scrum risk management approach |

5.3.4 Incremental delivery

**Overview of incremental delivery**

Incremental development or staged-delivery (McConnell 1996) is defined as a “development of a system in a series of increments throughout the project timescale” (Graham 1989, p. 9). Many literature sources overly incremental with evolutionary development and emphasize that a specific incremental development method is evolutionary development (Haskins et al. 2010). In order to distinguish incremental development from evolutionary development, this thesis follows the incremental delivery (ID) approach, proposed by Forsberg et al. 1995) (see Figure 5-4). Unlike evolutionary development, the plan for ID are determined up front and will be delivered to the customer in discrete increments (Ferdowski 2003, MacCormack et al. 2001b). Therefore, incremental processes begin like waterfall processes, as planning takes typically place for multiple increments at the beginning of the project (Ferdowski 2003). ID can furthermore be defined as a plan-driven approach: Basic requirements are known early in the life cycle and the development of functionality is processed incrementally to allow for latest technology insertion or potential changes in needs or requirements (Haskins et al. 2010, p.34).
Incremental processes are typically used on a number of programs or projects where particular development aspects of the product are not expected to complete at the same time. A more simplistic example of ID is a development project of new rail, which might plan for a length of thirty miles, but deliver these in ten mile increments in order to serve a basis for the additional rail parts (FERDOWSI 2003).

In practice, ID is a preferred strategy for large acquisition programs at the US Air Force (FERDOWSI 2003). WONG (2009) combined significant up-front specifications with ID in an air defense system project to deal with the complex, continuous, iterative and repetitive process of Software Development.

**Incremental delivery risk management approach**

The ID model by FORSBERG et al. (1995) does not fully address the first principle of RdD. There is no actual described process that creates transparency regarding design risks up-front. However, there are several uncertainties that are essentially addressed and reduced throughout the process. The uncertainty regarding the stability of customer requirements is decreased with continuous user or customer integration after every subset. The increment is subsequently upgraded or augmented until the total scope of stated user requirements is satisfied. Customers can use the software or hardware after the first delivery and refine requirements much earlier than in a traditional waterfall process (FORSBERG et al. 2000, ZHANG et al. 2010). This user or customer involvement fosters early discovery of problems and provide strong feedback from market after the first or second increments (SMITH et al.
The company-internal uncertainty is reduced with a clear and short development horizon, an easier forecast and a less complex system that has to be managed. However, McConnell (1996) emphasize that careful planning both at management and technical levels are necessary in order to assure that all component dependencies are addressed in the PD-project.

The uncertainty regarding system integration is just weakly addressed in ID: Most of the complexity comes from the interfaces and interactions with the rest of the system. If the second increment causes hardware or software of previous increment to be discarded, the project is likely to fail due to loss of technical confidence (Forsberg et al. 1995). ID also just weakly addresses the uncertainty regarding the quality of understanding customer requirements. An explicit “VOC” gathering phase is not clearly described in the reviewed literature sources (see Table 5-1). Only the first release of the product shall be configured to meet a reduced set of user or customer requirements to add and “complete” functionality and performance with subsequent releases. Both the waterfall and the DfSS framework provide a much more detailed description of methods and procedures that aim at understanding customer requirements and needs in the PD process. The uncertainty due to new technology is not addressed. In this regard, Smith et al. (1998) point out that the most serious disadvantage of ID is the difficulty to create a technology breakthrough. The scope of ID is more on small innovations and a stable development process.

Decisions in ID are mainly based on performance issues, whether the produced design will be discarded or kept as a starting point for another increment. However, no actual risk-driven decisions in the context of RdD are explicitly addressed. Some authors argue that incremental delivery can be defined as a very flexible, or adaptable development approach due to its ability to take selected events out of sequence when risk is acceptable (Forsberg et al. 1995, Smith et al. 1998). On the other hand, Gilb (1985) emphasize the “revolutionary” focus as a disadvantage of ID because every feedback from real world leads to significant effort of re-planning the detailed PD plan. Both the latter aspect and the plan-driven character of ID lead to the conclusion, that the characteristics of a responsive development system in the context of RdD are just partly addressed. Table 5-5 summarizes the ID risk management approach.
### Incremental Delivery

**Principle 1: Creating Transparency regarding Design Risks**
- Not addressed in incremental delivery

**Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties**
- Go-/No-go decisions based on performance details, which can be kept as a starting point for the next increment.

**Principle 3: Minimizing uncertainty in Design**
- Customer stability uncertainty is reduced with continuous user or customer integration after every subset to upgrade and augment the total scope until requirements are satisfied
- Company-internal uncertainty are reduced due to the short development horizon with easier forecasting, less management complexity and a clear process guideline
- Uncertainty due to system integration is weakly addressed due to the focus on incremental system development
- Uncertainty of understanding customer requirements are weakly addressed with a reduced set of customer needs that are used in subsequent releases to add functionality to the product

**Principle 4: Creating Resilience in the Design System**
- Characteristics of a responsive development system are weakly addressed due to some flexibility in the process

*Table 5-5: Summary of incremental delivery risk management approach*

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### 5.3.5 Evolutionary Development

**Overview of Evolutionary Development**

Evolutionary Development (ED) is the most extreme form of progressive development, as it takes the increments right back to the beginning of the PD process. The primary outcome of ED is increased feedback from both customers and developers (GRAHAM 1989). Software companies that need to quickly deliver a solid system to the customer and iterate rapidly often use the ED approach. The process is defined by two terms: evolutionary prototyping and evolutionary delivery (FERDOWSI 2003). In evolutionary delivery, the initial emphasis is on “the visible aspect of the system which consists of lower level system function that are unlikely to be changed by customer feedback” (McCONNELL 1996, p.152). Evolutionary prototyping focuses on the fast development of the visible aspect of the system to incorporate as much customer feedback in the PD process as possible (McCONNELL 1996). This thesis is focusing on the latter ED type (see Figure 5-5).

The main difference between incremental delivery (see Section 5.3.4) and evolutionary prototyping (EP) is well described by DAVIS et al. (2002): “Whereas incremental development implies that we understand most of our requirements up front and simply choose to implement it in subsets of increasing capability, evolutionary prototyping implies that we do not know up front all requirements, but need to experiment with an operational system in order to learn them” (p.1454). Therefore the emphasis of EP is to create an “open-ended” system architecture to better cope with any unexpected requirement changes.
Hence, ED is appropriate in research and development when the objectives are to explore the bounds of knowledge, or to expand frontiers in new applications where customer needs may not presently exist (FORSBERG et al. 1995). In this context, ED allows a team to quickly change requirements between prototype builds (UNGER 2003). GILB et al. (1988) compare evolutionary development with chess to characterize the process and emphasize that in both cases, the focus is not on detailed activity planning, but on “being able and flexible to make an adequate reply no matter what the opponent does” (GILB et al. 1988, p.97).

**Evolutionary development risk management approach**

In ED, the focus of decision-making is based on performance reviews and checklists after successful increment validation. No other aspect of the first or second principle of RdD is explicitly addressed.

The uncertainty regarding new technology is reduced with a strong focus on experimentation. As already stated, ED is often used in software development or pure R&D to finalize unknown requirements or to generate new knowledge when system requirements cannot be specified a priori. Its strong focus on iterations to enhance functionality is helpful to incorporate customer feedback. However, this open-ended development approach is disadvantageous for reducing system integration uncertainties and makes the technical planning process very difficult (GILB et al. 1988). ED just weakly addresses company-internal uncertainties. It does not provide a definite total plan when to stop the evolutionary process. Prototype iterations must continue until reaching an ambiguous acceptable outcome. The resulting schedule and budget risk can be very high (UNGER 2003).

ED strongly reduces the uncertainty of customer stability due to its extensive incorporation of customer needs after every evolutionary step. Even more than ID (see Section 5.3.4), ED is actually driven by customer feedback after each interim delivery. However, it also just weakly reduces the uncertainty of understanding customer requirements. The whole PD-approach focuses more on including customer feedback into the PD process in order to gain knowledge about the product itself, than to actually understand the customer needs at the start of the project.
ED is as a very responsive development approach that helps developers to gain experience and insights while building the prototype model. Resulting costs of change are relatively low compared to the waterfall model in which late changes often lead to costly cross-phase iterations. ED also includes development flexibility. The team can make changes in direction during the development by altering the focus of subsequent micro-projects. The number and length of micro-projects can be tailored to match the context of the project (MacCormack et al. 2001b). Haskins et al. (2010) describe velocity as an advantageous aspect of ED. Due to the continuous customer integration into the working-level teams, the highest customer needs can be addressed first. Table 5-6 summarizes the risk management approach of evolutionary development based on the principles of RdD.

### Evolutionary Development

<table>
<thead>
<tr>
<th>Principle 1: Creating Transparency regarding Design Risks</th>
<th>• Not explicitly addressed in evolutionary development</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties</strong></td>
<td>• Go-/No-go decisions after successful increment validation and requirements check based on customer feedback</td>
</tr>
<tr>
<td>• No decisions based on transparent risks; no assessment of probability of success</td>
<td></td>
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<tr>
<td><strong>Principle 3: Minimizing uncertainty in Design</strong></td>
<td>• Technology uncertainty is reduced due to the strong focus on experimentation and knowledge gathering when system requirements are not known at the start of the PDP</td>
</tr>
<tr>
<td>• System integration uncertainties weakly addressed due to the planning difficulties regarding technical feasibility when requirements are not exactly known</td>
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<tr>
<td>• Uncertainty regarding customer stability is reduced due to the extensive incorporation of customers in the PDP and the customer-driven process execution</td>
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<tr>
<td>• Reducing Company-internal uncertainty is just weakly addressed due to the “open-ended” PDP with no definite development plan, and no respective defined development ending</td>
<td></td>
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<tr>
<td><strong>Principle 4: Creating Resilience in the Design System</strong></td>
<td>• ED is a very responsive development system, due to the customer-driven process execution, the low costs of change, its continuous customer integration and the build-in flexibility</td>
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Table 5-6: Summary of the evolutionary development risk management approach

### 5.4 Product Development Principles

#### 5.4.1 Design for Six Sigma

**Overview of Design for Six Sigma**

Design for Six Sigma (DfSS) is a structured method that aims at developing products to meet ‘six sigma’ expectations and customer requirements (Yang et al. 2009). It provides tools and methods to proactively manage PD risks. Preliminary steps include comprehensive analysis, assessment and prioritization of risks associated with the business case and the project schedule (Yang et al. 2009, Maass et al. 2010). There are several possible alternatives for
Risk Management in Product Development Frameworks

structuring the overall DfSS process, such as CDOV, DMADV or RADIOV. (for a detailed description and comparison, see MAASS et al. 2010, p.12ff). However, during the process execution, all process structures rely on the same (or very similar) set of methods e.g. Monte Carlo Simulations, Design Failure Mode Effects Analysis (DFMEA) or Quality Function Deployment (QFD). This thesis focuses on the sequenced RADIOV (Requirements, Architecture, Design, Integrate, Optimize, Verify) approach by MAASS et al. (2010) in order to analyze and discuss it regarding the applicability of the four RdD principles. Figure 5-6 provides an overview of the structured method for DfSS in form of a flowchart.

The actual phases of DfSS are summarized as follows (MAASS et al. 2010, p.73 ff):

- **Requirement phase** - Includes the identification of critical parameters, requirements and competitive differentiators based on the voice of the customer (VOC) as well as implicit customer and business expectations. It also comprises the development of a finalized set of requirements that can effectively respond to any changes and is sufficient to provide guidance for the team when they choose the architecture.

- **Architecture phase** - Includes the critical parameters that are flowed down to measurable requirements for hardware and software subsystems. Key stakeholder and supply chain resources are integrated in the process in order to analyze and select the required functions, features and customer expectations flowed down from the system level requirements.
• **Design phase** - Includes the determination of the transfer function aspect of Predictive engineering with key tools and methods such as Regression Analysis, Simulation or Design of Experiment.

• **Integrate Phase** – Is the starting point process of combining and integrating the components.

• **Optimize Phase** - A so called “flow up” is performed to evaluate the capabilities of the design, allowing for variability in manufacturing, environment and use cases. This is done with the transfer function from the Design phase and statistical methods such as Monte Carlo simulation, Robust Design or Multiple Response Optimization.

• **Verify Phase** - The main goals in the verify phase include that the product will be reliable, will meet performance expectations with high confidence, and that the supply chain is ready and able to deliver the product dependably in the quantities and time frames required.

**Design for Six Sigma risk management approach**

Unlike PD processes, such as the waterfall or spiral development model, DfSS is a supportive or integrated part of the PD process and provides useful methods and philosophies for the development process (see Section 2.2.3). In this regard, it explicitly addresses risk management in the early requirement phase (see Figure 5-6). The first principle of RdD is strongly addressed regarding the identification of knowable uncertainties and the quantification of risks with an extensive toolset of methods.

The RADIOV process of Design for Six Sigma furthermore strongly reduces system integration and new technology uncertainties in the process with comprehensive quality methods to meet Six Sigma expectations (e.g. TRIZ, DFMEA or Monte Carlo simulations). Critical product specifications are identified, assessed and prioritized regarding performance risks and feasibility in the requirement phase. Customer expectations are translated to measurable product requirements and summarized in a quality “system-level of house". Based on the key deliverables in the requirement phase, the following Architecture, Design, Integrate, Optimize and Verify phases integrate the product system (MAASS et al. 2010).

DfSS also reduces supplier uncertainty in the last verification phase: The supply chain readiness is checked regarding the ability of delivering the product with pilot and early production samples. Used verification methods include DFMEA, lead time or on time delivery model and product launch plan. DfSS is strongly oriented towards reducing customer requirement uncertainty in the requirement phase with a comprehensive voice of the customer (VOC) gathering step. The goal of VOC is to identify, assess, prioritize and predict the impact of customer requirements with methods like interviews, Kano Analysis, Conjoint Analysis, Customer Requirements Ranking or System Level of House (MAASS et al. 2010).

However, DfSS only partly addresses uncertainty regarding the stability of customer requirements throughout the process. After the requirement phase in the beginning of the RADIOV process, the customer expectations are frozen and translated as “key deliverables” for downstream processes. DfSS strongly reduces company-internal uncertainties due to its clear guided structure and the detailed methodical support within the different phases.
However, it should be noted that the DfSS process is complex and needs methodical knowledge and risk management capability.

The schedule and business case risk management processes in the requirement phase are used to both improve confidence and prioritize risks to business goals and schedule adherence. Unlike the spiral model, the project resources are not allocated to retire the biggest risks first, but to support the most profitable project. The project profitability is identified and evaluated based on financial or portfolio risk assessment in the business case phase. The comprehensive use of probability methods in these phases e.g. Monte Carlo simulations, make sure that project objectives are considered with the associated probability of success. Based on this risk transparency, DfSS addresses entrepreneurial decision making through the aggregation of risks on the project level. Decisions about pursuing or to stop pursuing a project are made both based on quality checklists between the subsequent phases and on addressed key challenges in the business case.

DfSS also addresses parts of a responsive development system in the context of RdD. Due to its focus on integrated quality in the process and transparency regarding influencing risk factors, it leads to fewer changes and low costs of change because possible failure sources are transparent upfront. However, some aspects of a responsive development system such as versatility or cost efficiency are not explicitly addressed in DfSS. Yet the framework establishes generalized shared schedule buffer in the project plan to avoid personal buffer that can lead to schedule risk (MAASS et al. 2010). Table 5-7 provides an overview of the DfSS risk management approach.

### Design for Six Sigma

#### Principle 1: Creating Transparency regarding Design Risks
- Identification and quantification of uncertainties and risks are strongly addressed with an extensive methodical toolset

#### Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties
- Decision about resource allocation is based on probability functions of project profitability
- Objectives are associated with the probability of success to support decision making
- Entrepreneurial decision making is based on project risk aggregation
- Go/No-go decisions based on meeting performance requirements

#### Principle 3: Minimizing uncertainty in Design
- System integration and technology novelty uncertainties are reduced with comprehensive probability methods and risk management in the requirement phase
- Customer requirements uncertainty is reduced with an intensive VOC gathering process
- Company-internal uncertainties are reduced due to the clear guided process structure
- Supplier uncertainty is reduced with methodical verification of the readiness level

#### Principle 4: Creating Resilience in the Design System
- Addresses some aspects of responsiveness (low costs of change, ability to detect errors quickly)
- Aggregated “shared schedule buffer” in the project plan

*Table 5-7: Summary of the DfSS risk management approach*
5.4.2 Lean Product Development

Overview of Lean Product Development

Lean operation practices have achieved a great deal of success in both manufacturing industry and many service industries, such as banking, insurance, and health care (YANG et al. 2009). This thesis addresses Lean Product Development (Lean PD) according to the comprehensive investigations of the Toyota Product Development System by different authors (KENNEDY et al. 2003, MORGAN et al. 2006). HOPPMANN (2009) extensively reviewed the Lean PD literature and synthesized eleven Lean PD components and forty-four Lean PD characteristics. The Lean PD components and the related literature basis are shown in the following Table 5-8. A detailed description of each factor can be found in (HOPPMANN 2009, p.22-51).

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<tr>
<td>Strong Project Manager</td>
<td>X</td>
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<td>Specialist Career Path</td>
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<td>Workload Leveling</td>
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<td>Responsibility-based Planning and Control</td>
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<td>Cross-project Knowledge Transfer</td>
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<td>Simultaneous Engineering</td>
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<td>Supplier Integration</td>
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<td>Product Variety Management</td>
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<td>Rapid Prototyping, Simulation and Testing</td>
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<td>Process Standardization</td>
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<td>Set-based Engineering</td>
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</table>

Table 5-8: The eleven components of Lean Product Development related to literature sources (HOPPMANN 2009)

In general, Lean PD is an efficiency-driven management approach that focuses simultaneously on value creation and waste elimination in the PD process (MURMAN et al. 2002). Additionally it aims at establishing a continuously learning- and improving organization (HOPPMANN 2009). A special point of interest for the following analysis of the Lean PD risk management approach is the principle Set-based Concurrent Engineering (SBCE) which is originally examined and defined in WARD et al. (1995), LIKER et al. (1996) and SOBEK et al. (1999). SBCE differs significantly from conventional iterative-point-based PD approaches as the waterfall model (see Section 5.3.1). Instead of setting sharp product
definitions early in the PD process, converging on a design concept rapidly and then iterating over the design until it meets all requirements and specifications, SBCE considers and tests a broader range of design possibilities. As such, it explicitly pursues concurrent engineering, using parallel approaches and considering multiple alternatives (Schmitt et al. 2011). The set of alternatives is then only narrowed down when sufficient data indicates that a particular alternative is clearly inferior to another one (Hoppmann 2009).

Oppenheim (2004) recommends Lean PD for smaller development programs based on a high degree of legacy knowledge, with predominantly mature technology and low risk of major uncertainty. As a main limitation of this research, it has to be noted that the understanding of Lean PD is incomplete, as the reviewed literature (see Table 5-1) primarily draw on the same single case of Toyota (Schmitt et al. 2011).

**Lean Product Development risk management approach**

This research aims at investigating the risk management approach of Lean PD from a holistic point of view with a special focus on SBCE. Due to the strong focus on efficiency-driven project execution, Lean PD addresses company-internal and system integration uncertainties very well. The Strong Project Manager is extensively involved in technical details, continuously reviews cost, schedule and performance targets of the project, is concerned with the integration of subsystems, and chooses the technology used for the product. Cross-Project Knowledge Transfer is used to provide a company-wide knowledge database. The resources of the workforce are leveled evenly to avoid over- or underutilization. Product variety management is used to avoid large number of drawbacks that are connected with a high variety in products. An established specialist career path ensures continuous learning, high expertise and a standardized technical skillset of every manager (Hoppmann 2009). SBCE fosters communication and coordination in the PD process and facilitates knowledge integration (Schmitt et al. 2011). The different sets allow for more transparency on what to choose within clearly defined constraints (Ward et al. 1995).

The uncertainty of understanding customer requirements is also well addressed and reduced by the Strong Project Manager. He or she is responsible for investigating and defining customer value (voice of the customer) at the beginning of the project and has to evaluate the product throughout the PD project to meet customer expectations. As already stated, Lean PD ultimately focuses on customer value. In the case of Toyota, every vehicle development cycle begins with an evaluation of the current model, customer reaction to the product and predicted market conditions. Customers’ requirements are anticipated in the beginning of the PD process in a broad extend and synthesized in form of sets. These sets make sure that all likely requirements are met and provide the opportunity to offer discrete product combinations to the customer (Ward et al. 1995). However, the uncertainty regarding the stability of customer requirements is not strongly addressed by Lean PD. Although SBCE, as a underlying principle of Lean PD, aims at delaying decisions to “establish feasibility before commitment”, the main focus at each gate or milestone is to manage system integration and organizational uncertainties and not uncertainties due to changing customer requirements (Sobeck et al. 1999).
While delaying decisions about specifications enables the development team to make late adjustments with a relatively low cost of change, the product design still converge rather than evolve. Therefore if a product change is necessary (e.g. due to a significant market shift) and the “new” requirements are not covered within the originally anticipated design sets, it might also be necessary to costly iterate across PD phases in order to provide an appropriate product solution.

Unlike conventional development approaches, the suppliers are directly integrated in the development processes at an early stage and are actively supported to improve their performance (HOPPMANN 2009). Rather than focusing simply on contracts, Toyota intensively communicates with a smaller portion of its supplier and gives them large influence on the product design itself. Hence, the company has a talented, well-coordinated and high-quality supplier network that maintain very long term relationships and are organized based on different hierarchy levels (Partnerships, Mature and Parental) with different responsibilities and objectives (WARD et al. 1995, p.54).

The uncertainty regarding new component technologies is weakly addressed in Lean PD. Although Toyota focuses on keeping many of the subsystem and components essentially the same over time, new technologies can still be explored due to the freedom of designing a full set of alternatives with relatively low requirement constraints. Within these restrictions SBCE allows to pursue product improvements with a fair degree of safety (WARD et al. 1995).

Most notably, Lean PD does not directly address risk management. In this regard, decisions are basically made according to checklists, so called “lessons learned books” that include careful documentation of past experience, as well as special matrices that facilitate the review of designs (WARD et al. 1995). As SOBEK et al. (1999) point out: “Toyota appears to judge uncertainty based on experience”. However, the process of quantifying risks is not explicitly described in the reviewed literature. Lean PD is more primarily oriented towards implicitly avoiding or reducing risks throughout the process for example by establishing a stock of knowledge in the context of SBCE.

As already stated in Section 4.3.4, the efficiency-driven Lean PD strongly addresses the characteristics of a responsive design system. For example, the costs of change are low due to SBCE and the flexible, responsibility-based planning and control support quick error detections in the process. Although, creating costs and performance buffer is contradictory to the concept of Lean Thinking (KRAFCIK 1988). SBCE actively develops, balances and manages a stock of knowledge in terms of design sets to avoid costly cross-phase iterations. Table 5-9 summarizes the risk management approach of Lean PD based on the principles of RdD.
Lean Product Development

**Principle 1: Creating Transparency regarding Design Risks**
- Exploring uncertainties weakly addressed due to generating a stock of knowledge or ideas to address different performance targets that are gradually narrowed to a single solution

**Principle 2: Making Risk-Driven Decisions based on transparent risks/uncertainties**
- Go/No-go decisions are mainly based on performance checklists, lessons learned books and special matrices that facilitate the review of designs

**Principle 3: Minimizing uncertainty in Design**
- System integration and company-internal uncertainty is reduced due to an efficiency-driven project execution and maximizing value and minimizing waste in the PDP
- Uncertainty due to customer requirements is reduced with extensive investing and defining voice of the customer by Strong Project Manager
- Stability of customer requirements is not addressed because Product Design still converges rather than evolves
- Supplier uncertainty is strongly reduced with an early and extensive integration in the project

**Principle 4: Creating Resilience in the Design System**
- Fully addresses the aspects of a Responsive Design System (low costs of change, ability to detect errors quickly, ability to generate and manage and integrate a stock of knowledge)
- Stock of knowledge is used as a “lower-level buffer” to avoid costly cross-phase iterations and allows to change to different technical solutions if feasibility proves to be wrong
- Organizational and project buffers (cost, schedule and manpower) are not addressed

| Table 5-9: Summary of the Lean PD risk management approach |

### 5.5 Comparison and Interpretation

All of the discussed PD approaches have different foci of managing risk in product design (see Table 5-10). Other than DfSS and partly Scrum, no discussed approach explicitly creates transparency regarding knowable design risks up-front. As a consequence, the reduction of uncertainties focuses on pre-defined, “standard” uncertainties and does not necessarily reflect the specifics of the project. This aspect might then lead to the implementation of isolated and retrospective risk management processes after major risks occurred during development. All PD frameworks except DfSS need improvement regarding risk identification and quantification, for example through the integration of the appropriate DfSS or risk management methods into the up-front planning and regular project reviews.

Risk-based decision making is most strongly addressed by DfSS and partly by the Spiral model and the Scrum methodology. Spiral development directly allocates resources to retire the biggest quantified risks first through the iterative planning and execution of PD activities. The risk quantification process in the Spiral model is however retrospective after every completed cycle and not necessarily predictive as in the case of DfSS. Scrum development just implicitly assesses and quantifies risks but does not provide a clear process description concerning this aspect. The traditional Waterfall model, Evolutionary Development, Incremental Delivery or the Lean PD approach focus their decision-making process primarily on quality/performance checkpoints or milestone gates. In case of the Waterfall, Spiral and Scrum model, risk-return analyses could be incorporated into the early planning stages when
specific development projects are chosen. They could also be used at each decision point where a decision between alternatives (e.g., technologies) has to be made. In the early planning phases of the waterfall model, the assessment of objectives or value propositions regarding their likelihood of success could also be integrated.

The different PD approaches address markedly different types of uncertainties. The Waterfall model with its well-planned development phases, rigid design reviews and emphasis on clear structure mostly addresses system integration and company-internal uncertainties. Contrary, the spiral model focuses on comprehensive cross-phase iterations, the integration of critical stakeholders throughout the process and flexible reviews after several stages to reduce the uncertainty of changing customer requirements or technology novelty. Evolutionary development and Incremental Delivery also both focus on reducing the uncertainty of shifting customer needs by delivering “interim” versions of the product to the customer in order to shorten time-to-market. In this respect, Incremental Delivery follows a more structured plan-driven project execution and therefore focuses on reducing company-internal uncertainty; whereas Evolutionary Development strongly focuses on reducing new technology uncertainty by progressively evolving “open-ended” system architecture to better cope with any unexpected requirement change. The Scrum methodology addresses a large number of uncertainties and is the only PD framework that strongly considers both the uncertainty of understanding customer needs by the project team as well as the stability of the customer understanding their own requirements. It also incorporates feedback from marketing divisions to reduce market uncertainties. DfSS addresses a larger number of risk sources with comprehensive probability assessments. As already stated in the previous section, Lean PD has some weaknesses regarding volatile customer requirements. Compared to the spiral model or the scum methodology, it is not designed to handle significant changes in customer requirements in later development phases due to its very efficiency-driven design approach. However, compared to the sequential and linear Waterfall model, it is much less risk sensitive regarding system integration. If a technical solution is proven wrong in the subsequent testing phase, SBCE relates to other design alternatives and narrows the solution space down, whereas the Waterfall model has to execute costly cross-phase iterations that can lead to high schedule risk. Lean PD is furthermore very well suited to make sure that (current) customer requirements are understood well, the system is integrated properly and company-internal processes can flow with highest efficiency.

All approaches show a general weakness tendency to address competition, supplier or market/environmental uncertainties. Only Lean PD directly focuses on reducing supplier uncertainties due to its emphasis on strong relationships with a small amount of suppliers, as well as an extensive integration of suppliers in early phases of the PD process. However, if any of the mentioned uncertainties post significant risks, the PD processes must be customized to include the appropriate treatment actions.
Creating a resilient design system in the context of RdD is not in the primary focus of any of the discussed PD frameworks. The aspects of a responsive design system are well addressed by the Spiral model, Evolutionary Development, Scrum and Lean PD by their emphasis on fast, flexible and efficient processes. However, the creation of critical buffers is not explicitly considered in either case. Transparency regarding the projects risk exposure could form the basis for making a business case in favor of establishing critical buffers, and against excess buffers, in each PD approach. This would lead to a more robust PD approach that would be able to absorb risks sufficiently throughout the design phases (see Section 4.3.4)

<table>
<thead>
<tr>
<th>RDD - principles</th>
<th>PDP-Framework</th>
<th>PD-Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Waterfall model</td>
<td>Spiral</td>
</tr>
<tr>
<td>1.) Creating transparency regarding design risks</td>
<td></td>
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<tr>
<td>Explore and identify knowable uncertainties</td>
<td></td>
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<tr>
<td>Quantify resulting risks</td>
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<tr>
<td>2.) Making risk-driven decisions based on transparent risks / uncertainty</td>
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<tr>
<td>Go/no-go decisions, quality checkpoints</td>
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<td>Resource allocation to retire biggest risks first</td>
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<tr>
<td>Objective setting associated with risk assessment</td>
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<tr>
<td>Entrepreneurial decision making based on risk-return analysis</td>
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<tr>
<td>3.) Minimizing uncertainty in design</td>
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<tr>
<td>New component technology</td>
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<td>System integration</td>
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<td>Quality of understanding customer requirements</td>
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<td>Stability of customer requirements</td>
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<td>Company-internal</td>
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<td>Competitor</td>
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<td>Supplier</td>
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<td>Market</td>
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<td>4.) Creating resilience in the design system</td>
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<tr>
<td>Responsive design system</td>
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<td>Critical buffer in design system</td>
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Table 5-10: Overview of Extend of Risk Management of Different PD Frameworks

- ... strongly addressed
- .. ... weakly addressed
- ... not addressed
5.6 Limitations and discussion

The described comparison and interpretation in the previous chapter showed that each PD approach has a different risk management focus. Before discussing the results of the previous section, some important limitations of the theoretical research are described in the following.

First, personal judgment of the author played an important role in the prioritization of the literature as well as in the assessment of the intrinsic risk management capabilities of the different PD frameworks. Although several interviews with practitioners in industry confirmed the theoretical valuation of the author, especially the incomplete understanding of some PD approaches such as Lean PD can lead to different interpretations and assumptions of the proposed risk management approach.

Secondly, every PD approach has a partly different context, which is important to understand and to classify the results in Table 5-10. As companies have different products, organizations, iteration preferences and risk profiles, they cannot all use the same PD process with the same degree of effectiveness (UNGER et al. 2009). Therefore this thesis focuses on analyzing a broad range of PD approaches with different application backgrounds. Except the Waterfall model, DfSS or Lean PD, all of the reviewed PD frameworks are primarily applied in Software Development. However, software engineers have significantly different risk profiles than manufacturing counterparts, because product lifetimes are shorter and development cycles are more rapid and frequent. On the other hand, developing physical models often imply steep prototyping costs and long lead times (UNGER 2003). Furthermore, Lean PD and DfSS are not PD process frameworks but integrated or supportive parts of the PD process and provide useful methods and philosophies for the development processes. All of these important limitations should be considered when reviewing the comparison of the PD approaches.

The focus of this chapter is to analyze risk management capability tendencies of each PD approach in order to, among other things, describe the respective strengths and weaknesses as well as the relevant uncertainties that are primarily addressed. After conducting several in-depth case studies, UNGER (2003) accentuates that many companies still have great difficulties on choosing their PD process framework due to the lack of analytical guidelines in literature. Hence, firms make PD process decisions haphazardly as a result of management trends and corporate momentum. As one important empirical result, he emphasizes that the knowledge of the category of major risks faced is not enough to prescribe or predict which kind of PD process a company employs. He concludes that additional knowledge about the specific risks, rather than broad risk categories may provide greater insight (UNGER 2003).

To address this gap, the results of the theoretical discussion in this chapter (see Table 5-10) can help companies to find a suitable “base PD approach” to execute the development task based on several relevant uncertainties or risk sources in the PD project. From a theoretical point of view, a combination of the Scrum methodology with Design for Six Sigma methods yields the most comprehensive risk management oriented PD process. All findings in this section are empirically validated in the comprehensive survey in Chapter 6 to address the sixth and last main research question of this thesis:

- (RQ6) What is the RM related performance of the different PD frameworks?
5.7 Summary of the chapter

In the previous chapter 4, the four principles of Risk-driven Design (RdD) are validated and further developed. Based upon these findings, this chapter investigated the extent to which seven common PD frameworks manage risk using the principles of RdD based on a literature review. As a result, and not surprisingly, there is no PD approach that “fits it all”. Each PD framework has specific strengths and weaknesses and is suited for different development projects.

In general, all PD approaches predominantly focus on reducing design uncertainties and not explicitly on creating transparency regarding design risks up-front. As such, the reduction of company-internal and system integration uncertainty (see Section 4.3.1) are the strongest addressed risk sources. On the other hand, all approaches show a general weakness to address competition, supplier or market/environmental uncertainty. Risk-based decision making in the context of Risk-driven Design is also not well addressed. Five of the seven reviewed approaches primarily use quality checkpoints or milestone gates as a basis for their decision-making process. Although several approaches match the characteristics of a responsive design system, the creation of critical buffers in order to absorb unexpected risks in later PD phases is not explicitly considered.

From the theoretical discussion, a combination of the Scrum PD process framework with Design for Six Sigma methods yield the most comprehensive risk management oriented PD approach as they strongly address most of the types of uncertainty as well as the principles of RdD.

The findings of this chapter are used as a theoretical basis to investigate the empirical research questions in the next chapter 6. This includes the risk management related performance of the analyzed PD frameworks in industry.
6 Survey on Risk Management in Product Development

This chapter describes the empirical research approach of this thesis. Building upon the underlying research questions and the general research methodology, Section 6.2 emphasizes the general context of the comprehensive survey that was conducted at MIT’s LAI and the KFUPM-MIT Center for Clean Water and Clean Energy as a greater research project. This includes main goals, the development and the general structure of the survey as well as the collection of the survey data. Section 6.3 underlines the main contributions of this thesis to the risk management survey project. Among other aspects, these comprise a descriptive and exploratory analysis of the survey data. The findings are presented in Sections 6.4 and 6.5 respectively.

The following Section 6.6 accentuates the main survey limitations. The last Section 6.7 interprets and discusses all empirical results of this thesis and references them to the theoretical findings with regard to the main topic of this thesis, the integration of risk management as an intrinsic part of product development.

6.1 Research questions and methodology

This chapter addresses the last three empirical research questions of this thesis with a comprehensive survey on risk management practices in PD (see Section 2.4):

- (RQ4) What existing Risk Management frameworks are mostly used in industry?
- (RQ5) To what extent is industry following the principles of Risk-driven Design?
- (RQ6) What is the Risk Management related performance of different Product Development Frameworks?

Besides several fundamental new insights on current risk management practices in industry, this research approach also contributes a dynamic excel-based risk management analysis and benchmarking tool as well as a conceptual framework for better integrating risk management into product development.

6.2 Context of Survey on Risk Management Practices in Product Development

6.2.1 Goals of the Survey

As was pointed out above and in section 2.5.3, the survey on risk management practices in product development was part of a greater research project that was conducted at MIT’s LAI and the KFUPM-MIT Center for Clean Water and Clean Energy during the stay of the author.
The following goals of the survey are therefore divided into two parts: (1) the general goals in regard to the research project and (2) the specific goals in regard to this thesis.

**General Goals in Regard to the Research Project**

The general goal of the survey was to understand better what the current state of practice in industry and government services is regarding the management of risk in engineering development programs and projects. From a practical point of view, this research gap was identified and formulated on an industry workshop in June 2010. In summary, the survey had four main goals:

- Understand the current state of the art in industry regarding program risk management
- Create a benchmarking standard for own risk management processes
- Understand interest and main drivers for program risk management in industry
- Develop a research agenda for future activities that focus on the most significant industry needs and gaps in knowledge

Following the main goals of the research project, the next section underlines the specific goals of the survey in regard to this thesis.

**Specific Goals in Regard to this Thesis**

The specific goals of the survey on risk management practices in product development can generally be divided into a descriptive and an exploratory part.

The descriptive part addresses the fourth and parts of the sixth research question of this thesis (see Section 6.1). As such, the goals of the survey were to give a descriptive overview of:

- Project and organization characteristics of the survey respondents
- The use of risk management process frameworks
- The use of product development frameworks and their application context

The first goal aimed at providing a general overview of the background of the survey participants and it should be clarified how risk management is currently executed in terms of dedicated time and cost. Since the severity of risks and the risk mitigation effectiveness of different methods are typically influenced by the project characteristics, it was also of great interest for further investigations whether greater variability exists regarding the respondent’s project complexity and novelty.

As was pointed out in Section 2.4, existing literature lacks on providing a detailed empirical analysis and comparison of risk management process frameworks and PD frameworks. Therefore the second and third goal was to give an overview of the use of both framework types. Furthermore it was considered of interest to link the specific application context (i.e. the main type of product of the project) to each PD framework.
This thesis already contributed a comprehensive analysis of risk management approaches of different PD frameworks along the principles of Risk-driven Design (RdD) (see Chapter 5). Furthermore different examples of risk, risk related decisions, risk mitigation actions and characteristics of resilience were presented in Section 4.4. Building upon these theoretical findings, the exploratory part of this survey addresses research question five and six (see Section 6.1). As such, the goals went beyond a mere description of the survey results and include the following aspects:

- Investigation of risk severity profiles regarding the first principle of RdD.
- Analysis of the current state of practice regarding risk related decisions (second principle of RdD).
- Investigation of mitigation intensity profiles regarding the third and fourth principle of RdD.
- Aggregation of the risk severity and mitigation intensity profiles.
- Classification of high and low performer and investigation of how they address the principles of risk-driven design.
- Empirical validation of the risk management approach of all PD frameworks along the principles of risk-driven design.
- Investigation of how project managers and risk manager understand and perceive risk management.

As can be seen above, the main objective of the exploratory part is to empirically address each principle of RdD along different criterion. Regarding the first principle, it was considered of interest to investigate specific risk severity profiles on the basis of the different types of uncertainty of RdD (see Section 4.3.1). As such, risk sources that have a potentially strong or weak impact on the PD project should be explored by examining both the impact and the occurrence frequency of different risks (see Table 4-1).

Regarding the second principle of RdD, a descriptive overview of the current state of practice regarding risk related decisions should be given (see Table 4-2). It was expected that these aspects are not well addressed since existing PD frameworks predominantly focus their decision making process on quality checkpoints or milestone gates (see Section 5.5).

Regarding the third principle of RdD, it was deemed of interest to investigate specific risk mitigation intensity profiles on the basis of the uncertainty types of RdD (see Table 4-3 and Table 4-4). In this regard, the goal was to aggregate and combine both the frequency of use and the risk reduction achieved of different mitigation actions. Furthermore a “risk management map” combining the risk severity and mitigation intensity profiles should be investigated in order to identify the extent of how the occurred uncertainty types are addressed by different mitigation activities.

The comprehensive empirical investigation of the four principles of RdD design was considered of great value from a scientific point of view. However, the contribution of the survey went beyond a rather “isolated” analysis of each aspect of the RdD framework.
Therefore all described results should be standardized, combined and linked to project performance metrics. This investigation should address the fifth and sixth research questions of this thesis in more detail and can therefore be divided into two aspects:

First, it was of great interest to differentiate between low and high performer and their respective behavior on addressing the principles of RdD. Since it was claimed that both RdD is a promising framework to integrate RM as an intrinsic part of PD (see Section 4.3) and risk management directly contributes to project success (see Section 2.1.1), this investigation should give a first indication of the influence of RdD principles on PD project performance.

Secondly, the theoretical findings regarding the risk management approach of the reviewed PD frameworks should be empirically validated. Therefore the survey results should be filtered and aggregated in such a way as they can be compared to the theoretical findings (see Table 5-10).

Since it was expected that risk managers and project managers understand and perceive risk management differently, the last goal of the exploratory part included investigating empirical examples that can confirm or refute this assumption.

### 6.2.2 Development of the Survey

The general survey questions were developed with two different research approaches: (1) a comprehensive literature review and (2) various interviews with practitioners in industry.

Regarding the first research approach, the following literature sources were reviewed and consolidated: DoD (2006), HASKINS et al. (2010), GAO (2010), ISO (2009a), ISO (2009c), NASA (2008), PMI (2008a).

From an empirical point of view, several interview sessions were conducted with an industry focus group consisting of four major companies from the aerospace and defense industry. Furthermore, a close collaboration with a consultancy, which is specialized in the field of risk management, was realized during the development phase of the survey. The interview sessions helped to adjust the questions and infrastructure of the survey to better fit the industry needs. They also provided insightful feedback of current RM practices.

It should be noted that the author was primarily involved in the revision and completion of the survey questions and in the development of the survey infrastructure. As such, the deployment of the survey questions itself was out of the scope of this research (see Section 6.3).

### 6.2.3 General Structure of the Survey

As shown in Table 6-1 the survey consists of twelve pages and thirty-eight main questions. The questions comprised a total number of 206 items (i.e. options to choose) and mainly contained multiple choice question types.
Most notably, the question blocks were assigned to three different respondent groups in order to both shorten the total completion time per group and to better distinguish between project/program managers (PM) and risk practitioners (RM1 and RM2) (see Section 6.3.2 and Table 6-1). This distinction and apportionment are conducted by asking the role of the participants in question Q1.14. All described survey questions can be seen in the Appendix A (see Chapter 9).

<table>
<thead>
<tr>
<th>Question block</th>
<th>Adressed RdD-Principle</th>
<th># of pages</th>
<th># of questions</th>
<th># of items</th>
<th>Question type</th>
<th>Respondent group</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Introduction and General Overview</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2. General Questions - Organization</td>
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<td>5</td>
<td>20</td>
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<td>All</td>
</tr>
<tr>
<td>4. RM Process 1: Planning and Preparation</td>
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<td>1</td>
<td>3</td>
<td>20</td>
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<td>PM, RM2</td>
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<td>5. RM Process 2: Risks and Their Impact</td>
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<td>4</td>
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<td>Mult. Choice</td>
<td>RM1</td>
</tr>
<tr>
<td>7. RM Process 4: Risk Evaluation</td>
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<td>1</td>
<td>8</td>
<td>Mult. Choice</td>
<td>All</td>
</tr>
<tr>
<td>8. RM Process 5: Risk Mitigation</td>
<td>3, 4</td>
<td>1</td>
<td>5</td>
<td>32</td>
<td>Mult. Choice</td>
<td>RM1</td>
</tr>
<tr>
<td>Total</td>
<td>-</td>
<td>12</td>
<td>38</td>
<td>206</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

*Table 6-1: Structure of the Survey on Risk Management Practices in Product Development*

The first page of the survey included an introduction about the survey purpose, the benefit of both industry and research, the total time required to complete the questionnaire and a statement reassuring that all collected data is treated as confidential. Furthermore the second page provided a general overview of the survey structure and emphasized that participants should choose one project that: (1) focuses on product development and (2) was finished most recently as a reference for all further questions.

On the next three pages, general questions are asked about the respondent’s organization and project such as the type of organization, the yearly budget of the company, the respondent’s role during the project, the general project background, the relevant risk management and PD frameworks and the characteristics of the project along the two dimensions complexity and novelty.

The following six pages each address one RM process step of the ISO 31000 RM standard (see Section 3.2.1). As shown in Section 4.3.5 and Table 6-1, the RM processes can be mapped to the principles of RdD. In general, these questions include different assessments of:

- The way risk management was planned and prepared (RM process 1)
- The impact of different risks on the project as well as the frequency of their occurrence (RM process 2)
- The dimensions and methods that were used to quantify risks (RM process 3)
The techniques to make decisions about risks in the project (RM process 4)
- The risk reduction achieved by different mitigation actions (RM process 5)
- The way risk management was monitored and tracked (RM process 6)

The last page of the survey inquires information on the overall risk management performance. The respondent is asked about the role and perception of risk management in the project, the influence of risk management on the project, different statements of the overall project execution and finally the project success for the organization. Especially the last question is considered of great importance for addressing the fifth and sixth goal of the exploratory part of the survey (see Section 6.2.1).

After reviewing several web-based survey solutions such as SurveyMonkey, QuestionPro, Survey Gizmo and EFS Survey, it was finally decided to use the online software Qualtrics for implementing the survey. The main reasons for this purpose included both the sophisticated user interface which allowed an easy development and maintenance of all questions and most importantly the opportunity of dividing the questions into several blocks which could then be assigned to the respective respondent groups (see Table 6-1). This investigation is described in more detail in section 6.3.2.

6.2.4 Data Collection

The survey was extensively pre-tested with research assistants, professional organizations and industry practitioners before it was finally sent out. This phase was an important step to make sure that all questions were formatted and phrased correctly as well as the data entered was transferred to the database without any failures or loses.

After the successful testing phase, several employees of companies with leading roles in the area of risk management were directly contacted via e-mail or phone. Since they were considered to have the best insight into risk management practices, they were asked to forward the survey to both risk practitioners and project managers within their company. In addition, the survey was also distributed by contacting several professional organizations and associations, such as the Risk Management Special Interest Group (RiskSIG), the National Defense Industrial Association (NDIA) and the International Council on Systems Engineering (INCOSE).

One goal of this research included investigating the current state of practice regarding risk management in PD. Therefore it was considered preferable to receive answers from various industry areas in order to avoid a bias towards one particular branch of industry. Especially the distribution of the survey through different organizations and associations helped to contact and address companies in various industries (see Section 6.4.1).

In total, a number of 185 respondents filled out the survey at the date of the data analysis. Up to this point in time, the field study went for 58 days. An accurate respondent rate could not be estimated as the majority of participants were members of RiskSIG and NDIA and were directly contacted via these associations.
It should be noted that since the participants only answered parts of the survey (see section 6.2.3 and 6.3.2) the total responses are not equally distributed along all questions. As such, some questions had been answered by more than 150 participants, whereas some questions that are just addressed by one respondent group only received less than 50 answers. However, it was carefully considered to group the question blocks along different coherent topics so as to avoid creating a bias in the results. For example, the first group of risk managers answered the risk management process question blocks regarding both risks and their impacts and corresponding mitigation activities.

6.3 Contribution of this Thesis

As already stated in the previous section, the author worked closely on a survey research project on RM practices in PD that was conducted at LAI and the KFUPM-MIT Center. This section underlines the different contributions of this thesis which include the revision and completion of the survey questions (see Section 6.3.1), the identification of an appropriate online survey infrastructure and the implementation of the survey in its final web-based format (see Section 6.3.2), the development of an automated benchmarking tool (see Section 6.3.3) and a descriptive and in-depth exploratory analysis of the survey data (see Section 6.3.4 and 6.3.5 respectively).

6.3.1 Revision and Completion of Survey Questions

Requirements

The original survey questionnaire was developed in regard to the ISO 31000 risk management process framework (ISO 2009a) based on a literature review and several interviews (see Section 6.2.2). Therefore the different questions were not yet classified along the principles of RdD. In addition, the five different types of uncertainty (see Section 4.3.1) were also not explicitly considered.

Results

To address these requirements, all survey questions are carefully revised and restructured along both the principles of RdD and the five different uncertainty types.

The results of this investigation can be seen in Table 4-1, Table 4-2, Table 4-3 and Table 4-4. In this context, the respective bibliographic information point out whether the different examples of risk, risk-related decisions, risk mitigation actions and resilience along each principle were applied to the revised survey questionnaire (“industry focus group”). All examples of risk regarding principle one are furthermore linked to the mitigation aspects of principle three and four.

For the final completion and the subsequent distribution of the survey, minor changes are made regarding the format and phrasing of the questions.
6.3.2 Online Survey Infrastructure

Requirements
In its original version, the survey took around 30-35 minutes to complete it. The requirement for the updated survey was to shorten the duration to 10-15 minutes without taking any questions out of the survey structure.

Results
To address the described requirement, the survey infrastructure is completely redesigned by using more sophisticated web-based survey software.

The requirements for the new survey software include:

- Combining several questions to distinctive question blocks
- Dividing the respondents into two different groups – project manager and risk practitioner - based on their respective role in the project
- Assigning these respondent groups to different question blocks in a specific order
- Dividing the question blocks for risk managers into two additional parts which are evenly selected respectively
- Transferring all responses of the three different groups to one database

The originally used survey supplier ‘SurveyMonkey’ was not capable of addressing these requirements. As already described in Section 6.2.3, it is finally decided to use Qualtrics for the implementation of the survey in its web-based format. This survey software features a very sophisticated user interface and allows assigning customizable question blocks to different respondent groups.

As a result, the newly developed survey flow (i.e. infrastructure) can be seen in Figure 6-1. The respondents are either assigned to the survey questions of the group of project manager or risk practitioner based on their role in the PD project. Furthermore, the question blocks of the latter group are divided into two sections. Both of these parts are evenly selected assuring that both segments are equally addressed by the group of risk practitioners.
Due to the advanced survey infrastructure, the completion time is reduced to 9-15 minutes per respondent group while all original questions are still retained. Furthermore the answers are transferred to one database. A long version of the survey with no “question-logic” is also kept for participants that were willing to answer the complete questionnaire.

### 6.3.3 Automated Benchmarking Tool

**Requirements**

As described in Section 6.2.1, a main objective of the general research project was to create a benchmarking standard for RM processes. Among other aspects, this goal was formulated due to the fact that many interviewed companies wanted a greater incentive to participate in the survey than just total results. Therefore, a main requirement of the field study included the development of a sophisticated software solution that enables a dynamic benchmark of all participating companies.

**Results**

To address this comprehensive requirement, the author used Microsoft Excel 2010 for the development of the automated benchmarking tool (see Appendix B). As can be seen in Table 6-2, it consists of 25 different worksheets that are divided into four different sections.

---

**Table 6-2: Survey Flow of the Different Respondent Groups**

<table>
<thead>
<tr>
<th>Question block</th>
<th>Project Manager</th>
<th>Risk Manager - Group A-</th>
<th>Risk Manager - Group B-</th>
<th>Long Version of Survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Questions - Organization</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>General Questions – Project</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 1: Planning and Preparation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 2: Risks and Their Impact</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 3: Risk Analysis</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 4: Risk Evaluation</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 5: Risk Mitigation</td>
<td></td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>RM Process 6: Monitoring and Review</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td>Risk Management Performance</td>
<td>●</td>
<td>●</td>
<td>●</td>
<td>●</td>
</tr>
<tr>
<td><strong>Total Duration (in min.)</strong></td>
<td><strong>9-12</strong></td>
<td><strong>10-15</strong></td>
<td><strong>10-15</strong></td>
<td><strong>30-35</strong></td>
</tr>
</tbody>
</table>

*Figure 6-1: Survey Flow of the Different Respondent Groups*
The first part comprises nine result sheets which each cover one question block of the survey. Every data sheet includes various pivot charts and tables that can dynamically be filtered and adjusted to enable a benchmark of the company versus the rest of the firms in the sample. In this regard, Figure 6-2 shows an exemplary screenshot of the question block ‘General Project’ with dummy values.

The following three sections contain the main data of the survey. The second part comprises the static data which is copied from the Qualtrics software, whereas the third and fourth section accesses the static data and dynamically restructures and filters it based on different criterion. The data sheet ‘Master – Methods v2’ constitutes the central database which is both accessed by all result sheets and supplied by all other auxiliary tables in section four. An exemplary screenshot of this table can be seen in Figure 6-3. As the name implies, the ‘Mapping – Methods v2’ data sheet provides a comprehensive mapping of different risks and corresponding mitigation activities.

Besides the benchmarking feature, the software tool is also used for both the descriptive and exploratory analysis of the survey data which are described in the following sections.
<table>
<thead>
<tr>
<th>ID and description of survey question</th>
<th>Grouped calculations (e.g. Average, Standard deviation etc.) of data dimensions</th>
<th>Calculated data values of specific dimensions</th>
</tr>
</thead>
</table>

*Automated Result Graphs*  
*Pivot-Table Calculations*  

**Figure 6-2:** Screenshot of Benchmarking Tool (1) - Example of Result Sheet ‘General Project’  

**Figure 6-3:** Screenshot of Benchmarking Tool (2) - Example of Data Source ‘Master - Methods v2’
6.3.4 Descriptive Analysis of Survey Data

This section provides a brief overview of the methodical approach of the descriptive survey data analysis. The respective findings of this investigation are described in Section 6.4.

In general, Microsoft Excel 2010 was used for analyzing the data. After developing the overall structure of the benchmarking tool (see Table 6-2), the data was synthesized in a central database and subsequently filtered as well as refined using pivot table tools. Since not all questions were explicitly considered in this investigation, the following Table 6-3 provides an overview of the respective applied survey questions. It is organized along the areas that are further incurred in the findings of the descriptive analysis. The detailed description of the survey questions can be found in the Appendix A (see Chapter 9).

<table>
<thead>
<tr>
<th>Descriptive Analysis Sections</th>
<th>Analyzed Questions</th>
<th># of items</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1. Characteristics of Organization of Study Participants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Questions - Organization</td>
<td>Q 1.12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Q 1.13</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Q 1.14</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Q 1.15</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.16</td>
<td>2</td>
</tr>
<tr>
<td>General Questions - Project</td>
<td>Q 1.21</td>
<td>11</td>
</tr>
<tr>
<td><strong>2. Characteristics of Project of Study Participants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Questions – Project</td>
<td>Q 1.20</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.22</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Q 1.30</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.31</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.32</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.33</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Q 1.34</td>
<td>2</td>
</tr>
<tr>
<td><strong>3. Use of Risk Management Process Frameworks</strong></td>
<td>Q 1.24</td>
<td>7</td>
</tr>
<tr>
<td><strong>4. Use of Product Development Frameworks</strong></td>
<td>Q 1.22 Q 1.25</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>15 62</td>
<td></td>
</tr>
</tbody>
</table>

*Table 6-3: Overview of Applied Survey Questions to the Descriptive Analysis*

For most of the questions the average and the standard deviation over all data points was calculated. However, for questions with multiple possible answers, e.g. the use of risk management or PD frameworks, an intermediary evaluation was necessary since the pivot analysis was not capable of directly determine the total number of respondents per question. Therefore a separate count mechanism was implemented in the database to calculate the percentage of the responses per item and the total replies.
6.3.5 Exploratory Analysis of Survey Data

As in the case of the descriptive analysis, not all questions of the comprehensive survey on risk management practices in PD were used for the exploratory survey data analysis. In this context, the following Table 6-4 provides an overview of the applied survey questions. As can be seen, it is organized along the principles of RdD in order to explicitly address the specific goals of the survey (see Section 6.2.1). The findings of this study are presented in Section 6.5.

<table>
<thead>
<tr>
<th>Risk-driven Design Principle</th>
<th>Analyzed Questions</th>
<th># of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Creating Transparency regarding Design Risks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RM Process 1: Planning and Preparation</td>
<td>Q 2.5, Q 2.6, Q 2.7</td>
<td>10, 5, 5</td>
</tr>
<tr>
<td>RM Process 2: Risks and Their Impact</td>
<td>Q 3.5, Q 3.6, Q 3.7, Q 3.8</td>
<td>5, 4, 5, 7</td>
</tr>
<tr>
<td>RM Process 3: Risk Analysis</td>
<td>Q 4.4, Q 4.5</td>
<td>6, 5</td>
</tr>
<tr>
<td>RM Process 6: Monitoring and Review</td>
<td>Q 7.4, Q 7.6, Q 7.7</td>
<td>5, 5, 6</td>
</tr>
<tr>
<td>2. Making Risk-driven Decisions</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RM Process 4: Risk Evaluation</td>
<td>Q 5.6</td>
<td>8</td>
</tr>
<tr>
<td>3. Minimizing Uncertainty</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RM Process 5: Risk Mitigation</td>
<td>Q 6.4, Q 6.6, Q 6.7, Q 6.8, Q 6.9</td>
<td>4, 5, 5, 3, 7</td>
</tr>
<tr>
<td>4. Creating Resilience in the Design System</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RM Process 5: Risk Mitigation</td>
<td>Q 6.6, Q 6.8</td>
<td>3, 1</td>
</tr>
<tr>
<td>Risk Management Performance</td>
<td></td>
<td></td>
</tr>
<tr>
<td>General Performance Factors</td>
<td>Q 8.3, Q 8.5</td>
<td>10, 6</td>
</tr>
<tr>
<td>Project Performance Metrics</td>
<td>Q 8.6</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>21</td>
<td>124</td>
</tr>
</tbody>
</table>

Table 6-4: Overview of Applied Survey Questions to the Exploratory Analysis

In general, the exploratory analysis required more sophisticated aggregation of the survey data since all responses had to be filtered and structured in different levels of granularity. Several auxiliary tables were developed that all addressed parts of the total data points and filtered the responses regarding different criterion. For example, the data sheet ‘Data – Water’ (see Table 6-2) dynamically lists all responses of the survey participants that indicated to
make use of the waterfall PD framework. All auxiliary sheets independently calculated the average, standard deviation and number of total responses of each question before the data was sent to the central data base ‘Master – Methods v2’. In order to compare all question blocks with each other, these calculated averages were furthermore converted to a standardized value.

For the presentation of the final results, pivot table tools were used to aggregate and structure the central data source in such a way as they address the principles of RdD and different risk management performance metrics as it is shown in Table 6-4.
6.4 Findings of the Descriptive Analysis

The following section illustrates the findings of the descriptive analysis. First the characteristics of both the organization and the project of the survey participants are presented in Section 6.4.1 and 6.4.2 respectively. Then, Sections 6.4.3 and 6.4.4 underline the use of risk management process frameworks and provide a descriptive overview regarding the use and the application background of PD frameworks.

6.4.1 Characteristics of the Organization of Study Participants

Figure 6-4 displays both the type of organization as well as the industry sector of the survey participants. As shown on the left chart, 89% of the companies in the sample are for-profit firms and 11% belong to government organizations. The right graph illustrates the distribution of the participating companies among industry sectors. As can be seen, half of the firms taking part in the survey (50%) appertain to various industry sectors ranging from automotive and consumer goods to service, energy and information technology sectors. This group is followed by 21% from the defense sector and 16% from the aerospace sector. Finally, 9% of the companies in the sample belong to the process industry and 4% have their background in medical devise and technology.

![Figure 6-4: Organization type and industry sectors of participating companies](image-url)
Figure 6-5 shows the revenue or yearly budget of the participating companies. As such, the majority of the firms had revenues of more than 1 billion dollar (64%). Only 35 companies (31%) filling out the survey had revenues of less than 100 million dollar and in between of these two groups, 16% of the firms had a budget or revenue of 100 million to 1 billion dollars.

It becomes apparent that there is a clear over-representation of companies with large revenues which is due to the fact that the general survey project aimed at investigating current risk management practices in programs. Since a program is defined as “a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually” (PMI 2008b, p.5), it was considered that companies with a lower revenue most likely play a minor important role in programs and therefore might not provide greater insights regarding integral risk management.

Furthermore, large companies were also deemed having high risk management expertise as many of them hold distinctive functional risk management departments in the field of PD.

The following Figure 6-6 gives on overview regarding the program level of the participating companies. As can be seen, the majority of the companies taking part in the study are related to the highest level of the program (66%) followed by the level of main contractor or integrator (15%). The remaining 20% of the firms in the sample belong to lower program levels such as system supplier (12%), component supplier (3%), lower-tier supplier (1%) and others (4%). This finding underlines that the majority of the participating companies can provide great general insights about risk and risk management at first hand as they are mainly responsible for the integral result of the program.
The role of the survey participants during the project is shown in Figure 6-7. As already described in Section 6.3.2, this question determined the specific survey path (i.e. flow of the question blocks) of the study participants and divides them into the group of program and risk managers. It can be seen, that 61% of the persons taking part of the survey belong to the category of program managers (PM), such as general program managers and executive decision makers. The remaining 39% of the participants had the role of risk managers or practitioners (RM) during the program.
Figure 6-8 finally illustrates both the dedicated time and budget on risk management activities. By reviewing the left graph, it becomes apparent that the majority of the firms in the sample (62%) indicate to spend a significant portion of time on risk management activities. However, almost the same percentage of survey participants (66%) emphasize that the project does not allocate more than 10% of the yearly budget to conduct risk management actions. Since the number of 10% constitutes an industry average and was a recommended metric of the consultancy (see Section 6.2.2), it is debatable whether the companies in the sample either operate in an environment in which they don’t need to allocate this proportion of their budget to RM or whether they generally under-fund their RM activities.

Figure 6-8: Dedicated time and budget on RM activities of participating companies
6.4.2 Characteristics of the Project of Study Participants

After the general questions on their organization, the survey participants were asked to provide some general information of the particular project they have chosen for all further survey questions (see Section 6.2.3). As such, Figure 6-9 displays the main type of product of the PD project. The majority of firms in the sample developed software products (31%), followed by various other product types ranging from different services to power plant construction (25%). The product type of integrated mechatronic systems including mechanical, electronic and software components were addressed by 20% of the study participants. The remaining 24% of the firms in the sample developed products in the area of single mechanical components (13%), followed by the product categories integrated electronics or software systems (10%) and electronic components and assemblies (1%). These results are further referenced in Section 6.4.4 to investigate the specific application background of the PD frameworks along the main type of products shown below.

![Figure 6-9: Main type of product of the PD project](image)

The specific project profile of the studied companies along five uncertainty types (see Section 4.3.1) are shown in the following Figure 6-10. In this regard, the study participants were asked to characterize the project or program in the five areas of technology, customer, company, supplier and market regarding novelty and complexity. These two dimensions were aggregated to a single metric by calculating the average of the ‘complexity’ average value and the reversed ‘novelty (i.e. experience)’ average value. As such, it can be seen that all participating companies had a relatively constant project characteristic or in other words they all had the same proportion of complexity and experience in the PD project. However, as described in the limitations of the survey results (see Section 6.6), it has to be noted that the shown findings are only based on averages and not yet further analyzed with a variance analysis. Therefore the project profile factors might have a bias in the results due to the differing characteristic of the statistical spread.
Use of Risk Management Process Frameworks

As pointed out in Section 6.2.1, one specific goal of this survey was to investigate the use of risk management process frameworks in industry. In this regard, the participants were asked to indicate their relevant RM models (see Section 3.2.1) used for the design of the RM process. It should be noted that this questions allowed multiple answers. Each percentage value in Figure 6-11 therefore indicates the proportion of the specific RM framework to the total sample.

It can be seen that the Project Management Institute (PMI) RM framework is used most (62%) followed by the Department of Defense (DoD) RM model (26%). Interestingly, the ISO 31000 RM standard is already considered by nineteen study participants even though it was recently published (see Section 3.2.1). The other reviewed RM models (i.e. NASA, Prince2 and INCOSE) play a relatively inferior role for the companies in the sample.

Arguably, the relative high value regarding the use of the DoD RM framework can be explained due to the slight over-representation of companies from the defense and aerospace industry in the survey (see Figure 6-4).
6.4.4 Use of Product Development Frameworks

Besides the use of RM process frameworks, it was an additional important goal of the survey to empirically investigate the use of prominent PD frameworks not only to provide a descriptive overview by itself but to furthermore enable a validation of the theoretical findings regarding their intrinsic risk management approach (see Chapter 5). The first aspect is addressed in this section, whereas the latter part is discussed in more detail in the following exploratory analysis (see Section 6.5.7).

Figure 6-12 displays the use of PD frameworks in the PD project. As in the case of the previous section, this question also allowed multiple answers. Hence, the firms in the sample used the waterfall model most (54%), followed by spiral development (21%) and Scrum development (15%). Both PD principles DfSS and Lean PD were applied by seventeen (11%) and twenty five (16%) survey participants respectively.
The following Figure 6-13 provides a more specific overview of the PD frameworks distribution along the different product types (see Section 6.4.2). As such, the results shown in Figure 6-9 and Figure 6-12 were aggregated to present the relative percentage of each PD framework used in the different product category.

In this context, the waterfall model is almost evenly used in regard to all stated product types. Regarding spiral development, the analysis shows interesting results. Many literature sources emphasize that software development is conventionally the main application area of the spiral model (see Section 5.3.2). However, the survey findings illustrate that 23% of the participants using the spiral framework develop products in the area of integrated mechatronic systems which include both software programs and hardware components.

On the other side, scrum development is predominantly used in “pure” software development (67%), whereas Lean PD is slightly more deployed in various product types ranging from different services to construction projects. As in the case of the waterfall model, Design for Six Sigma is also almost evenly distributed along all shown product categories.

In summary, the findings in this section constitute that other than scrum development, all PD frameworks tend to be used in regard to several product types. They are therefore more widespread in practice than generally anticipated in theory (see Section 5.6) and not limited to their originated application context.
6.5 Findings of the Exploratory Analysis

This section discusses the findings of the exploratory analysis of the survey data. Starting with a brief overview of the questions that are applied and aggregated for the subsequent investigations (see Section 6.5.1) the following Sections 6.5.2 - 6.5.5 each cover specific results regarding one RdD principle.

Section 6.5.6 illustrates the findings of RM related performance and furthermore discusses exemplified results of how risk management is perceived by program managers and risk practitioners.

Finally, Section 6.5.7 aggregates all findings of the exploratory analysis and compares how low- and high performer (i.e. survey participants that indicated to either achieve or not achieve their project targets) as well as PD frameworks holistically address the four principles of RdD.

As an important limitation, it has to be noted that all subsequent survey findings of the exploratory analysis are only based on calculated average. In this regard, the results have a somewhat “preliminary” character and only present first indications as they are not yet verified with detailed analysis of variances. Therefore a bias in the findings due to strong statistical spread cannot be excluded.
6.5.1 Overview of Applied and Aggregated Questions

Whereas Table 6-4 already showed all survey questions generally applied to the exploratory analysis, the following Table 6-5 provides a more detailed overview of the classified questions in regard to the different uncertainty types or input factors of a PD system. For an easier alignment, a brief definition of the respective uncertainty type is also given.

As can be seen, the data of 21 survey questions (see Appendix A) are related to the specific results of the first principle of RdD (Section 6.5.2). On the other hand, the data of 28 questions are aggregated in regard to the findings of the third principle (Section 6.5.4). The questions in regard to the second and fourth principle of RdD are not explicitly related to the types of uncertainty and therefore not shown below.

<table>
<thead>
<tr>
<th>Uncertainty type</th>
<th>Definition</th>
<th>- RdD Principle 1 - Question #</th>
<th>- RdD Principle 3 – Question #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Technology</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New technology</td>
<td>Uncertainty of technology maturity influences the performance reliability under field conditions</td>
<td>Q3.8_1, Q3.8_7</td>
<td>Q6.9_1, Q6.9_2, Q6.9_5</td>
</tr>
<tr>
<td>System integration</td>
<td>Uncertainty of System integration readiness affects overall system performance and reliability</td>
<td>Q3.8_2, Q3.8_3, Q3.8_4</td>
<td>Q6.9_3, Q6.9_4, Q6.9_6, Q6.9_7</td>
</tr>
<tr>
<td><strong>Customer</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Customer requirements understanding</td>
<td>Uncertainty regarding quality of understanding of the requirements by the organization</td>
<td>Q3.7_1</td>
<td>Q6.6_2, Q6.6_6, Q6.8_2</td>
</tr>
<tr>
<td>Customer requirements stability</td>
<td>Uncertainty regarding stability of customer requirements</td>
<td>Q3.7_2</td>
<td>Q6.8_1</td>
</tr>
<tr>
<td><strong>Company-internal factors</strong></td>
<td>Uncertainty regarding the efficiency and effectiveness of design processes and their execution, including skill levels and productivity of the workforce</td>
<td>Q3.5_1, Q3.5_2, Q3.5_3, Q3.5_4, Q3.6_1, Q3.6_3, Q3.6_4, Q3.7_3, Q3.8_5, Q3.8_6</td>
<td>Q6.6_3, Q6.6_4, Q6.6_5, Q6.6_9, Q6.7_1, Q6.7_2, Q6.7_3, Q6.7_4, Q6.7_5, Q6.7_6, Q6.7_7, Q6.7_8</td>
</tr>
<tr>
<td>Supplier</td>
<td>Uncertainty regarding time, cost or quality of service or component deliveries</td>
<td>Q3.6_2, Q3.7_4</td>
<td>Q6.6_1, Q6.6_7, Q6.6_8</td>
</tr>
<tr>
<td>Competitor</td>
<td>Uncertainty of actions by competitors, e.g. new technology introduction or pricing strategy</td>
<td>Q3.5_5</td>
<td>Q6.8_4</td>
</tr>
<tr>
<td>Market</td>
<td>Macroeconomic uncertainty, such as political, social, environmental or economic developments</td>
<td>Q3.7_5</td>
<td>Q6.8_3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>21</td>
<td>28</td>
</tr>
</tbody>
</table>

*Table 6-5: Overview of applied and aggregated questions along types of uncertainty and RdD principles*
6.5.2 Principle 1 - Creating Transparency regarding Design Risks

Regarding the first principle of RdD – creating transparency regarding design risks – it was considered of interest to investigate a “risk map” of the companies in the sample. Therefore the survey participants were asked to rate the impact of different risks and whether or not the risks generally occurred in the PD project (see Appendix A).

Prior to this investigation an intermediate step was executed. Since it was expected that the impact of risk is strongly influenced by the complexity or novelty of the project, each survey response data was linked and adjusted to the particular project profile (see Figure 6-10). However, the results of the adjusted and non-adjusted risk impact values were proportional to each other. Thus, the original and non-adjusted survey data could be used for the subsequent survey analysis.

In general, for building the risk map of the firms in the sample, three analysis steps were conducted. In a first step the averages of impact and frequency regarding different risks were calculated based on the relevant survey data items shown in Table 6-4. The second step included the aggregation of the item results to the eight types of uncertainty (see Table 6-5). Finally, the risk map consolidated the frequency and risk impact of the uncertainty types to a particular graph.

The following Figure 6-14 displays the results of this investigation. The upper right area of the graph illustrates the most critical risks as they had a significant impact on the PD project and moreover occurred very frequently.

It can be seen that risk regarding customer requirements stability was evaluated on average as most critical. It had the highest impact and generally occurred in each of the survey participant’s PD project. On the other side, the mean of the occurrence frequency of risks regarding competitor or market uncertainty was less than 80%. Even if risks occurred, the survey participants assessed the respective impact on the PD project as comparatively low. Risks regarding system integration, new technology, supplier or company-internal processes all occurred in more than 85% of the PD projects in the sample but were assessed to just have a medium impact.
Figure 6-15 aggregates the findings discussed above and displays the risk severity profile of the participating companies which is defined as the product of occurrence frequency and risk impact.

As such and in accordance to the previous findings, the risk severity regarding customer stability was assessed highest. In general, this indication in the data is very interesting as in theory many PD frameworks strongly aim at incorporating the customer throughout the PD process and also tend towards more resilience in the PD system in order to respond to changing customer needs in an appropriate manner (see Section 5.5). However in practice, this risk source might still be perceived to threaten the overall project success most, whereas external uncertainty types such as market and competitor had a relatively little risk severity although the level of control regarding these uncertainty types is low (see Section 4.2).

Besides the exploratory findings of the risk severity profile it was also deemed of interest to link the results to the mitigation efforts spent on the different risks. As such, it can be determined whether the participating companies either undermanage the respective risk source or whether the mitigation actions might generally not be effective enough to reduce the risk impact sufficiently. These research aspects are addressed in Section 6.5.4.
6.5.3 Principle 2 - Making Risk-driven Decisions

As shown in Table 6-4, the survey question block “Risk Evaluation” (see Appendix A) was applied to the analysis of the second principle of Risk-driven Design (RdD).

The following Figure 6-16 illustrates the use of different risk evaluation techniques in the PD project. As can be seen, there is some indication in the survey data that the participating firms surprisingly addressed risk-driven decisions in the context of RdD to a great extent. Considering the theoretical findings regarding the intrinsic RM of different PD frameworks (see Table 5-10), it was rather expected that only very few risk evaluation actions are deployed. As such, especially the techniques - “decisions made based on risk-benefit tradeoff” and “risk assessment used to set more realistic objectives” – were on average often used in practice although they are almost not addressed by PD frameworks in theory.

However, this discrepancy can be explained due to the fact that companies generally apply risk management techniques much more comprehensively than it is described in the reviewed literature of PD approaches (see Section 5.2).

The indications of the results described in this section are nevertheless interesting as the firms in the sample only evaluated the aspect “contracts derived from cost assessment” below the average of the scale.
6.5.4 Principle 3 - Minimizing Uncertainty in Design

Based on the aggregated survey questions shown in Table 6-5, this section discusses the specific findings regarding the third principle of RdD: Minimizing Uncertainty in Design.

Similar to the first principle of RdD, one specific goal of the survey was to investigate a risk mitigation profile of the firms in the sample (see Section 6.2.1). Therefore the survey participants were asked both to rate the effectiveness (i.e. overall risk reduction achieved) of different mitigation actions and whether or not they were used in the PD project (see Appendix A). To consolidate both findings, the same analysis steps were conducted as in the case of the risk map (see Section 6.5.2).

The following Figure 6-17 shows the overall mitigation action effectiveness profile of the firms in the sample. In this regard, the highest average of risk reduction was achieved by mitigation actions related to new technology and customer requirements stability. On the other side, the survey participants rated the effectiveness of market, supplier and competitor related mitigation actions as relatively low.
By reviewing the frequency of use, there is some indication in the survey data that mitigation actions regarding technology (i.e. new technology and system integration) were used most whereas competitor and supplier related mitigation activities had the lowest frequency of use among the survey participants. As such, it can be argued that the companies in the sample focused on managing technology risks most although the mean of the risk severity of this category was not evaluated highest (see Figure 6-15).

Moreover, the mitigation action profile generally differs from the risk impact profile shown in Figure 6-14. In order to provide comparable results regarding both profiles, the following Figure 6-18 displays the mitigation action intensity distribution in regard to the different uncertainty types. Similar to risk severity, mitigation intensity is defined as the product of mitigation effectiveness and frequency of use.

In accordance to the data indications described above, it shows that mitigation actions regarding technology (i.e. new technology and system integration) had the highest average value of the overall mitigation intensity, followed by customer, company-internal, market, supplier and competitor related mitigation actions.
Finally, the following Figure 6-19 illustrates a “risk management map” that combines both the risk severity profile shown in Figure 6-15 and the risk mitigation intensity profile displayed in Figure 6-18.

From a theoretical point of view, the ideal scenario includes a proportional distribution of risk severity and mitigation intensity, i.e. the more risk severity affecting the PD project, the more mitigation intensity is necessary to sufficiently mitigate or reduce the particular risk. As both aspects have the same scale in this empirical study, the linear line divides the graph shown below into two areas.

The upper area displays “possibly” under-managed risk sources. As such, they have a higher risk severity than mitigation intensity and might therefore negatively affect the overall PD project performance to a greater extent. In this regard, risks regarding customer requirements understanding and stability, supplier and partly company-internal uncertainties are potentially critical as they are managed too little.

The lower area of the graph shows “possibly” over-managed risk sources. As such and in accordance to the discussion above, risks regarding technology uncertainty (i.e. system integration and new technology) have higher average values of mitigation intensity than risk severity. Furthermore risks regarding competitor and market uncertainty are also relatively over-managed.
In general, these results indicate that companies currently tend to focus less on mitigating risks regarding customer requirements and supplier uncertainty. On the other side, they aim more at addressing technological risks in the PD project and successfully applied different mitigation actions that sufficiently reduce the respective risk severity.

However as an important limitation, it has to be noted that since both assumptions are based on the “ideal” scenario described above, it is not necessarily a mandatory fact. For example, the risk severity of “over-managed” risks can possibly rise to a very high degree if the mitigation intensity is lowered very little. On the other side, the risk severity of “under-managed” risks might not necessarily decrease if more mitigation intensity or effort is spent.

In summary and based on the theoretical assumption that risk severity and mitigation intensity affect each other linearly, the findings indicate that companies need to focus more on under-managed uncertainty types in regard to the first and third principle of RdD. Hence, it is essential to create transparency regarding these types of design risks and mitigate them more effectively.

However, a second limitation regards the complexity and novelty of the PD project. As already stated, they are both relatively even among the survey participants (see Section 6.4.2). Therefore the stated risk management map might just be accurate for rather equal PD project characteristics. If for instance the complexity of one particular characteristic (e.g. new
technology) is very significant, it obviously has to be addressed to a greater extent in regard to both the first and third principle of RdD. These latter aspects are further discussed in the final interpretation and comparison of the survey results in Section 6.7.

Besides the total results, one important goal of the survey was to validate the theoretical findings regarding the RM approach of different PD frameworks (see Section 6.2.1). Addressing one aspect of this investigation, the following Figure 6-21 displays the risk mitigation effectiveness profile of the different PD approaches. In this context, the results can be compared to the theoretical findings of the third principle of RdD shown in Table 5-10.

At a first glance, Design for Six Sigma (DfSS) achieved the highest risk reduction average in the PD project in regard to most of the uncertainty types: The survey participants that applied DfSS indicated great risk mitigation effectiveness regarding company-internal, new technology, system integration and customer requirement stability. By comparing these results with the theoretical findings of this thesis (see Table 5-10) it becomes apparent, that these risk sources are also strongly addressed by DfSS in theory.

On the other side, the Waterfall Model generally achieved the worst average values regarding risk mitigation effectiveness. In theory, the PD framework was interestingly evaluated to have the least comprehensive RM approach. It was nevertheless expected that due to its emphasis on clear structure, well-planned development phases and rigid design reviews it strongly addresses system integration and company-internal uncertainties (see Section 5.5). It is therefore interesting that compared to all other investigated PD frameworks, the participants in the sample using the Waterfall Model achieved the lowest risk reductions in regard to these two uncertainty categories.

By reviewing the results of the survey participants using Spiral Development, it has to be considered that in theory, many authors argue that this PD framework has a strong focus on incorporating the customer into the PD process to reduce uncertainty regarding the stability of customer requirements (see Section 5.3.2). In this regard, the empirical results confirm the literature as the Spiral Model achieved relatively high risk mitigation effectiveness in regard to this uncertainty category. The same result can be seen regarding the uncertainty type “new component technology”.

An interesting finding is indicated in the data regarding Lean PD. In theory, it was considered to be well suited making sure that current customer requirements are understood well, the system is integrated properly and company-internal processes can flow with highest efficiency (see Section 5.5). In practice, the survey data indicates that survey participants applying Lean PD achieve comparably low risk reductions in regard to these three uncertainty categories.

In summary, it was hypothesized that Scrum Development and DfSS yield the most comprehensive RM approach (see Section 5.5). From the empirical point of view, this assumption can be confirmed regarding the average values of risk mitigation effectiveness of the PD principle DfSS. However in the case of PD process frameworks the empirical results indicate that the survey participants using Spiral Development achieved the highest average values of risk reduction in the PD project.
6.5.5 Principle 4 - Creating Resilience in the Design System

Regarding the fourth principle of risk-driven design – “creating resilience in the design system” – the data of two survey questions were analyzed (see Table 6-4). As such, the following Figure 6-21 displays the risk mitigation intensity profile regarding four characteristics of resilience. In general, the participating companies had a relatively ordinary risk mitigation intensity regarding schedule, financial reserves and the management and renegotiation of requirements. On the other side, holding excess resources attained comparably low risk mitigation intensity.
As in the case of the third principle of RdD, it was also deemed of interest to compare the theoretical investigations with the empirical results regarding resilience characteristics of PD frameworks. Therefore the following Figure 6-22 shows the mitigation effectiveness profile of the different PD approaches.

By reviewing the results of the survey participants using Lean PD it can be seen that the mitigation actions regarding buffers (i.e. financial, schedule and resource reserves) both achieved comparably low average values regarding risk reductions in the PD project and were furthermore used to a minor degree. Considering Lean PD as an efficiency-driven management approach (see Section 4.3) this result is coherent to the literature that describes the use of buffers as contradictory to the philosophy of Lean PD.

In general, DfSS and Spiral Development achieved the highest overall risk reduction in the PD project by creating both buffers based on main objectives (i.e. financial and schedule resources) as well as lower-level buffer (i.e. holding excess capacities). As such and in accordance to the theoretical findings (see Section 4.3.4), the results indicate that critical buffers can help to effectively mitigate risks by increasing the robustness of the PD system.

Figure 6-21: Risk mitigation intensity profile regarding characteristics of resilience
6.5.6 Risk Management Related Performance

General Project Performance Metrics

In order to investigate both the RM related performance of the different PD frameworks and the influence of the RdD principles on the PD project performance, the following Figure 6-23 displays the overall project success of the firms in the sample. In this regard, the survey participants were asked to evaluate whether the PD project met or exceed the target regarding cost, schedule, technical performance and overall customer satisfaction.

As can be seen, the average values indicate that no stated target was generally exceeded by the firms taking part in the survey. The targets regarding technical performance and overall customer satisfaction were just generally met. The performance metrics regarding cost and schedule targets were evaluated slightly below the average of the scale.

These indications are further discussed and aggregated in the following section. As such, they served to determine the behavior of low and high performer in their regard to addressing the principles of risk-driven design.

Figure 6-22: Resilience mitigation effectiveness (frequency of use) of PD frameworks
**Understanding of Risk Management of Risk Manager and Project Manager**

Besides the investigation of different performance metrics it was also considered of interest to analyze whether risk practitioners and project managers understand and perceive risk management differently. Figure 6-24 therefore illustrates the result regarding survey question Q8.3 (see Appendix A) which inquired different statements on the role and perception of risk management.

The average values indicate that risk managers generally more agree to the given statements than project managers. As an interesting example, risk managers endorse that RM is valuable for promotions whereas project managers more disagree to that aspect although they are supposed to have greater insights due to their general higher position in the company. It is also striking that risk managers on average more agree to the statement “findings from RM process translate into action (allocation of manpower and resources)” than project managers although it can be assumed that project managers are more responsible for the action plan of the PD project and the allocation of resources.

In summary, there is some indication in the data that risk practitioners are more optimistic in regard to their firms risk management practice. They perceive the role of risk management as more important and more successful compared to the group of project managers.
Summary of High vs. Low Performer addressing Risk-driven Design

As already stated above, the performance metrics shown in Figure 6-23 were used as a basis for dividing the survey participants into high and low performer. In this regard, the total results of the exploratory analysis consisting of 124 question items were carefully aggregated to single standardized measures and classified to the four principles of RdD and different performance factors. As such, the findings of the survey data can be compared to each other irrespectively of their original question type. An overview of the applied survey question can be seen in Table 6-4.
The following Figure 6-25 shows the final results of this investigation. At a first glance, the results show indications that high performer (i.e. the top 25 percent of the survey participants with the best overall results regarding PD performance metrics) show generally better results regarding the principles of RdD than low performer. They furthermore also achieved superior findings regarding general-performance factors.

Interestingly, the highest discrepancy of both groups can be found regarding the first principle of RdD As such, it can be interpreted that the high performers in the sample generally used different risk identification and quantification methods to a greater extent. They furthermore more often applied different risk evaluation techniques in regard to the second principle of RdD and had a lower risk impact in the project. Finally this group also achieved higher risk reductions with different mitigation actions in regard to both the third principle and fourth principle of RdD.

Although the results discussed in this section are preliminary as several limitations have to be considered (see Section 6.6), they still show striking tendencies. In general, there is some indication in the data that high performing survey participants that met or exceeded their targets regarding cost, schedule, technical performance or customer satisfaction better addressed the principles of RdD. This finding is not a mandatory phenomenon as the two groups were only separated and classified with respect to their overall PD performance results and not regarding other criterion.

Therefore, the survey data gives a first indication that addressing RdD and thus deploying risk management techniques positively influences the PD performance. However, further and more sophisticated investigations are necessary to clarify or measure the effect of RdD on the PD performance in more detail.

![Figure 6-25: Summary of addressing Principles of Risk-driven Design (High Performer vs. Low Performer)](image-url)
Summary of PD Frameworks addressing Risk-driven Design

The last investigation of the exploratory analysis included the extent of PD frameworks addressing RdD. The results were considered of great interest as they can be used for validating the theoretical findings shown in Table 5-10.

In the case of the third principle of RdD some detailed results have already been shown and discussed in Section 6.5.4. Taking a more global perspective, the following Figure 6-26 displays the integral findings of the extent of PD frameworks addressing RdD. In order to provide a proper comparability, the overall results of all firms in the sample are also illustrated.

Confirming the theoretical findings of this thesis, the survey data indicates that Design for Six Sigma addresses the principles of RdD most comprehensively. It also shows the best average results regarding general PD performance factors and metrics. In general and in accordance to the theory, the firms in the sample applying DfSS used risk management techniques to a great extent in regard to the first and second principle of RdD. As already discussed in Section 6.5.4 they also achieved the highest average values of mitigation effectiveness.

Considering the PD process frameworks, the survey participants using the Waterfall Model attained a comparably poor PD performance and also addressed most of the RdD principles below the average of the sample.

On the other side and in accordance to the theoretical investigations, the data indicates that Spiral development addressed RdD to a great extent and also achieved superior average results regarding the PD success (i.e. performance metrics). From an empirical point of view, this PD process framework yield the most comprehensive RM approach and also achieved significant risk reductions with different mitigation actions (see Section 6.5.4).

Interestingly, Scrum Development was evaluated in theory to extensively address the principles of RdD. However, there is some indication in the data that the survey participants using scrum development show differing results. In this regard, it is striking that the PD approach shows very substandard results regarding the first principle of RdD.

Although the reviewed literature discusses that Lean PD not explicitly considers risk management techniques (see Section 5.4.2) the survey results indicate that the PD framework addressed the first, second and third principle of RdD to a great extent. The firms in the sample applying Lean PD also achieved highest average results regarding general RM performance factors and also performed comparably superior in meeting their PD project targets. Regarding the fourth principle of RdD, the relatively poor results can be explained due to the strong survey focus on buffers, which are obviously not greatly addressed in Lean PD (see Section 6.5.5).

In summary, there is some indication in the data that the theoretical findings of the extent of risk management of PD frameworks (see Table 5-10) can be empirically confirmed in large parts. As such, the last Section 6.7 finally discusses the implications of both research findings (i.e. theory and practice) in regard to better integrating risk management as an intrinsic part of PD.
Figure 6-26: Summary of all PD frameworks addressing Principles of Risk-driven Design
6.6 Limitations of the Survey Results

Although the survey analysis already illustrated insightful new empirical results regarding current risk management practices in industry, some important limitations have to be considered.

First, the participating companies were only located in North America. Therefore it could not be tested whether the results differ in other organizations or management cultures. In addition, some question blocks were only answered to a minor degree as the survey questionnaire was divided to three subsets that were assigned to different respondent groups (see Section 6.3.2). In this regard, both the mitigation effectiveness profile of some PD frameworks and the integral findings regarding particular PD frameworks addressing the principles of RdD are based on a comparably small sample.

Another limitation regards the use of PD frameworks. The survey participants were only asked to indicate the PD approach that “played a significant role” in the project without further detailed definitions. Although it was discussed in various interview sessions that the inquired PD frameworks are commonly known in industry, they can nevertheless be perceived differently than the ones described in the reviewed literature.

The same or similar limitation has to be considered regarding the broad definitions of risks and mitigation actions inquired in question block “risks and their impact” and “risk mitigation” (see Appendix A). Thus, bias in the answers due to individual perceptions cannot be avoided.

Although deemed of interest, an isolated comparison of the survey data regarding participants using external RM process frameworks and those that more intrinsically integrated their RM actions into PD was not possible. The main reason included that all firms in the sample applied at least one of the stated external risk management models to the PD project.

Finally and most notably, an important limitation regards the analysis of the survey data. All survey results are only based on calculated averages. As such, no comprehensive analysis of variances has been conducted yet. Furthermore the findings regarding the positive influence of RdD on PD performance have to be further validated with more detailed correlation analysis.

6.7 Summary and Discussion of the Findings

This section briefly summarizes the survey findings and consolidates them with the theoretical results of the thesis. In this regard, it is discussed how to better integrate risk management as an intrinsic part of PD.

In general, the survey focused on striking a balance between high level investigations of RM frameworks that possibly provide not enough depth and low level investigations of RM methods that have a too limited scope. Therefore the questionnaire inquired specific program RM aspects such as general company and program information, the organizational context, risks and their severity, mitigation actions and their intensity, risk analysis, risk evaluation and decision making, monitoring and finally RM and program performance.
In regard to the specific goals of the survey (see Section 6.2.1), these question subsets were applied and aggregated to the four principles of risk-driven design (see Table 6-4).

Regarding the first principle a “risk map” was developed that consolidated the impact of risks regarding different types of uncertainty and the respective frequency of occurrence. There was some indication in the data, that customer stability requirements, was the most critical type of risk source of the firms in the sample whereas risks regarding market or competitor were perceived to only threaten the program to a minor degree.

Regarding the second principle of RdD and differing to the theoretical assumptions, the survey results indicated that the participating companies currently use different risk evaluation techniques to a great extent.

Regarding the third principle of RdD, the goal was to develop a “risk management map”. In this regard, different risk mitigation actions were inquired. Similar to the “risk map”, the frequency of use and the risk reduction achieved were consolidated to a risk mitigation effectiveness profile. Consequently, there was some indication in the data that the firms in the sample focused on mitigating risks regarding new technology and system integration most. Finally, both the risk severity and the mitigation intensity profile were combined to the “risk management map”. As such, the average values indicated that the participating companies currently focus their risk management effort too much on technological risks and too little on customer related risks. Besides the overall results, the risk mitigation effectiveness regarding the uncertainty types was also analyzed in the light of the PD frameworks. In this context the survey participants using DfSS and Spiral Development achieved the most comprehensive risk reduction effectiveness.

Regarding the fourth principle of RdD, the survey data indicated that various buffers such as financial and schedule reserves had comparably high mitigation intensity, whereas lower-level buffers (e.g. excess resources, manpower or facilities) were evaluated to achieve lower risk reductions.

Concluding, both industry and research can greatly benefit from the theoretical and empirical findings of this thesis.

For industry, the results help to better integrate RM into PD by choosing the “right” PD base framework and more intrinsically managing risk using the principles of RdD. As already stated in Section 5.6, UNGER (2003) accentuates that many companies still have great difficulties on picking their PD process framework due to the lack of analytical guidelines in literature. Hence, firms make PD process decisions haphazardly as a result of management trends and corporate momentum.

Addressing this literature gap, the theoretical research approach provided a structured and comprehensive comparison of popular PD frameworks in regard to their intrinsic risk management approach (see Chapter 5). Applying these findings to the survey results, the following Figure 6-27 illustrates a conceptual framework including four iterative steps that companies can apply to integrate RM as an intrinsic part of PD.
In this regard, the first step comprises the assessment of the PD project profile regarding the types of uncertainty (i.e. novelty and complexity characteristic) and the selection of the most suitable PD framework. As an example, Figure 6-27 shows a PD project in which high uncertainty exists regarding the factors “new component technology, customer requirements stability and competitors”. Based on the profile displayed above and the theoretical findings shown in Table 5-10, the PD framework that strongly addresses these types of uncertainty can be chosen. In the exemplary case, Scrum and Spiral development, combined with DFSS are the most suitable candidates as they strongly address the first two uncertainty factors.

The second step addresses the first principle of RdD. It includes the identification of the “risk management map” (i.e. risk severity and risk mitigation intensity) of past and similar PD projects of the company. The results can then be benchmarked internally and against the industry average. Moreover the identified RM map indicates where to spend more or less effort in the process of creating transparency regarding design risks. As such, the PD process can be customized in order to better identify and quantify the possible “under-managed” risks.
Addressing the second principle of RdD, the third step includes risk related decisions that can be made based on the transparency regarding design risks of the risk management map. In this context, the survey results give a first indication on currently used risk evaluation techniques (see Section 6.5.3).

Whereas the second step focused on assessing past PD projects in order to create transparency regarding risk severity and mitigation intensity, the fourth step focuses on the actual PD project and includes the identification of the risk reduction effectiveness of the PD framework used. Based on the empirical results (see Section 6.5.4), the company can both benchmark the actual RM related performance and identify potential strength and weaknesses. If required, the PD process can be customized to include different risk treatment actions or built-in buffers.

It has to be noted that all described steps are not necessarily mandatory or have to be executed in a subsequent manner. They rather have to be considered as guidelines that can be restructured or reorganized based on the specific requirements of the PD project.

From a scientific point of view, the survey findings provided general new insights regarding the current state of risk management practice in industry. As stated in Section 2.4, OEHMEN et al. (2010a) emphasizes that examples of specific design risks and real life applications of RM processes are hardly described in literature. As such, the survey addressed this gap and presented new empirical results regarding risk severity and frequency, the use of risk evaluation techniques, risk mitigation actions and their intensity and RM related performance. Mapping the findings to the principles of RdD, there is some indication in the data that high performer (i.e. survey participants that better met cost, performance, schedule and customer satisfaction targets) address the four principles to a greater extent. However, further investigations, most notably a detailed analysis of variances, are necessary in order to prove and strengthen the assumption that addressing RdD influences the PD success positively.
7 Conclusion and Future Research

7.1 Conclusion

This section briefly discusses the results of this thesis in the light of the goals and associated research questions (RQ) defined at the beginning.

Regarding (RQ1) “What existing Risk Management frameworks are relevant for Product Development?”

This thesis has addressed holistic risk management frameworks related to product development. Outlining the general context, risk and risk management was defined as “the effect of uncertainty on objectives” and “coordinated activities to direct and control an organization with regard to risk” respectively. General goals and benefits of risk management were laid out (Section 2.1). Since integral risk management in product development can either be treated as an intrinsic part or as an external process of product development, four current research communities were introduced and the research focus of the thesis was referred to these existing research groups (Section 2.3).

Addressing the first research question of the thesis, eight existing risk management frameworks that are relevant for product development were reviewed and classified (Section 3.2). Six of them consisted of different external processes and were developed by different popular societies and organizations such as the Department of Defense, NASA, the Project Management Institute, the Office of Government Commerce (OGC), the International Council on Systems Engineering (INCOSE) as well as the ISO 31000 RM standard. Contrasting, the latter two frameworks, including the concept of Risk-driven Design, addressed risk management as an intrinsic part of product development.

A detailed comparison of all frameworks, displaying the definition of risk and risk management, the type and the scope of each framework was presented and discussed (Section 3.3). In this regard, the key benefits of the Risk-driven Design framework in contrast to the external risk management process frameworks were outlined. It not only constitutes an integrated management approach that advocates the direct integration of risk identification and treatment actions into the PD process but also provides greater insights regarding the specific risk profile of the PD project. Risk-driven Design furthermore considers distinctive risk sources, risk related decisions, mitigation actions as well as characteristics of resilience.

Regarding (RQ2) “How can the Risk-driven Design principles be validated and further developed?”

After introducing the generic framework of Risk-driven Design (Section 3.3) the underlying concept and four principles were validated and further developed in chapter 4.

Taking a global perspective, a new causal network of uncertainty and risk in product development was developed and the differences between conventional efficiency-driven and
risk-driven product development systems were highlighted. Whereas conventional product development systems mostly treat input factors as static foreseeable point estimates or known uncertainty, Risk-driven Design more explicitly identifies and quantifies possible design risks. It was furthermore discussed that Risk-driven Design generally classifies risks along uncertainties regarding the input factors of the product development system (i.e. technology, company-internal, customer requirements, supplier and market) (Section 4.2).

From a more in-depth perspective, each of the four principles was validated and further developed based on a literature review. Among other things, it was shown that the principles of Risk-driven Design address both fundamental approaches on coping with uncertainty in product development – managing and reducing uncertainty. The principles were furthermore mapped to common risk management process elements demonstrating a possible knowledge link between the two risk management research communities (Section 4.3).

An extensive collection of 85 interlinked examples regarding possible design risks (principle 1), risk related decisions (principle 2), corresponding mitigation actions (principle 3) and characteristics of resilience (principle 4) were presented (Section 4.4). This list proved to be very helpful for subsequent discussions of Risk-driven Design both in theory and in practice.

**Regarding (RQ3) “How do common Product Development Frameworks manage risk?”**

Giving an overview of the research context, the research area of product development was narrowed down to the specific research domain of product development frameworks. It was shown that product development frameworks constitute risk management structures since they provide an organized approach for managing uncertainty in product development (Section 2.2).

Based on a comprehensive literature review, seven common product development frameworks were analyzed regarding their intrinsic risk management approach. The four principles of Risk-driven design were used as guidelines for this investigation (Section 5.3 and 5.4). As a result, a new detailed comparison of the extent to which the reviewed product development frameworks manage risk was presented. It was discussed that all product development frameworks only partly address the principles of Risk-driven Design and that no product development framework “fits it all”. Each framework has specific strengths and weaknesses and is therefore suited for different development projects (Section 5.5). Whereas the waterfall model with its predictable sequential character, clear focus on structure and rigid design reviews constitutes the least responsive PD framework, spiral and scrum development are on the other hand designed to better handle changes in customer needs. However, the advantages of more flexible design reviews and cross-phase iterations of the latter PD approaches are contrasted with the disadvantage of risk sensitivity regarding system integration and the limited PD project applicability. Creating transparency regarding design risks up-front (principle 1), making risk-driven decisions (principle 2) as well as creating a resilient design system (principle 4) is not in the primary focus of most of the PD frameworks.

From the theoretical discussion, it was shown that in the context of Risk-driven Design a combination of the scrum process framework with design for six sigma methods yield the most comprehensive risk management oriented product development approach.
Regarding (RQ4) “What existing Risk Management frameworks are mostly used in industry?”

Addressing the empirical research questions of the thesis, the author collaborated on a comprehensive survey on risk management practices in product development. In this regard, the contributions of the thesis included the revision and completion of the survey questions, the redesign of the online survey infrastructure, the development of a sophisticated automated benchmarking tool and a descriptive and in-depth exploratory analysis (Section 6.3).

Besides other important descriptive survey findings, it was shown that all survey participants generally used external risk management process frameworks (Section 6.4). The three mostly applied frameworks were the Project Management Institute risk management framework, followed by the Department of Defense risk management model and the ISO 31000 risk management standard.

Regarding (RQ5) “To what extent follows industry the principles of Risk-driven Design?”

Based on the exploratory survey findings, important aspects regarding each principle of Risk-driven Design were shown. Regarding the first and third principle, a “risk management map” was developed that consolidated the risk severity and risk mitigation intensity profile of the firms in the sample. The survey data indicated that the participating companies currently focus their risk management effort too much on technology risks and too little on customer related risks (Section 6.5.2 and 6.5.4).

Regarding the second and fourth principle of Risk-driven Design, it was shown that the firms in the sample use different risk evaluation techniques to a great extent and that buffers achieved comparably high risk mitigation intensity (Section 6.5.3 and 6.5.5).

From an integral perspective, the survey results indicated that high performer (i.e. the top 25 percent of the survey participants that achieved or exceeded their project targets) better addressed all principles of Risk-driven Design compared to low performer. Based on this finding, it was discussed that addressing the principles of Risk-driven Design can positively influence the product development success (Section 6.5.7).

A conceptual framework for the better integration of risk management into product development was presented and the corresponding benefits of the thesis findings for both industry and research were laid out (Section 6.7.). For industry, the four underlying iterative steps can be used as a guideline to choose the “base” PD framework that best fits the PD project characteristics, identify and benchmark the RM related performance and customize the PD process to include different risk identification, quantification and treatment actions using the principles of RdD.

Regarding (RQ6) “What is the Risk Management related performance of different Product Development Frameworks?”

To empirically validate the theoretical findings regarding the third research question, both the mitigation effectiveness profile (Section 6.5.4) and the integral findings regarding all principles of Risk-driven Design (Section 6.5.7) of the product development frameworks were discussed. It was pointed out that the theoretical findings largely match the survey results.
From the empirical discussion, there was some indication in the data that the Spiral process framework and Design for Six Sigma yield the most comprehensive risk management oriented product development approach. Furthermore the data indicated that the survey participants using Design for Six Sigma, Lean Product Development and Spiral Development achieved superior product development performance results (Section 6.5.7).

### 7.2 Future Research

This section briefly outlines possible future research in the area of this thesis. Several main research domains can be addressed by further investigations.

**Regarding Risk Management Frameworks**

This thesis primarily addressed the Risk-driven Design framework that aim at integrating risk management as an intrinsic part of product development. However, the survey results showed that companies currently still make extensive use of external risk management process frameworks. In this context, the ISO 31000 risk management standard model constituted a promising and more generalized external framework that well synthesized the different risk management process actions.

Using the ISO 31000 model as a basis, future research can focus on developing an integrated risk management process framework that is adapted to the specific application area of product development.

**Regarding Risk-driven Design**

Addressing the framework of Risk-driven Design, additional research can be done from both a theoretical and empirical point of view.

In theory, each of the four principles can be investigated in more detail. In this context, it would be interesting to further extent the collection of examples regarding each principle and to ultimately link the risks and mitigation actions in a complex causal network. On the other hand, future research can more specifically address the psychological literature regarding decision making under uncertainty and human perception of risk and uncertainty. Arising questions, e.g. is there a positive effect on the product development performance if the decision making process is based on more transparency regarding design risks, would be interesting to investigate further. Moreover many authors point out the importance of a resilient product development system in regard to managing uncertainty. Future research can therefore aim at deepening the knowledge of responsiveness (i.e. swiftness, cost efficiency, versatility and knowledge versatility) or the creation of critical buffers in product development and link it to the discussion of Risk-driven Design.

From the empirical discussion of this thesis, various aspects can be addressed by future research. Taking a more global view, the survey findings only included North American companies. It would therefore be interesting to investigate and differentiate the “risk management map” of other management cultures. As such, it can be determined how the risk severity and mitigation intensity profile differ in regard to country-specific management
approaches and whether the risk management effort is influenced by the firms’ policy or understanding of risk. Ultimately these results can help global enterprises to better understand cultural differences and to improve their communication and coordination of risk management activities in product development.

Taking a more in-depth perspective, the survey results in this thesis still need further detailed investigations such as correlation or variance analysis in order to provide a more precise informational value. Moreover, it would be interesting to execute case studies at different “high” or “low” performing companies in order to assess their respective risk management strengths and weaknesses. As such, generalized risk management best practices that help to effectively mitigate different risks can be determined. Furthermore, questions such as, what is the optimal balance of risk mitigation intensity and risk severity or what is the financial benefit of managing risks intrinsically in product development compared to using an external and prescribing risk management process, can be generally addressed.

Finally this thesis already discussed a first indication that addressing the principles of Risk-driven design positively influences the product development performance. This aspect also needs to be addressed to a greater extent by future work.

**Regarding Risk Management of Product Development Frameworks**

Overall, the theoretical findings and the survey results both indicated that the combination of Spiral Development and Design for Six Sigma yield the most comprehensive risk management oriented product development approach. In this regard, future research can address the understanding of how these two approaches can be combined effectively. Moreover, additional product development frameworks should be investigated in their regard to intrinsically manage risk in order to enlarge the discussion of different design processes.

On the other side, this thesis only superficially addressed the respective project applicability of the different product development frameworks. Therefore it would be interesting to further investigate how well particular development approaches are suited for different product types. Hence, the comparison and discussion of the different development frameworks can be extended to include the most adequate project background (i.e. hardware, software or integrated mechatronic system development etc.) of the respective approaches.
8 References

ABRAHAMSSON et al. 2002

AHMADI et al. 1999

ANSELL et al. 1992

BASSLER et al. 2011

BAYUS et al. 1997

BECK 2000

BECK et al. 2001
References

BEN-HAIM 2001

BIAZZO 2009

BOEHM et al. 1994

BOEHM et al. 2000

BOEHM et al. 2003

BOEHM 1988

BOEHM 1989

BOEHM 1991

BOEHM et al. 2009
BROWN 2007

BROWNING 1999a

BROWNING 1999

BROWNING et al. 2003

BSTIELER 2005

CHALUPNIK et al. 2009

CHAO et al. 2006

CHAPMAN et al. 1997
CHOI 2006

CLARK et al. 1987

COCKBURN 2007

COOPER 1990

COOPER 2001

COOPER 2008

COOPER et al. 1986

CUNNINGHAM 1997
Cunningham, J. B.: Case study principles for different types of cases. Quality and quantity 31 (1997) 4, S. 401-423.

DAVIS et al. 2002
References

DE WECK et al. 2007

DoD 2006

DoD 2008

EISENHARDT et al. 1995

EISENHARDT 1989

FERDOWSI 2003

FORSBERG et al. 1995
Forsberg, K.; Mooz, H.: Application of the “Vee” to incremental and evolutionary development. In: (Hrsg.): Proceedings of the National Council for System Engineering Symposium St. Louis, MO,

FORSBERG et al. 2000

FOSTER et al. 2001
Foster, R. N.; Kaplan, S.: Creative destruction: why companies that are built to last underperform the market, and how to successfully transform them. New York: Currency 2001.
References

Fowler 2009

Freeman et al. 2005

GAO 2009

GAO 2010

Gerring 2007

Gilb 1985

Gilb et al. 1988

Graham 1989

Graham 1992
GRIFFIN et al. 1996


GUIMARÃES et al. 2005


HALL 1998


HASKINS et al. 2010


HIGHSMITH 2000


HOPPMANN 2009


IPL 1997

IPL: Software testing and software development lifecycles. working paper - Information Processing Ltd. 1997 – Software testing and software development (1997)

ISO 2009a

ISO 2009b

ISO 2009c

KALYANARAM et al. 1997

KARLSSON et al. 1996

KEIZER et al. 2005

KENNEDY et al. 2003

KHALIFA et al. 2000

KMENTA et al. 1999

KRAFCIK 1988
References

KRUCHTEN 2000

KRUEGER et al. 1994

KWAK et al. 2005

LARMAN et al. 2003

LEITCH 2010

LEUNG et al. 2008

LIKER et al. 1996

MAASS et al. 2010

MACCORMACK 2000
MacCormack 2001a

MacCormack et al. 2001b

MacCrimmon et al. 1988

March et al. 1987

Markeset 2003

McConnell 1996

McManus et al. 2006

Meyer et al. 2001

Miles et al. 1994
MOLLENHAUER et al. 2007

MORGAN et al. 2006

MU et al. 2009

MULLINS et al. 1999

MURMAN et al. 2002

NASA 2008

OEHMEN 2005

OEHMEN 2009
OEHMEN et al. 2010a


OEHMEN et al. 2010b

Oehmen, J.; Rebentisch, E.: Risk Management in Lean PD. In: (Hrsg.): LAI Paper Series "Lean Product Development for Practitioners", Cambridge, MA, LAI and MIT

OEHMEN et al. 2011


OGC 2009


OPPENHEIM 2004


PALMER et al. 2002


PATÉ-CORNELL 1996


PMI 2008a

PMI 2008b

Purdy 2010

Radner 2000

Reich et al. 2008

Royer 2000

Scacchi 2002

Schmitt et al. 2011

Schuh et al. 2008

Schuh et al. 2007
SCHWABER 1995

SCHWABER et al. 2002

SEGISMUNDO et al. 2008

SIMON 1997

SMITH 2007

SMITH et al. 2002

SMITH et al. 1991

SMITH et al. 1992

SMITH et al. 1998
SOBEK et al. 1999

SOMMER et al. 2008

SONG et al. 2001

STAKE 1995

STAPLETON 1997

TAKEUCHI et al. 1986

TANG et al. 2009

THOMKE et al. 1998
THUNNISSEN 2003


TUFTET al. 1983


ULRICH et al. 2008


UNGER et al. 2009


UNGER 2003


WAGNER 2007


WARD et al. 1995


WARD 2007

References

WILLIAMS 1999

WOMACK et al. 1991

WONG 2009

YANG et al. 2009

ZHANG et al. 2010

ZIEGENBEIN 2007
9 Appendix A – Survey on Risk Management Practices in Product Development
Appendix A – Survey on Risk Management Practices in Product Development

Risk Management Benchmarking Survey

Q1.2 Welcome to the survey on “Best Practices in Engineering Program and Project Risk Management”

The goal of the survey is to understand better what the current state of practice in industry and government services is regarding the management of risk in engineering development programs and projects.

This survey was developed by MIT’s Lean Advancement Initiative (LAI) and the MIT-KFJIPM Center in collaboration with the Air Force Institute of Technology and Futron.

Direct benefits for participants:
- Understand what your and your organization’s standing in risk management is compared to the industry average
- Identify risk management best practices
- Be able to make better informed decisions on risk management practices, and be able to justify these decisions better to management and colleagues
- Free and exclusive access to survey results

Benefits for the industry and research:
- Understand the current state of the art in industry regarding program risk management
- Create a benchmarking standard for own risk management processes
- Understand interest and main drivers for program risk management in industry
- Develop a research agenda for future activities that focuses on the most significant industry needs and gaps in knowledge

Duration:
Completion of this survey will take about 30-35 minutes.

Confidentiality:
All personally identifiable information, for example information that identifies you, your program or organization, will be treated as confidential.

Results of this survey will only be reported in an aggregated format so that no conclusions can be drawn regarding specific individuals, programs or organizations.

Contact Information:
The responsible point of contact for this survey is Dr Josef Oehmen at MIT. For any questions, please contact him via:

Email: oehmen@mit.edu
Phone: (617) 452-2904
Mail: Massachusetts Institute of Technology, Room 3-471, 77 Massachusetts Avenue, Cambridge, MA 02139

Q1.3 This survey was developed by:

Appendix A – Survey on Risk Management Practices in Product Development

Q1.5 This survey is supported by:

Figure 9-1: Introductory pages of the survey
Appendix A – Survey on Risk Management Practices in Product Development

Figure 9-2: Introductory pages of the survey structure
Figure 9-3: General Questions - Organization
Q1.20. Please provide some general information on the program/project you chose as the example for this survey:

<table>
<thead>
<tr>
<th>Development budget for all contractors / suppliers for program/project</th>
<th>Less than $50k</th>
<th>$50k - $1m</th>
<th>$1m - $5m</th>
<th>$5m - $10m</th>
<th>$10m - $50m</th>
<th>$50m - $100m</th>
<th>$100m - $500m</th>
<th>$500m - $1bn</th>
<th>more than $1bn</th>
<th>Do not know</th>
</tr>
</thead>
<tbody>
<tr>
<td>Development budget within your organization for program/project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Q1.21. What type of industry sector does the program fit best?
- Commercial aerospace program
- Government-sponsored aerospace program
- Defense program: ACAT I
- Defense program: ACAT II
- Defense program: ACAT III
- Automotive
- Consumer goods
- Medical technology & devices
- Other manufacturing
- Oil, gas or other process industry
- Other (please specify) [ ]

Q1.22. What was the main type of product of the program/project?
- Mechanical: Components, materials, assemblies etc.
- Electronics: Electronic components and assemblies
- Software: Programs, control software etc.
- Integrated electronics / software system
- Integrated mechatronic system: Mechanical, electronic and software components
- Other (please specify) [ ]

Q1.23. At what level of the program/project enterprise were you working?
- Program level: Coordination of the entire development effort between customers, contractors and suppliers.
- Main contractor/integrator: Organization mainly responsible for the customer or contractor side.
- System supplier / tier-1 supplier: Main supplier for a high level system, integrator of that system.
- Component supplier / tier-2 supplier: Supplier for key components for a specific system or assembly.
- Lower-tier supplier / tier-3 or lower: Supplier that delivers parts for system components.
Appendix A – Survey on Risk Management Practices in Product Development

Figure 9-5: General Questions – Program/Project Part 1
Q1.27. General Questions on Your Program/Project (2/2)

1. General Questions - Organization
2. General Questions - Program/Project
3. Risk Management Processes
4. Risk Management Performance

Q1.29. The following questions will ask you to generally characterize the project/program posed in the 5 areas of
- Technology
- Customer
- Company
- Supplier
- Market

regarding
- novelty and
- complexity

Q1.30. Please rate the challenge that the program/project posed for your organization regarding technology:

| Technology experience: Familiarity of your organization with key technologies. | Very low | Low | Average | High | Very high |
| Technology complexity: Size and level of integration of the technical system (mechanical, electronics and software). |       |     |         |      |          |

Q1.31. Please rate the challenge that the program/project posed for your organization regarding the customer:

| Experience with customers or stakeholders: Familiarity of your organization with key customers and stakeholders. | Very low | Low | Average | High | Very high |
| Customer or stakeholder complexity: Number and diversity of customers or stakeholders. |       |     |         |      |          |

Q1.32. Please rate the challenge that the program/project posed for your organization regarding the internal processes and skills:

| Experience with relevant processes and skills: Familiarity of your organization with the relevant processes and skills needed to execute the project/program. | Very low | Low | Average | High | Very high |
| Complexity of relevant processes and skills: Difficulty and variety of processes and skills needed in your organization to execute the project/program. |       |     |         |      |          |

Q1.33. Please rate the challenge that the program/project posed for your organization regarding the supply chain:

| Experience with supply chain: | Very low | Low | Average | High | Very high |

Figure 9-6: General Questions – Program/Project Part 2
Appendix A – Survey on Risk Management Practices in Product Development

Figure 9-7: General Questions – Program/Project Part 2

<table>
<thead>
<tr>
<th>Experience with supply chain</th>
<th>Complexity of supply chain: Size, diversity and level of integration of the project’s or program’s supply chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Management Benchmarking Survey</td>
<td></td>
</tr>
<tr>
<td>Q1.34 Please rate the challenge that the program/project posed for your organization regarding external factors:</td>
<td></td>
</tr>
<tr>
<td>Experience with external factors: Familiarity of your company with the external factors (e.g. competitors, legal and regulatory environment).</td>
<td></td>
</tr>
<tr>
<td>Complexity of external factors: Number and diversity of external factors (e.g. competitors, legal and regulatory environment).</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Very low</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
<th>Very High</th>
</tr>
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<tbody>
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</table>

Q1.35 Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.
## Appendix A – Survey on Risk Management Practices in Product Development

### Figure 9-8: Questions on RM Process 1: Planning and Preparation

**Q2.1: Risk Management Process - Planning and Preparation**
Integration of stakeholders in communication and consultation of risk management activities. Choosing the right processes, tools and methods for risk management.

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>3.5. Risk Mitigation</td>
<td>3.6. Risk Monitoring</td>
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</tbody>
</table>

### Q2.6: Please indicate your assessment of the way risk management was executed.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither/Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Our employees are motivated to perform/implement risk management.</td>
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<tr>
<td>Our risk management has available, qualified experts to help implement the processes.</td>
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<tr>
<td>There are available resources or manpower to conduct risk management.</td>
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<tr>
<td>Our risk management explicitly addresses uncertainty.</td>
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<tr>
<td>Our risk management is systematic, structured and timely.</td>
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<tr>
<td>Our risk management is based on the best available information.</td>
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<tr>
<td>Our risk management is tailored to specific program/project needs.</td>
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<tr>
<td>Our risk management takes human and cultural factors into account.</td>
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<tr>
<td>Our risk management is transparent and inclusive towards all stakeholders.</td>
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<tr>
<td>Our risk management is dynamic, iterative and responsive to change.</td>
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</tbody>
</table>

### Q2.6: Please indicate which of the following statements regarding stakeholder communication and consultation apply to your risk management.

- [ ] There is a formal document (e.g., risk management plan) that defines when, how and by whom the risk management process is executed.
- [ ] There is a board that oversees risk management activities of the program/project.
- [ ] Risks and risk management activities are communicated to stakeholders (incl. management).
- [ ] Risks are communicated as consolidated reports (e.g. PDF files as email attachments).
- [ ] Risks are communicated via managed register/database.

### Q2.7: Please indicate if the following statements apply to the risk management process step in your project/program.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither/Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>We tailor the risk management process and the methods to the specific program/project. We coordinate and integrate risk.</td>
<td></td>
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</table>

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Page 8 of 22
We coordinate and integrate risk management activities of different functions and across the hierarchy.
Risk management is integrated with higher-level risk management processes, e.g., portfolio-level risk management or enterprise-level risk management.
The risk management process is effectively integrated with other project/program management processes.
Risk management teams are cross-functional and cross-organizational.

Q2.8. Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.
### Q3.4 Risk Management Process - Types of risk and their impact

#### 4. Risk Management Performance

**Q3.4.** In the following, a list of risks is presented. Please indicate below the impact that these risks did have on your program/project. The impact can be on any program or project target, e.g., cost, schedule or performance.

Please rate in the following questions the **overall risk impact** in the project:

- Not occurred: The described risk did not play a significant role in the program/project.
- Very low impact: The risk occurred, but could be dealt with in the routine workflow.
- Medium impact: The risk required special attention and resource allocation to overcome.
- Very high impact: The risk significantly threatened the overall program/project success.

If you don’t know the answer, please leave the question blank.

#### Q3.5 Risks regarding organizational efficiency

<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Not occurred</th>
<th>Very low impact</th>
<th>Low impact</th>
<th>Medium impact</th>
<th>High impact</th>
<th>Very high impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of cross-functional integration &amp; communication within the organization.</td>
<td></td>
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<tr>
<td>Lack of cross-organizational integration &amp; communication with suppliers.</td>
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<tr>
<td>Lack of cross-organizational integration &amp; communication with customers / government.</td>
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<tr>
<td>Resources are re-allocated or become unavailable.</td>
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<td>Activities of competitors disrupt project/program execution (e.g., aggressive pricing, new technology introduction)</td>
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<tr>
<td>Other (please specify)</td>
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</tbody>
</table>

#### Q3.6 Risks regarding general project/program management efficiency

<table>
<thead>
<tr>
<th>Risk Description</th>
<th>Not occurred</th>
<th>Very low impact</th>
<th>Low impact</th>
<th>Medium impact</th>
<th>High impact</th>
<th>Very high impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progress monitoring and management (e.g., Earned Value Management) insufficient.</td>
<td></td>
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<tr>
<td>Supplier failure causing development delays, cost overruns or quality problems.</td>
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<tr>
<td>Insufficient skills or intellectual capital leading to problems in executing the program/project plan.</td>
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<td>Insufficient change management or improvement process (e.g., Lean Management, Six Sigma)</td>
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<tr>
<td>Other (please specify)</td>
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</tbody>
</table>

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**Figure 9-10: Questions on RM Process 2: Risks and Their Impact**
**Appendix A – Survey on Risk Management Practices in Product Development**

**Risk Management Benchmarking Survey**

**Q3.7. Risks regarding requirements, contracting and compliance:**

<table>
<thead>
<tr>
<th>Customer/stakeholder requirements are poorly understood.</th>
<th>Not occurred</th>
<th>Very low impact</th>
<th>Low impact</th>
<th>Medium impact</th>
<th>High impact</th>
<th>Very high impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers/stakeholders change or extend requirements or their priority.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Unrealistic objectives regarding cost, schedule or performance are set.</td>
<td></td>
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</tr>
<tr>
<td>Misalignment of incentives between customer and contractor.</td>
<td></td>
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</tr>
<tr>
<td>Insufficient management of compliance leads to issues with regulatory policies.</td>
<td></td>
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</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**Q3.8. Risks regarding Technology, Product Design and Systems Engineering:**

<table>
<thead>
<tr>
<th>Technology readiness level (component-level) too low to meet objectives.</th>
<th>Not occurred</th>
<th>Very low impact</th>
<th>Low impact</th>
<th>Medium impact</th>
<th>High impact</th>
<th>Very high impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>System-level integration readiness level too low to meet objectives.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Production readiness level for the entire system too low to meet delivery objectives.</td>
<td></td>
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</tr>
<tr>
<td>Service readiness level for the system too low to effectively support operations and maintenance.</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Product development / systems engineering processes ineffective.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Management and development process was unstable; time was wasted by frequent deviations from or changing process standard.</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Test plan schedule (component and system level) incomplete, or lacking dependencies.</td>
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</tr>
<tr>
<td>Other (please specify):</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Q3.9. Optional:** If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.

---

**Figure 9-11: Questions on RM Process 2: Risks and Their Impact**
Appendix A – Survey on Risk Management Practices in Product Development

Figure 9-12: Questions on RM Process 3: Risk Analysis

Q4.4. Please indicate what dimensions were used to quantify the impact of risks:

- Cost
- Technical performance or quality
- Human health, environmental, systems safety or reliability
- Schedule
- Supportability (infrastructure, logistics, workforce)
- General customer utility or customer satisfaction
- Other (please specify)

Q4.5. Please indicate how often the different methods were used to quantify risks:

<table>
<thead>
<tr>
<th>Method</th>
<th>Never</th>
<th>Rarely used</th>
<th>Sometimes used</th>
<th>Often used</th>
<th>Always used</th>
</tr>
</thead>
<tbody>
<tr>
<td>No direct quantification, but rank ordering of risks, e.g., 1 to 10 for top 10 risks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Assessment of risk on scales, e.g., 1-5 scale for probability and impact</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Probabilistic Risk Assessment (PRA) method</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Probability distributions, e.g., triangular distributions with minimum, most likely and maximum value</td>
<td></td>
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</tr>
<tr>
<td>Monte Carlo simulations (or similar) to aggregate different types of risk estimates</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Q4.6. Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.
Figure 9-13: Questions on RM Process 4: Risk Evaluation

<table>
<thead>
<tr>
<th>Q5.6. How often did you use the following techniques to make decisions about risks in your project/program?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Make go/no-go decisions based on risk assessment.</td>
</tr>
<tr>
<td>Resources are allocated to reduce largest risks as early as possible.</td>
</tr>
<tr>
<td>Risk assessments are used to set more 'realistic' or 'achievable' objectives.</td>
</tr>
<tr>
<td>Forecasts and projections (e.g., cost, schedule, performance) are adjusted based on risk assessment.</td>
</tr>
<tr>
<td>The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs.</td>
</tr>
<tr>
<td>Decisions are made based on risk-benefit trade-offs, e.g., larger risks are only acceptable for a significant expected benefit.</td>
</tr>
<tr>
<td>Risk-benefit trade-offs are used systematically to favor 'low risk - high benefit' options and eliminate 'high risk - low benefit' options.</td>
</tr>
<tr>
<td>Contracts are derived from detailed cost-risk assessments.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Never</th>
<th>Rarely used</th>
<th>Sometimes used</th>
<th>Often used</th>
<th>Always used</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q5.7. Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.

Page 13 of 22
Risk Management Benchmarking Survey

Q6.1. **Risk Management Process - Risk Mitigation**
Treatment of risks with effective mitigation actions

![Diagram](Diagram.png)

Q6.4. Please indicate which dimensions are used to evaluate risk mitigation actions before they are implemented.

- Cost/resource needs for mitigation action
- Time requirement for mitigation action
- Reduction of impact of risk through mitigation action
- Reduction of probability of occurrence of risk through mitigation action
- Other (please specify)

Q6.5. Please rate in all following questions on the overall risk reduction achieved by different mitigation actions (e.g. by reducing probability of occurrence or reducing the impact of risks):

- Very low risk reduction: The mitigation action slightly reduced a significant risk.
- Low risk reduction: The mitigation action reduced a significant risk.
- Medium risk reduction: The mitigation action reduced a number of significant risks.
- High risk reduction: The mitigation action resolved one significant risk.
- Very high risk reduction: The mitigation action resolved several significant risks.

If you don't know the answer, please leave the questions blank.

Q6.6. Mitigation actions to reduce risks regarding organizational efficiency:

<table>
<thead>
<tr>
<th>Supplier/Enterprise integration and management, e.g. process harmonization and data integration.</th>
<th>Not used</th>
<th>Very low risk reduction achieved</th>
<th>Low risk reduction achieved</th>
<th>Medium risk reduction achieved</th>
<th>High risk reduction achieved</th>
<th>Very high risk reduction achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customer/government integration, e.g. reporting, feedback, voice of customer.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organization-internal integration, e.g. process harmonization and data integration.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Financial reserves.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule reserves.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractual sharing of cost overruns with customer.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contractual sharing of cost overruns with suppliers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost-Plus contracts.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holding excess resources (e.g. manpower, inventory, or facilities).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other (please specify).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 14 of 22

**Figure 9-14: Questions on RM Process 5: Risk Mitigation**
### Appendix A – Survey on Risk Management Practices in Product Development

#### Q6.7. Mitigation actions to reduce risks regarding general project management efficiency:

<table>
<thead>
<tr>
<th>Not used</th>
<th>Very low risk reduction achieved</th>
<th>Low risk reduction achieved</th>
<th>Medium risk reduction achieved</th>
<th>High risk reduction achieved</th>
<th>Very high risk reduction achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed cost, schedule and performance simulations and trade-off studies.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Self-assessments, continuous improvement and implementation of best practices (e.g. Six Sigma, Kaizen).</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>More detailed design reviews, increased process monitoring.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Training program or specialist career path to increase skill level.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Define “standard work” or “standard processes” to increase process reliability.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Improved engineering change process to speed up changes.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Adaptation of PO process to match specific project requirements.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Active internal lobbying towards top management to promote project / program.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

#### Q6.8. Mitigation actions to reduce risks regarding requirements, contracting and compliance:

<table>
<thead>
<tr>
<th>Not used</th>
<th>Very low risk reduction achieved</th>
<th>Low risk reduction achieved</th>
<th>Medium risk reduction achieved</th>
<th>High risk reduction achieved</th>
<th>Very high risk reduction achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Help customer understand what their needs are and make trade-offs (e.g. MATE or other trade-off simulations and calculations).</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Management (and re-negotiation, if necessary) of requirements.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Active lobbying with key stakeholders outside of direct customer / contractor relationship, e.g. regulatory agency or policy makers.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Monitor activities of competitors (e.g. technology disclosures, bidding strategy, product launches, market entries, analysis of existing products, etc.).</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Other (please specify)</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

#### Q6.9. Mitigation actions to reduce technological risks:

<table>
<thead>
<tr>
<th>Not used</th>
<th>Very low risk reduction achieved</th>
<th>Low risk reduction achieved</th>
<th>Medium risk reduction achieved</th>
<th>High risk reduction achieved</th>
<th>Very high risk reduction achieved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased testing and prototyping activities.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Reuse existing components or off-the-shelf components.</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Develop flexible product architecture (e.g. modular platforms).</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
<tr>
<td>Strict configuration control to manage</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
</tr>
</tbody>
</table>

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Figure 9-15: Questions on RM Process 5: Risk Mitigation
### Risk Management Benchmarking Survey

1. and minimize complexity and uncertainty.
2. Engineering with redundancy or safety margins.
3. Pursue several engineering solutions in parallel (e.g., set-based design).
4. Focus on design for manufacturing and/or design for service.
5. Other (please specify):

---

**Q6. Optional:** If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.

---

*Figure 9-16: Questions on RM Process 5: Risk Mitigation*
Appendix A – Survey on Risk Management Practices in Product Development

Q7.1 Risk Management Process - Monitoring & Review
Sufficient monitoring of risks and execution of the risk management process

Q7.4. To what degree do you agree or disagree to the following statements on Monitoring & Review processes?

<table>
<thead>
<tr>
<th>Statement</th>
<th>Completely Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Completely Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risks were escalated to senior management according to guidelines.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk were regularly re-assessed according to guidelines, e.g. after specific events or after a certain time interval.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The risk management process was regularly reviewed and improved.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An early warning system was used to monitor the execution of risk mitigation actions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An early warning system was used to track critical risks and decide on activating mitigation measures.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q7.5. How often are the following elements formally reviewed in your organization?

<table>
<thead>
<tr>
<th>Element</th>
<th>Daily</th>
<th>Weekly</th>
<th>Monthly</th>
<th>Quarterly</th>
<th>Bi-annually</th>
<th>Annually</th>
<th>Once (e.g. at program start)</th>
<th>Only after specific events</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification of new risks.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quantification of risks.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk mitigation measures.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management process.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Based on occurrence of specific events (please specify)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Q7.6. Please indicate if the following methods are used for monitoring

- [ ] Risk register or risk catalog
- [ ] Top 10 risks
- [ ] Risk elimination or risk burn-down plans
- [ ] Risk mitigation plans
- [ ] Graphical risk metrics dashboard

Q7.7. Please indicate if the following Key Performance Indicators are used to track risks.

- [ ] Tracking of error / issue / failure rates

Page 17 of 22
Risk Management Benchmarking Survey

- Tracking of number of total risks
- Tracking of number of retired risks
- Tracking of aggregated risk severity
- Tracking of number of risk mitigation measures
- Tracking of resource expenditure on risk mitigation measures (cost, manpower)

Q7.8. Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.

Page 18 of 22

Figure 9-18: Questions on RM Process 6: Monitoring and Review
## Q9.1 Risk Management Performance

Questions to assess how effectively the program dealt with risk and uncertainty, and how stable it ran.

### Q9.3 Please indicate to what extent you agree with the following statements regarding the role and perception of risk management in the program/project:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Program/project managers supported risk management activities.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management results (e.g., risk reports, risk reduction matrix) play an important role in the decision-making of senior managers.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management results influence trade-off decisions (e.g. between cost, schedule and performance targets).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Experience in risk management is valuable for promotions.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management processes are the primary mechanism to determine management reserves for a program/project.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Findings from the risk management process translate into action (allocation of manpower and funds).</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>There is adequate funding and manpower to conduct risk management process and mitigation activities.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall, the organization is satisfied with the performance of the risk management system.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The fact that the program/project manager has to &quot;budget&quot; for risks (i.e., allocate management reserves) is an incentive against identifying additional risks.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>The ROI of doing risk management was positive.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Q9.4 Please indicate to what extent you agree with the following statements regarding the influence of risk management on the program/project:

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk management creates and protects value.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management is an integral part of all organizational processes.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management is central part of decision making.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management facilitates continuous improvement in the organization.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Risk management has a positive</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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*Figure 9-19: Questions on RM Performance*
Appendix A – Survey on Risk Management Practices in Product Development

Figure 9-20: Questions on RM Performance

| Q8.5. How strongly do the following statements apply to the overall program/project execution? |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Strongly Disagree | Disagree | Neither Agree nor Disagree | Agree | Strongly Agree |
| Program/project management took a proactive stance in addressing risks and issues. | | | | | |
| The program/project ran stable and smoothly. We followed our defined processes. | | | | | |
| We spent a lot of time on “firefighting”, i.e. continuously changing and fixing problems. | | | | | |
| If people had concerns, they were heard and addressed. | | | | | |
| It was OK to report “bad news” and concerns; a constructive solution was sought as early as possible. | | | | | |
| We identified the key risks and were able to mitigate them successfully. | | | | | |
| A large number of unexpected interruptions occurred that caused significant unplanned resource expenditures. | | | | | |

| Q8.6. Please rate the overall program/project success for your organization (if applicable). |
|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|--------------------------------------------------|
| Complete failure to meet target (by more than 30%) | Failed to meet target (by 10-30%) | Met the target (by +/- 10%) | Exceeded our target (by 10-30%) | Strongly exceeded our target (by more than 30%) |
| Cost target | | | | | |
| Schedule target | | | | | |
| Technical performance target | | | | | |
| Overall customer satisfaction target | | | | | |

Q8.7. Optional: If you have any comments regarding the questions on this page or if you would like to provide additional information, please enter it in the box below.
Figure 9-21: Option to receive survey results and general feedback
Thank you very much for taking your time to fill out this survey.

A summary of the results will be emailed to you (if you provided your email address before) as soon as the analysis of the results is completed.

If you would like to comment on another aspect of our program that you wish to comment on, please feel free to fill out a second...
10 Appendix B – Folder Structure of the Enclosed DVD-ROM

- 01 Literature
- 02 Notes
- 03 Presentations
- 04 RM-Survey
- 05 ICED Paper
- 06 RDD Interviews
- 07 Figures
- 08 Benchmarking Software Tool
- 09 Diploma Thesis
11 Appendix C – Glossary

In the following, important key terms of this thesis are outlined:

- **Risk** is the “effect of uncertainty on objectives” (ISO 2009a)
- **Risk Management** is defined as “coordinated activities to direct and control an organization with regard to risk” (ISO 2009a, p.2).
- **Product Development** is defined as “set of activities beginning with the perception of the market opportunity and ending in the production, sale and delivery of a product” (ULRICH et al. 2008, p.2)
- **Product Development Processes** are “sequence of steps or activities which an enterprise employs to conceive, design, and commercialize a product” (ULRICH et al. 2008, p.14).
- **Program** is defined as “a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually” (PMI 2008b, p.5).

The following types of uncertainty i.e. risk sources are considered in the RdD framework:

**Technology**

- Uncertainty of technology maturity (i.e. new technology) influences the performance reliability under field conditions
- Uncertainty of system integration readiness affects overall system performance and reliability

**Customer requirements**

- Uncertainty regarding quality of understanding of the requirements by the organization
- Uncertainty regarding stability of customer requirements (i.e. customers’ uncertainty regarding their needs)

**Company-internal factors**

- Uncertainty regarding the efficiency and effectiveness of design processes and their execution, including skill levels and productivity of the workforce

**Supplier**

- Uncertainty regarding time, cost or quality of service or component deliveries
Market

- Uncertainty of actions by competitors, e.g. new technology introduction or pricing strategy
- Macroeconomic uncertainty, such as political, social, environmental or economic developments