Product Development Risk Management and the Role of Transparency

by

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ABSTRACT

Risks in product development lead to schedule and cost over-runs and poor product quality. While numerous risk management frameworks have been published and research on specific risk management practices and methods has been conducted, there is little understanding of what the key characteristics of successful risk management in product development are.

This research consists of two phases: an empirical study of the best practices in product development risk management, and a qualitative study of the role of transparency in the same.

The results of a survey of over 200 product development practitioners in industry were analyzed. Of the 170 practices from the literature addressed in the survey, 36 best practices in product development risk management were identified. These best practices were categorized in to six groups: 1- Risk Management Personnel and Resources; 2- Tailoring and Integration of the Risk Management Process; 3- Risk-based Decision Making; 4- Specific Mitigation Actions; 5- Monitoring and Review, and; 6- ISO 31000 Principles. The best practices in these categories show strong evidence not only for achieving effective risk management, but also the ability to positively affect overall project stability and the achievement of the project cost, schedule, performance and customer satisfaction targets. All eleven of the ISO 31000:2009 Risk Management Standard principles (ISO 2009b) were found to be best practices of product development risk management, suggesting the standard is applicable to product development.

The practice with the highest correlation with product development success was found to be one of the eleven ISO principles: "risk management is transparent and inclusive." The second phase of this research aimed to qualitatively validate the observed correlation between transparency and product development success, through twelve semi-structured interviews with product development practitioners from industry.

Transparency was found to be an essential feature of product development risk management. Transparency of risk management is beneficial to product development in many ways: it is a vehicle for an accurate shared representation of the current state of the product development project; it facilitates stakeholder collaboration; it is a means of aligning efforts towards critical tasks. Requirements for and barriers to transparency were also explored.

These results not only inform current product development practitioners on where to focus risk management efforts, but also contribute an empirical evaluation of the impact of specific risk management practices on product development success.

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Now, let's get to it.

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1. Introduction and Overview

1.1 Motivation

1.1.1 Risk

"Risk" is a word that is used widely across subject matter – from medicine to finance to weather.

The term itself has a number of subtly varied meanings; a search of "risk" in the New York Times of April 8th, 2012 (Various 2012) reveals 27 results. The following three quotations – taken from three different sections - illustrate the subtle differences of use and resulting ambiguity in interpretation of the term.

In this first quotation, risk is used to mean chance. There is no probability or consequence associated with the statement. The statement implies that the consequence of this decision is unknown, not necessarily good or bad.

> *"But talking with Iran's leaders also carries considerable political* ***risk*** *for Mr. Obama, with Iran emerging as one of the few major foreign policy issues in the presidential campaign."*

- by Sanger and Erlanger, *U.S. Defines its Demands for Iran Talks* (World)

Next, risk is a synonym for likelihood. However, as is often the case in popular use of the term, the risk applies to an event with negative consequence.

> *"Many patients will be surprised at the tests and treatments that these expert groups now question. They include, for example, annual electrocardiograms for low-****risk*** *patients and routine chest X-rays for ambulatory patients in advance of surgery."*

- Editorial, *Do You Need That Test?* (Health)

The term "at-risk" is common. As is the case in the following instance, it is used to explain what the negative loss would be, given a certain (sometimes unknown) event or threat.

> *"But that kind of down-home access to world-class performers is now at* ***risk****."*

- by Lutz, *Mainstay for Music, Trying Not to* Leave (Arts)

Risk can be a noun or a verb. Risk is often interpreted to mean exposure to danger; sometimes it means something that could have a good turn-out or bad turn-out; sometimes it is an indication of the scale of the consequence and other times it is only reflective of the likelihood of an event.

Consistent across all of these interpretations and usages, risk is fundamentally linked to uncertainty, but in its use, it is not consistent how or why.

1.1.2 Risk in product development

Product development is defined as "the set of activities beginning with the perception of a market opportunity and ending in the production, sale, and delivery of a product", where a product is "something sold by an enterprise to its customers" (Ulrich & Eppinger 2008). Product development is a highly complex, and uncertain undertaking. For many firms, effective product development has been shown to be critical to business success since new products are the basis for competition (Brown & Eisenhardt 1995). The three traditional objectives of product development are to create a product with appropriate quality, costing a reasonable amount, finished on schedule. The dimension of quality can be decomposed to represent target technical performance, customer satisfaction, reliability, or environmental footprint, among others.

Despite the invention of various processes and tools for managing the product development process (Total Quality Management, Lean Engineering, Six Sigma, Earned Value Management, etc.) there remains a great deal of uncertainty in the development process; product development is often multi-disciplinary, involves fast-changing or unproven technology, requires collaboration with external suppliers or customers, and often requires accelerated timelines or cutting-edge innovation to stay competitive (Kim & Wilemon 2003). This means that product development projects are started with incomplete knowledge and countless uncertainties.

Risk, defined as "the effect of uncertainty on objectives" (ISO 2009b) is an ongoing threat to successful product development. Objectives in this definition are interpreted to mean intermediary (for example, milestone completion on time, safety test passed) as well as final objectives (schedule, cost, quality). Examples of risks in product development are: supplier failure causes delivery delay of component; regulation change requires re-work of product; resources are re-allocated from the project; technology readiness too low to meet objectives; tooling problems require rework of tooling. Although the definition views "effect" as potentially both positive and negative, this thesis will align with the general risk focus of industry practitioners, where risk is seen as the negative effects of uncertainty.

To some, product development and risk management work to achieve the same objectives, as explained in (Ulrich & Eppinger 2008) in Chapter 2:

> *[Another] way to think about the development process is as a risk management system. In the early phases of product development, various risks are identified and prioritized. As the process progresses, risks are reduced as the key uncertainties are eliminated and the functions of the product are validated. When the process is completed, the team should have substantial confidence that the product will work correctly and be well received by the market.*

But this view of product development is rarely adopted in industry. Uncertainty and risk continue to be under-addressed in project development projects, disrupting objective product success and project management performance (de Weck et al. 2007).

According to a report put out in 2006 by the U.S. Government Accountability Office (GAO), the Department of Defense continues to have significant cost and schedule overruns in their product development activities (United States Government Accountability Office 2006). In fact, the 23 programs assessed in the report combined "represent a cost increase of $23 billion and an average delay in delivery of initial capability of around 2 years." The report states that "even though acquisition policy states that technologies shall be mature before beginning system development, the practice of accepting high levels of technology risk at program start continues to be the norm and not the exception."

In the commercial world, there are different but still real consequences to schedule overruns resulting from risks; a study of the impact of product introduction delays found that delay announcements decrease the market value of the firm by 5.25% (Hendricks & Singhal 1997).

A report on the Joint Strike Fighter from the GAO (United States Government Accountability Office 2009) warns of high manufacturing, development, and financial risks, stating that "while the program must move forward, we continue to believe that the program's concurrent development and production of the aircraft is extremely risky. By committing to procure large quantities of the aircraft before testing is complete and manufacturing processes are mature, DOD has significantly increased the risk of further compromising its return on investment—as well as delaying the delivery of critical capabilities to the warfighter." The report is titled: "Strong Risk Management Essential as Program Enters Most Challenging Phase."

In recent years, a great deal of attention has been paid to risk and its management, in the form of academic research, published processes and frameworks, and case studies (Greenberg et al. 2012).

Given the high level of uncertainty throughout a typical product development (PD) project, it is not surprising that risk management processes have become increasingly common in product development organizations. Academic and industry studies have led to new understandings and techniques, with risk management in product development seen as a means of decreasing schedule and cost over-runs, and missed quality targets.

With so many risk management practices available, and little validation of their effectiveness, this study of the effectiveness of risk management specifics – applied to product development – aims to clarify the current state of risk management in PD and to identify and explore those practices which are empirically found to contribute to product development success.

1.2 Overview of Study and Thesis Organization

This thesis is composed of five chapters and multiple appendices.

Following the initial introductory chapter, in Chapter 2 we will review a collection of literature relevant to the overall themes of the thesis, including definitions of product development terminology and frameworks, as well as risk management and uncertainty.

In the third chapter I present the first research phase of the work, Phase 1: Empirical Investigation of Risk Management Best Practices. This phase consists of a statistical analysis of a large-scale survey of industry on the topic of risk management in product development. I identify best practices in product development risk management, and highlight particular practices for further investigation in Phase 2. Additionally, I consider all responses on risk occurrence and use of mitigation actions from the survey to investigate whether the current state of risk mitigation attention is proportional to the expected risk loss for different risk types.

Chapter 4 consists of Phase 2: Qualitative Investigation of Transparency in Risk Management. There I present the findings of a set of detailed interviews conducted with product development practitioners. These interviews were conducted to qualitatively validate the statistical findings of Phase 1, focusing on the role of transparency in product development risk management.

In the final chapter I discuss overall conclusions of this work, including lessons learned and future work.

The Appendices contain additional materials related to this work. They include additional tables of statistical results (A), the findings of a short research project in Singapore which aimed to provide the author with an understanding of the current state of product development and risk management process grounded in industry (B), additional interview quotations (C), and a full copy of the administered survey (D).

2. Literature

Presented in this chapter is a review of literature relevant to this work. Building on the introduction, the discussion begins with a deeper presentation of uncertainty in product development, and concludes with the presentation of risk management practices specifically aimed at product development. Terminology used throughout the thesis is defined and key concepts are described.

2.1 Uncertainty in Product Development

Uncertainty in engineering risk analysis is thoroughly explored in (Paté-Cornell 1996). The author decomposes uncertainty and risk into various levels. Uncertainties are classified into two categories: uncertainties from the variability in known populations (aleatory) and uncertainties from basic lack of knowledge about a phenomenon (epistemic). Both have an effect on product development; while there are some factors which are random and can be modeled, for example materials pricing or dimensional variation in manufactured parts, the design process is almost entirely made up of uncertainties due to lack of knowledge about the design solution and how to make that product. The author concludes that aleatory uncertainties can be treated by classical frequentist methods, for example, Monte Carlo simulation. Epistemic uncertainties, however, can be approached only through Bayesian probability methods (evidence-based) and expert opinion.

An example of epistemic uncertainty and its effect from (United States General Accounting Office 2003): The Department of Defense follows a best practice whereby 90 percent of a program's engineering drawings should be completed to ensure design maturity before the program is allowed to pass a key design review. A report on the SBIRS High satellite program states that the program was allowed to pass the critical design review with only 50 percent of engineering drawings complete. The program later encountered "persistent problems with and changes to the design" which are reported to have impacted both the program cost and schedule. In this case, completed engineering drawings indicate knowledge and resolution of the design, and correspondingly a lack of drawings results in a greater degree of uncertainty.

Other frameworks and decompositions of uncertainty in engineering design exist. (de Weck et al. 2007) review a collection of definitions and categorizations from the literature before presenting their own.

Uncertainties in the design process, and methods to model and address that uncertainty, have been explored in a variety of publications. (Wynn et al. 2011) present a task-based model of uncertainty in design. (Tatikonda & Rosenthal 2000) explore task uncertainty and product development project characteristics.

Literature also exists to address uncertainty in project management. A model of a complex project under uncertainty is presented in (Pich et al. 2000), where uncertainty is represented by information adequacy. The role of uncertainty in technology selection for new products is addressed in (Bhattacharya & Krishnan 2002). The influence of environmental uncertainty – that of markets and technology evolution – on product development innovation is explored empirically by (Bstieler 2005).

2.2 Risk Management and Product Development

While literature on the topic of uncertainty tends to be composed of descriptive studies and models, risk management literature includes generalized prescriptive works.

Risk management is often thought of in the context of safety or component failure. A well-known risk management tool is the Failure Mode and Effect Analysis (FMEA), and there is significant literature discussing its use primarily at the detail design phase, with some extensions to all phases of the design process (Chin et al. 2007; Stamatis 2003; Segismundo & Miguel 2008; Kmenta et al. 1999). However, given the definitions of uncertainty and risks previously discussed, it is not surprising that risk management can be applied beyond FMEA to all aspects of product development.

A number of papers have explored specific aspects of risk management in product development and project management as a means of reducing uncertainty, creating information, integrating various stakeholders, and ultimately achieving better results (Browning et al. 2002; S. C. Ward & C. B. Chapman 1991; Ahmadi & Wang 1999; Williams 1995). Reviews of specific risk management practices in product development include the work of (Oehmen et al. 2010) focusing principally on the identification and quantification of design-related risks, and (Ahmed et al. 2007), which argues that the role of risk management in product development is to uncover weaknesses in methods used through a structured approach so that timely mitigation actions are initiated to avoid, transfer or reduce risk likelihood or impact.

Risk management related to various parts of the product development process, for example supply chain (Spekman & Davis 2004), decision-making (Gidel et al. 2005), and portfolio management (Petit & Hobbs 2010) has been explored. There is also research into the traits of effective risk management personnel (Lopez & Slepitza 2011).

The capability of various product development processes to manage risks has been explored (Unger & Eppinger 2009; Bassler et al. 2011). (Browning & Eppinger 2002) explore and model the impact of product architecture on schedule and cost risks. It is true that the structure and methods that product development processes provide reduce uncertainty and therefore risk, but standard product development process alone does not adequately address uncertainty and reduce risks.

(Oehmen & Seering 2011) and (Bassler 2011) have introduced the concept of "Risk-Driven Design", an integrated product development process which aims to shift the narrow focus of efficiency as the goal of product development to that of a balance on risk and return. The concept aims to address uncertainty and reduce risk through four principles: 1) Creating transparency regarding design risks; 2) Risk-driven decision making; 3) Minimizing uncertainty; and 4) Creating resilience.

Generally lacking from these papers, however, is an empirical evaluation of the effectiveness of these practices.

3. Phase 1: Empirical Investigation of Risk Management Best Practices

The following chapter presents the results of a large-scale web survey of the product development industry on the topic of risk management. The survey responses were analyzed in a descriptive manner to explore the state-of-the-art of risk management in the product development industry, and in a confirmatory manner to identify those risk management practices which were positively correlated with product development success. Descriptive methods are used to describe the distribution of a phenomena in a population, in this case the current state-of-the-art in risk management in industry. Confirmatory methods are used to test the adequacy of concepts developed previously, in this case to test the collected "best practices" from the literature to see which are truly significant in effecting performance.

The analysis presented in this chapter builds on the previous work of Oehmen and Bassler, published in (Bassler 2011). Those researchers created and disseminated the survey, as is briefly described in section 3.2.1 below.

3.1 Literature

Below, I present a collection of literature that is relevant to this chapter. We will first briefly review existing risk management frameworks, with particular discussion of the newly published International Organization for Standardization Risk Management standard. Next, those risk management practices and methods particularly aimed at product development are discussed. Finally we investigate the limited collection of published empirical studies of effective product development in risk management. This thesis contributes to addressing the literature gap that exists regarding the evaluation of the impact of risk management practices on product development performance.

3.1.1 Risk management frameworks and standards

There exist a large number of recommended risk management processes, with various organizations proposing overlapping process standards, for example NASA (NASA 2010), INCOSE (INCOSE 2004), the US Department of Defense (Department of Defense 2006) and the Project Management Institute (Project Management Institute 2008). Raz and Hillson (Raz & Hillson 2005) present a comparative review of nine risk management standards. This review does not include the ISO 31000:2009 standard but does examine its most similar predecessor, the AS/NZS 4360:2004 standard.

ISO 31000:2009

Published in 2009, the International Organization for Standardization (ISO) 31000 risk management standard presents a generic approach for managing risk (ISO 2009b; ISO 2009c; ISO 2009a). This is the first risk management process that claims universal applicability.

The standard presents a new definition of risk: "risk is the effect of uncertainty on objectives". The definitions in Table 3-1 are included in the standard and provide additional precision.

Table 3-1: ISO 31000:2009 definitions related to risk (ISO 2009b)

Term	Risk	Uncertainty	Effect
Definition	effect of uncertainty on objectives	the state of deficiency of information on event, consequence, or likelihood	deviation from the expected (positive or negative)

The ISO was deliberate in defining risk as both an upside and a downside effect of uncertainty. However because it is the industry norm, this work will focus primarily on risk as a negative deviation from the expected.

It is clear that the committee behind the ISO 31000 risk management standard faced the challenging task of assigning a widely applicable, precise and useful definition of risk. There exist a number of different interpretations and uses of the term 'risk', not only by the general public but also in the community of risk management practitioners. Likely due to the intention for a generalizable and widely applicable standard, there are no examples included by the ISO in the standard. This makes it challenging to precisely interpret the definitions and concepts.

The content of the ISO 31000 is summarized in Table 3-2. In this work, we will focus on the Risk management principles.

Particularly relevant to this discussion is (C. Chapman & S. Ward 2004), which introduces and explores 'risk efficiency' through a theoretical framework and case studies as a means of understanding risk management best practices. Risk efficiency is defined as: "the minimum risk decision choice for a given level of expected performance, expected performance being a best estimate of what should happen on average, 'risk' being the possibility of adverse departures from expectations." This definition of risk is quite similar to that of ISO 31000:2009 – "the effect of uncertainty on objectives" (ISO 2009b), although ISO considers both upside and downside risks. Risk efficiency appears to align with the concept of risk presented in the ISO standard.

Table 3-2: Overview of ISO 31000 (ISO 2009b)

Risk management principles	Risk management process	Implementation framework
• Creates value • Integral part of organizational processes • Part of decision making • Explicitly addresses uncertainty • Systematic, structured and timely • Based on the best available information • Tailored • Takes human and cultural factors into account • Transparent and inclusive • Dynamic, iterative and responsive to change • Facilitates continual improvement and enhancement of the organization	• Communication and consultation • Establishing the context • Risk identification • Risk analysis • Risk evaluation • Risk treatment • Monitoring and review	• Mandate and commitment • Design of framework for managing risk • Implementing risk management • Monitoring and review of the framework • Continual improvement of the framework

The authors further argue that the traditional Project Management Institute (Project Management Institute 2008) risk management focus on risk events is not effective, and that in order to move to best practices in risk management, industry should move towards the concept of managing risk efficiency, a concept they introduce and discuss.

The ISO 31000 standard notes that "objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process)". This is aligned with the aim of the standard to be broadly applicable across a range of organizations and applications. A common risk management framework has the potential to resolve interface issues not only within core product design risk management activities, but especially with boundary-spanning activities across business functions (e.g. supply chain management, marketing, production) and other levels of the hierarchy (e.g. project, business unit and corporate risk management) (Olechowski et al. 2012).

Discussion and criticism of ISO 31000:2009

A number of papers have been published in response to the ISO 31000:2009 standard. These papers point out both strengths and weaknesses in the standard, discuss ambiguity and interpretations, and anticipate acceptance, adoption and prominence.

Particularly relevant to the context of product development, (Oehmen et al. 2010) argues that the ISO 31000 is a useful framework to discuss product design risk management. The authors note that "the general ISO 31000 process model seems applicable to risk management in product design." It is further concluded that the ISO recommendations constitute an extensive process, and common risk management processes do not address all of the ISO 31000 elements fully. Finally, the paper reveals that little research has been done to explore the relationship between risk management frameworks for various applications, including product development. Therefore, although a universal risk management standard would seem to be appealing in order to have consistent terminology and process across all aspects of an organization, there is no evidence in the literature to support this idea.

Leitch (Leitch 2010) presents his overall view of the ISO 31000:2009 standard. In critique of the standard, the author says of the vocabulary "key words and phrases are either vague, have meanings different from those of ordinary language, or even change their meaning from one place to another. The definitions provided rarely help." The definition of risk is discussed, with emphasis on the focus on achievement of objectives and the questionable concept of an "expected" state. The author shares positive comments for the standard, including approval of its emphasis on the importance of risk management in the management process at all levels. Further, with respect to risk analysis, Leitch points out the following three ideas: risk analysis can be done to varying levels of detail depending on the risk; it is important to consider the interdependence of different risks and their sources; confidence in assessments of risk should be considered and communicated.

Purdy (Purdy 2010) discusses the ISO 31000:2009 risk management standard as an individual who was part of the ISO working group that wrote the standard. The majority of the paper presents re-printing and paraphrasing of sections of the standard. The author discusses the definition of risk as "the effect of uncertainty on objectives" without criticisms, instead emphasizing the noteworthy features of the definition, including its emphasis on effects and objectives and considering risk as not just a negative concept.

Aven (Aven 2011) focuses on the terminology used in the ISO 31000:2009 standard. The paper is generally critical of the vocabulary, arguing that its definitions are inconsistent and non-meaningful. The main focus of the criticism is the ISO definition of risk, with each element (objectives, uncertainty, deviation, expected) dissected. The author believes the uncertainty dimension is missing from the risk description concept (it contains sources, events, causes and consequences), and that this is inconsistent with the inclusion of this dimension in the definition of risk level as "the magnitude of a risk or combination of risks, expressed in terms of the combination of consequences and their likelihood".

Published research which empirically tests the validity of the new ISO standard, its principles, or definitions does not exist, with the exception of (Olechowski et al. 2012).

3.1.2 Empirical research in project management risk management

There is a significant lack of empirical testing of the actual success rates of various types of risk management or the application of different guiding principles. Table 3-3 summarizes the relevant empirical studies.

Table 3-3: Summary of empirical studies of product development or project management risk management

Authors	Research Question	Method and Test Subject	Empirical Findings
(Raz et al. 2002)	To what extent is RM used in technology projects? What is the impact of RM on various project success dimensions?	Questionnaire - 100 Israeli projects through	Only a limited number of projects use RM. When they do, it relates leads to project success. RM is more applicable to higher risk projects. RM mostly leads to schedule and budget target achievement.
(Mu et al. 2009)	Does risk management strategy targeted at specific risk factors (technology, market or organization) lead to better NPD performance?	In-depth field interviews (14) and a survey questionnaire of Chinese firms (221).	Risk management strategies targeted at specific risk factors affect the performance of NPD and improve the odds of NPD success.
(Jiang & Klein 2000)	What is the impact of development risks on different aspects of system development?	Survey - 86 project managers	Lack of expertise, lack of clear role definition and conflicts on the team are elevated risks that effect overall project effectiveness.
(Na et al. 2007)	What is the impact of specific risk management strategies and residual performance risk on performance measures?	Questionnaire - 3 of Korea's largest software firms - 123 development projects	Residual performance risk is positively correlated with objective cost and schedule overrun.
(Zwikael & Ahn 2011)	Does the level of project risk vary across countries and industries?	Survey - 701 project managers in seven industries and three countries	Project context (industry and country of execution) significantly impacts perceived level of project risk and mitigation intensity. Moderate levels of risk management planning reduce the negative effect of risk on project success.
(Crossland et al. 1998)	What is the need for risk management? How widespread is the use of various techniques and tools? What are sources of risk? How do sectors compare?	Questionnaire – 63 UK design companies Case studies - 6	There is a strong interest in risk management. Use of quantitative risk modeling techniques is not widespread, but qualitative techniques are. Brainstorming and risk registers are widely used. There are differences in technique between sectors.
(Voetsch 2004)	Does risk management make a difference?	Survey – 175 risk special interest group members	There more senior managers are sensitive to risk management, the more they will support it with tools and resources. The more formal risk planning is, the more rigorous risk monitoring is. Project success and senior management support of risk management are correlated. Various other state-of-the-art findings.

With a survey of 63 design companies, (Crossland et al. 1998) present a state-of-the-art in design risk management from various industries. The analysis found that quantified risk modeling techniques are not widespread. While qualitative techniques are much more widely used, the principal emphasis is on risk identification rather than quantification. Risk registers, paper or computer-based, are widely used. 37% of respondents stated that when faced with design project decisions under uncertainty, they "occasionally" or "never" had sufficient information to make a rational decision. No general correlations between risk practices and product development success are reported.

A study of seven hundred project managers (Zwikael & Ahn 2011) explores the effectiveness of risk management practices to reduce risks in project management, and lead to project success. The study also examined the baseline level of project risk across various countries and industries. The analysis found that risk was negatively correlated with project success, but that effective risk management planning could moderate the effect of those risks. The survey also found different levels of risk aversion in organization from nations with correspondingly different cultural levels of uncertainty avoidance. Actionable findings towards effective risk management were threefold: integrate risk into various project management processes; functional managers should be charged with risk management responsibilities, and; risks should be discussed with relevant stakeholders in open form. This final point pertains to the idea of transparency, which is the main focus of Chapter 0 of this thesis.

(Voetsch 2004) presents the findings of a survey of 175 risk management professionals, focusing on project management risk. The study has four principal findings: 1) the higher the (perceived) sensitivity of senior management to project risk management, the more frequent the use of risk management practices; 2) the more that senior managers provide adequate resources to perform risk management, the more frequent the application of risk management processes; 3) the higher the degree of implementation of formal of risk management practices, the more rigorous the risk monitoring, and; 4) project success was found to occur more frequently with greater senior management support of risk management, actual practice of risk management practices, and regular risk monitoring. The study also reports general state-of-the-art of risk management in industry. A majority of the survey respondents reported a formal organization-wide risk management policy. 98% of respondents reported the use of project-team risk identification sessions. A low reported use of quantitative methods was found.

An even smaller collection of literature focuses specifically on product development. Among the few publications touching on this issue, an empirical study based on over 100 projects in various industries was reported in (Raz et al. 2002). The study examined the extent of usage of some risk management practices such as risk identification, probabilistic risk analysis, planning for uncertainty, the difference in application across different types of projects, and their impact on various project success dimensions. The findings of this study are limited because only a small number of projects used any kind of risk management practices, but it was found that projects using risk management better met time and budget goals. In (Mu et al. 2009) the authors propose and validate a risk management framework for new product development. Validation was performed empirically through a survey of Chinese firms. The results show that risk management strategies aimed at technological, organizational, and marketing risk factors contribute both individually and interactively to the performance of new product development.

Further research exists to empirically explore risk management applied to information systems (Jiang & Klein 2000) and software development projects (Na et al. 2007).

In conclusion, although there is some empirical exploration of the current state of product development risk management, there is limited validation of the positive effect of specific risk management frameworks or practices on project success. The existing studies also lack clearly implementable findings.

3.2 Survey Details

3.2.1 Survey development and dissemination

This section summarizes the work of Oehmen and Bassler, published in (Bassler 2011). A survey on the topic of risk management in product development was developed and tested over a period of six months with a focus group consisting of twelve individuals from three academic institutions, one risk management consultancy from the aerospace sector, and six companies from the aerospace and defense sector, all based in the United States.

The development of the survey focused on pre-filtering the questions as much as possible to only include risk management characteristics and practices, as well as risks and mitigation actions, that were agreed on as being "best practice" or of significant impact on the risk management process by general expert and practitioner consensus. Pertinent literature, specifically: (INCOSE 2004; NASA 2008; Department of Defense 2006; ISO 2009b; Project Management Institute 2008) were reviewed and consolidated for inclusion in the survey.

The total time needed to complete the survey was approximately 45-60 minutes. The survey was administered online and distributed in two ways: The survey was sent to the risk management organization of a number of large aerospace and defense companies as part of a benchmarking process. Through this distribution, 90 complete datasets of the survey were collected. The survey was also distributed to practitioners through professional organizations and mailing lists. To encourage participation by shortening the response time required for survey completion, the survey was broken down into smaller parts according to respondent function: Part 1 with questions relevant for general program managers (i.e. respondents not working in a dedicated risk management role), and parts 2 and 3 with questions relevant for respondents directly involved in risk management. The respondents that were binned into the 'risk manager' category were randomly assigned to one of the two risk management parts, with a 50/50 distribution.

In total, 375 responses of various degrees of completion were recorded over a period of seven months from the start of March to the end of September, 2011. Exact response rates are difficult to ascertain, as recipients were encouraged to forward the invitations to colleagues within their organization.

Table 3-4 below refers to the specific survey sections. Please see Appendix D for a copy of the full survey.

Table 3-4: A summary of all survey questions with pointers to the section in which they are analyzed. Details of the Specific Questions are located in the full survey, presented in Appendix D

Specific Questions	Number of Questions	Brief Description	Where Analyzed in this Work
Q1.12 – Q1.25	23	General questions about the respondent's organization and specific project.	Not analyzed
Q1.30 – Q1.34	10	Questions to characterize the project.	Not analyzed
Q2.5 – Q2.7	15 Likert 5 Yes/No	Questions about the risk management process, including seven ISO 31000 Principle questions	Best Practices (section 3.3.1)
Q3.5 – Q3.8	21, split into: 21 Yes/No and 21 Likert	Questions about the occurrence and impact of risks	Risk Severity (section 3.3.2)
Q4.4 – Q5.6	6 Yes/No 13, split into: 13 Yes/No and 13 Likert	Questions about risk management techniques	Best Practices (section 3.3.1)
Q6.4	4 Yes/No	Questions about evaluation of risk mitigation actions	Best Practices (section 3.3.1)
Q6.6 – Q6.9	28, split into: 28 Yes/No and 28 Likert	Questions about the use and impact of various mitigation actions	Best Practices (section 3.3.1) and Mitigation Intensity (section 3.3.2)
Q7.4	5 Likert	Questions about risk monitoring and review	Best Practices (section 3.3.1)
Q7.5	5	Questions about the frequency of review	Not analyzed
Q7.6 – Q7.7	11 Yes/No	Questions about monitoring and key performance indicators	Best Practices (section 3.3.1)
Q8.3 – Q8.6	26 Likert	Four ISO 31000 Principle questions, 22 performance questions	Best Practices (section 3.3.1)

3.2.2 Survey respondents

Although 375 practitioners accessed the survey, there are varying response rates for each question stemming from the fact that the survey respondent could leave a question blank if they felt it was not applicable. 213 respondents completed the first sections of the survey: Q1.12 - Q1.25 and Q1.30 - Q1.34. 188 respondents completed the final section of the survey: Q8.3 – Q8.6.

Figure 3-1 through Figure 3-4 below present a general view of the projects and organizations represented by the survey data.

As presented in Figure 3-1, the majority of the companies surveyed were large, with a budget over $1 billion USD.

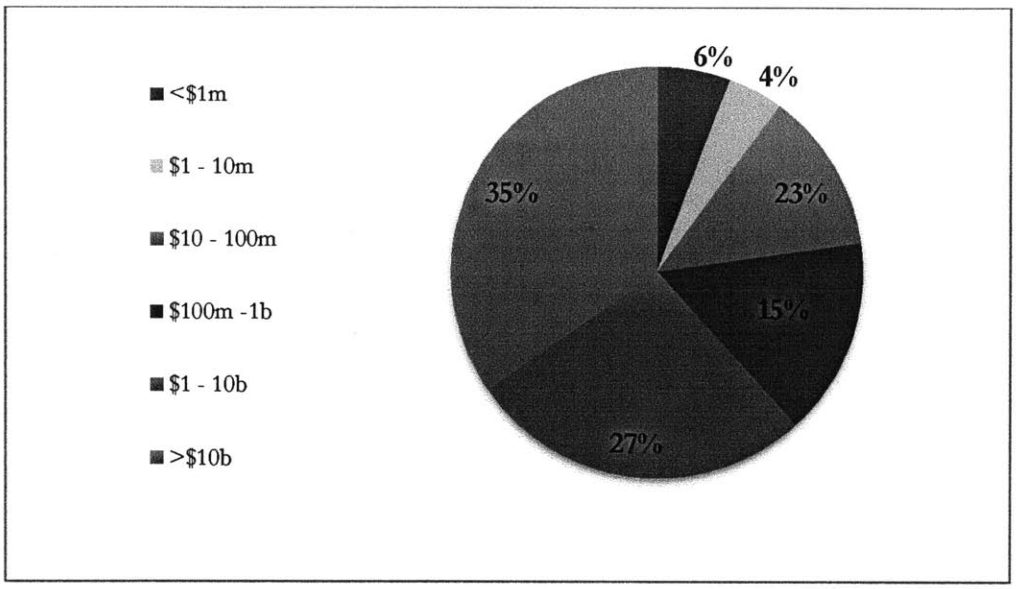

Figure 3-1: Yearly company budget

As can be seen below in Figure 3-2, nearly half of all projects were in the aerospace and defense sector.

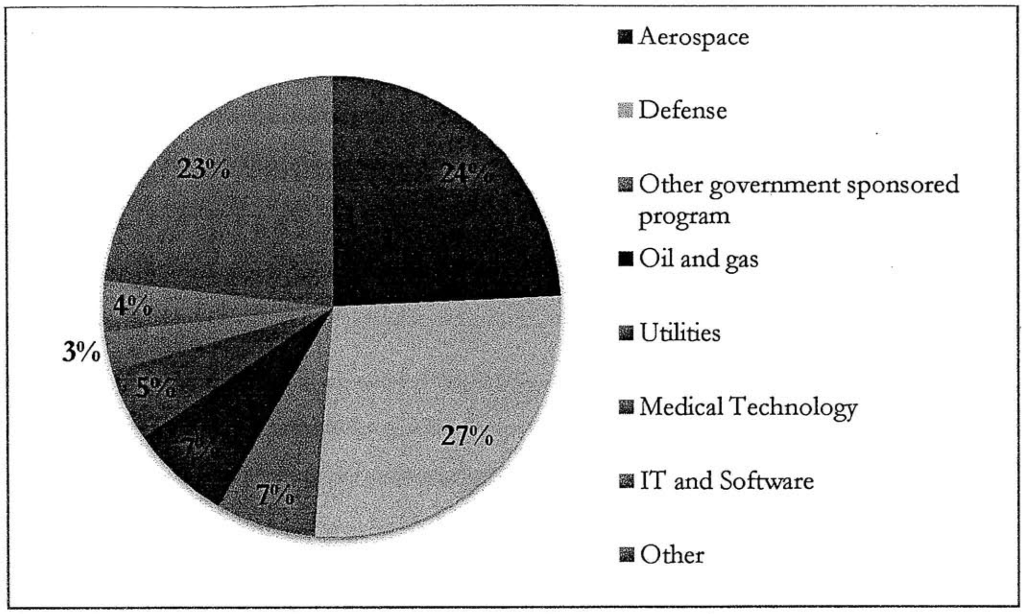

Figure 3-2: Industry sector of organization

The survey collected data from a wide variety of projects with varying budgets, as can be seen in Figure 3-3.

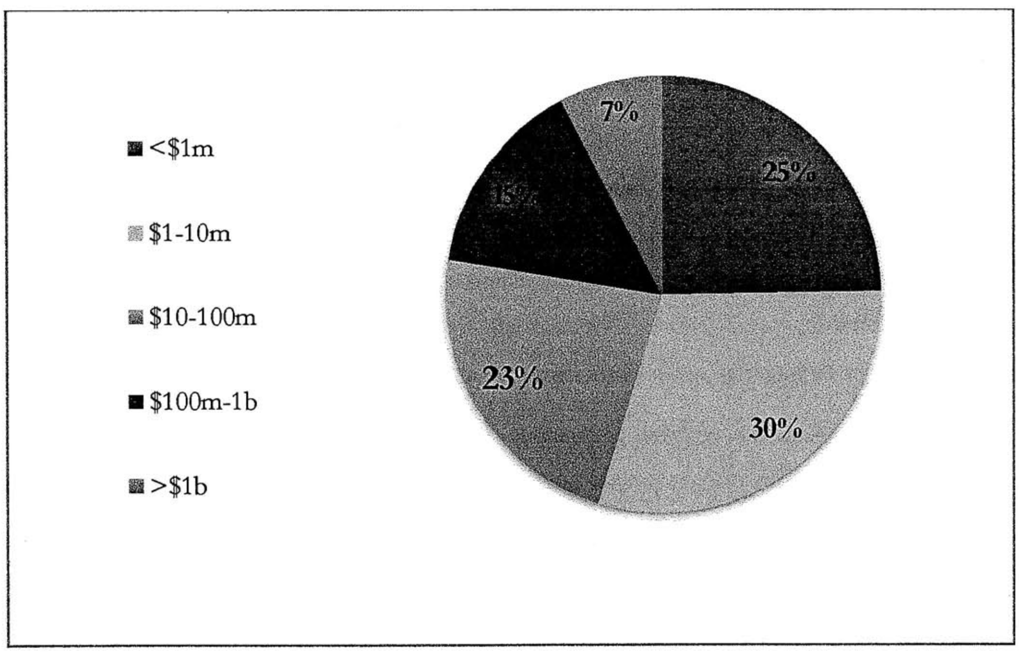

Figure 3-3: Development budget of project

The types of products represented in the survey are varied; the highest represented group is integrated mechatronic systems, as can be seen in Figure 3-4.

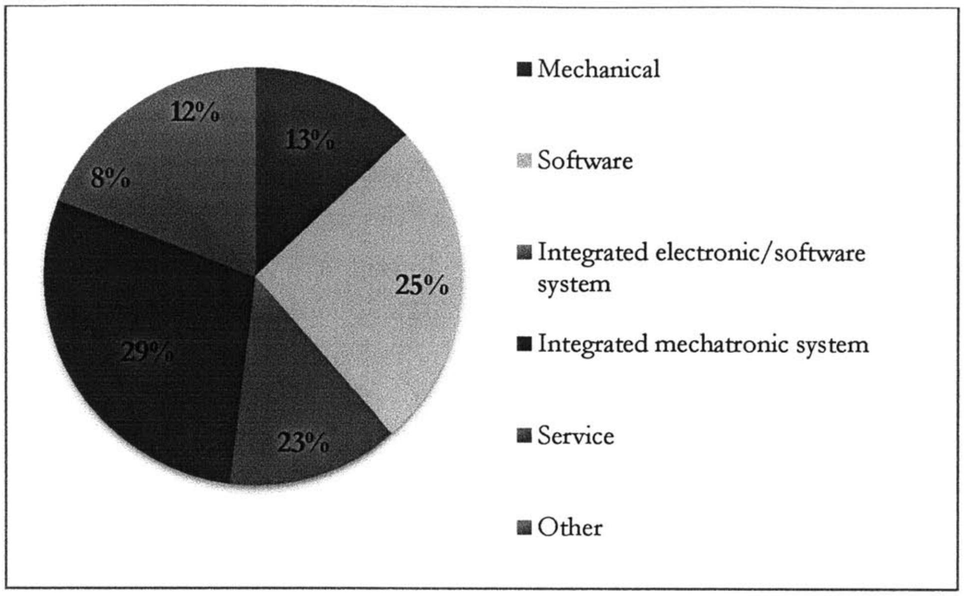

Figure 3-4: Type of product

This survey sample represents a diverse group of product development projects.

3.3 Survey Analysis

To better prepare the reader for the following section, I will briefly present examples of risk management practices and performance criteria from the survey (the entire survey is included in Appendix D):

Example risk management practices:

1) Forecasts and projections (e.g. cost, schedule, performance) are adjusted based on risk assessment (with 5 response options from never used to always used)
2) Risks are monitored using a graphical risk metrics dashboard (with 2 response options: yes or no)
3) Risks are quantified using Monte Carlo simulations (or similar) to aggregate different types of risk estimates (with 5 response options from never used to always used)

Example risk management and project performance questions:

1) Rate the success regarding schedule target for this project (with 5 response options from complete failure to meet target to strongly exceeded target)
2) We spent little time "firefighting", i.e. continuously chasing and fixing problems (with 5 response options from strongly disagree to strongly agree)
3) Risk management facilitates continuous improvement in the organization (with 5 response options from strongly disagree to strongly agree)

Using confirmatory methods, I analyzed the survey responses to identify those risk management practices which were positively correlated with product development success (section 3.3.1). Using descriptive methods, I explored the state-of-the-art of risk mitigation focus in the product development industry (section 3.3.2). Confirmatory methods are used to test the adequacy of concepts developed previously, in this case to test the collected "best practices" from the literature to see which are truly significant in affecting performance. Descriptive methods are used to describe the distribution of a phenomena in a population, in this case the current state-of-the-art in risk management in industry (Forza 2002).

3.3.1 Analysis of best practices

Preliminary parts of the following results were published by the author (Olechowski et al. 2012). The analysis consisted of the following three steps:

1) Definition of performance dimensions.
2) Identification of successful and unsuccessful projects/programs.
3) Statistical determination of the degree to which risk management practices differ between these two groups.

An overview of the data analysis process is presented below in Figure 3-5. First I defined four performance dimensions, which I then calculated for each project using responses on project performance. To identify those characteristics that set successful and unsuccessful risk management apart, I binned all projects into top and bottom quartiles along four dimensions of risk management and project performance. For each performance dimension, I identified those risk management practices whose use was significantly different between the top and bottom set: For Likert-scaled variables, the mean and mean rank were analyzed, for binary (yes/no) questions, a Chi-Square analysis was performed to compare frequency of use. If a variable showed a significant difference in at least three of the four dimensions, it was considered a best practice of product development risk management and is presented in Table 3-9.

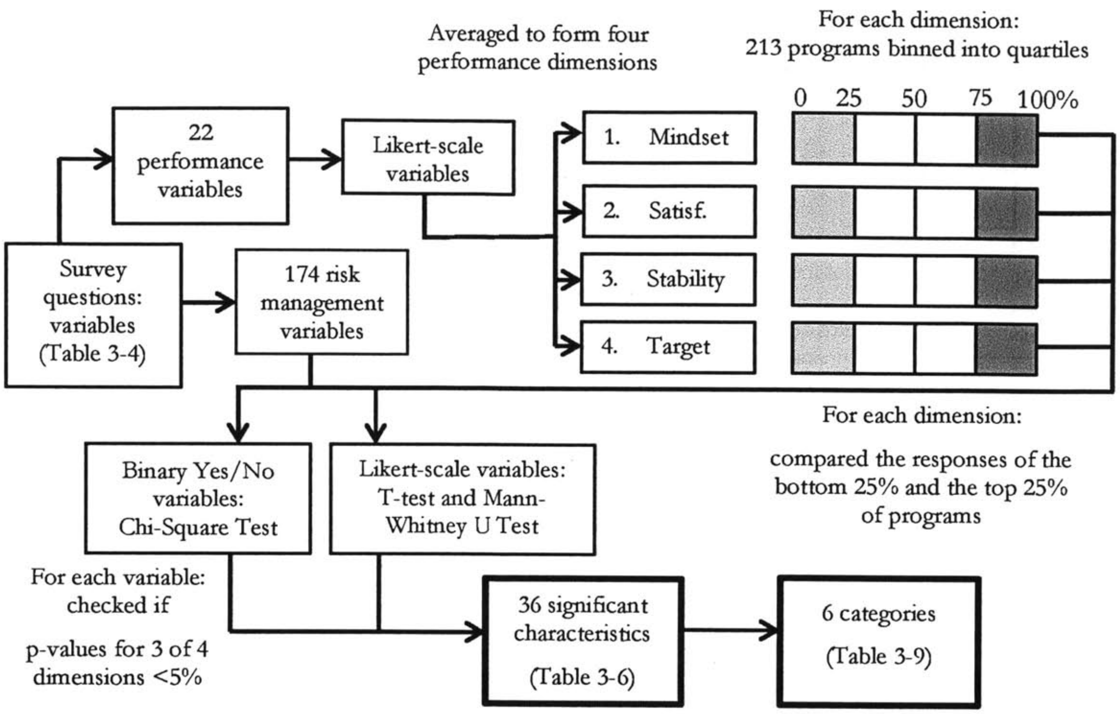

Figure 3-5: Overview of analysis of best practices, presented in section 3.3.1

Performance dimensions

In order to compare the practices of successful and unsuccessful product development projects, I first clearly define the metrics for judging success. Because product development is a complex process, and risk management is only one factor that (likely) contributes to success, four different performance dimensions were created, as shown in Figure 3-6.

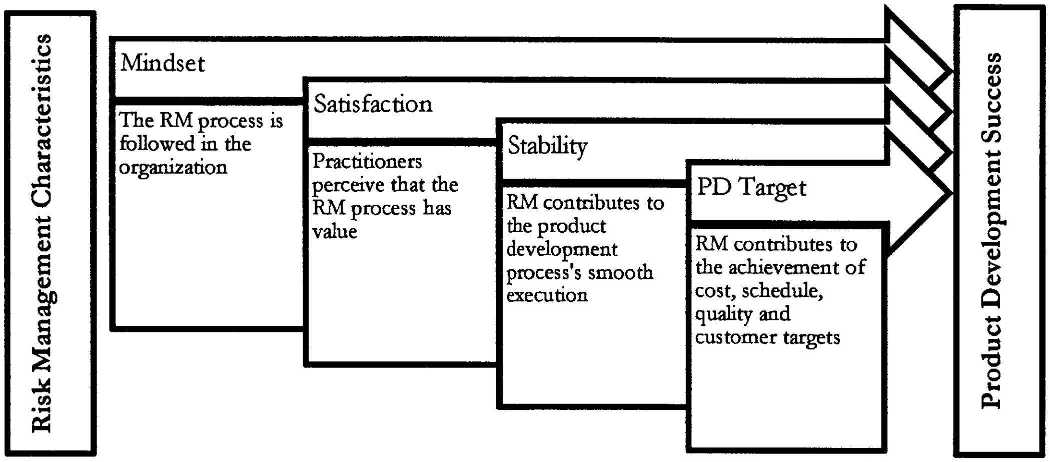

Figure 3-6: Relationship between four performance dimensions, with proximity to "risk management process" indicating the expected influence of the risk management practices on each dimension.

The dimensions therefore are created based on the hypothesis that risk management success is an incremental objective. The four dimensions are ordered from the most influenced by risk management to the least. The acceptance of risk management in the organization is greatly influenced by the characteristics of the risk management system. However, overall product development performance is influenced by a large number of factors, risk management being only one. In other words, the first dimension (Mindset, i.e. acceptance of the risk management process in the organization) is most dependent on risk management while the last dimension (PD Target, i.e. technical, cost, schedule and customer satisfaction target achievement) is dependent on a larger number of factors and is the least dependent on risk management. The dimensions are not mutually exclusive; in fact, it is expected that each dimension is dependent to a certain extent on the previous dimension.

All survey respondents answered a series of 22 Likert questions (discrete response options 1-5) about risk management and project performance. These 22 questions were divided into four performance dimensions: Mindset, Satisfaction, Stability and PD Target Achievement.

The four performance dimensions and the questions within are:

1. Mindset: Acceptance of the risk management process in the organization

    - Program/Project managers support risk management activities
    - Risk management results (e.g. risk reports, risk reduction metric) play an important role in the decision making of senior managers
    - Risk management results influence trade-off decisions (e.g. between cost, schedule and performance targets).
    - Experience in risk management is valuable for promotions

- Risk management processes are the primary mechanism to determine management reserves for a program/project
- Findings from the risk management process translate into action (allocation of manpower and funds)
- There is adequate funding and manpower to conduct risk management process and mitigation activities
- The fact that the program/project manager has to "budget" for risks (i.e. allocate management reserves) is an incentive against identifying additional risks (reversed)
- 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

2. Satisfaction: Perceived value of risk management on project/program success
    - Overall, the organization is satisfied with the performance of the risk management system
    - The ROI of doing risk management was positive
    - Risk management has a positive influence on program success
3. Stability: Stability of the development project/program
    - 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 chasing and fixing problems (reversed)
    - 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 (reversed)
4. PD Target: Overall target achievement of the development project/program
    - Cost target
    - Schedule target
    - Technical performance target
    - Overall customer satisfaction target

For each project (each survey response set) the answers to the outcome questions were grouped into the four performance categories and averaged, resulting in four corresponding performance dimensions. A non-answered question was left out of the average (i.e. was not treated as a zero).

Performance quartiles

For each of the four dimensions, I binned the 213 valid cases into quartiles. This, in essence, creates four ordinal variables from the continuous (averaged) performance dimensions.

Because we have inconsistent N for various questions, we need to pick a robust percentile group for comparison. Using the Visual Binning capability in SPSS, if the source variable contains a relatively small number of distinct values or a large number of cases with the same value, the software will not create as many bins as requested (SPSS 2007). Therefore, because of the resolution of the data – a five-point Likert scale, and only 3 answers averaged in the stability group, quartiles were found to be the most reliable grouping.

I then grouped those programs in the highest quartile (top 25%) as the high performing programs, and those in the lowest quartile (bottom 25%) as the low performing projects. This created two samples - high performing and low performing programs - for each outcome dimension. The two middle quartiles (between 25% and 75%) were not used in this analysis.

Another feature of the SPSS Visual Binning: if there are multiple identical values at a cutpoint (in this case at each percentile edge), all of these values will go into the same bin (SPSS 2007); therefore, the actual number of cases in each bin may not always be exactly equal (is not always equal to 25% of the total population).

Figure 3-7 below shows the performance in each dimension of the high and low performing project bins.

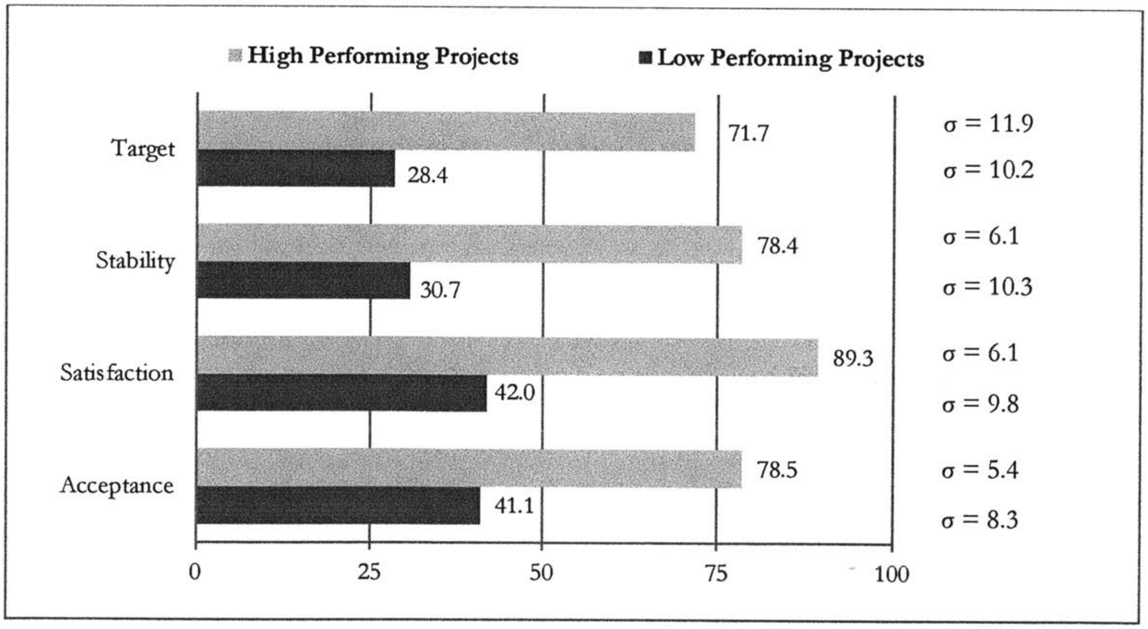

Figure 3-7: Mean performance dimensions, adjusted to a 0-100 scale from the 1-5 scale for simplified viewing. Standard deviations for each population are presented on the right hand side of the figure in order to indicate the spread of the data around the mean.

This figure illustrates the significant difference in the outcomes of the two groups; indeed a test of equal means for the performance dimension in each group results in a p-value smaller than 5%, indicating a statistical difference. This verifies that the high performing and low performing project can be treated as separate populations.

Statistical identification of significant risk management practices

I then identified which of the 174 risk management variables were significantly different between high and low performing programs.

Two different types of survey questions were analysed; 86 Likert questions (on a 5-point scale) and 88 Yes/No questions. The Pearson Chi-square test was used to compare frequencies of Yes/No between the high performing and low performing groups, the null hypothesis being that the frequencies are equal. The test assumes that the expected value for each frequency is at least 5 (i.e. in the full data set there are at least 5 Yes and 5 No responses), which was met for all cases in this analysis.

I analyzed the Likert-scale questions using both the t-test (considering the Likert-scale an interval scale) and Mann-Whitney U Test (treating the Likert-scale as an ordinal scale). These two tests are summarized below in Table 3-5.

Treating the responses as interval data, I analyzed the Likert-scale questions using the two independent samples T-test. This tests whether the means of two normally distributed groups of interval data are equal. In this analysis, the two groups are the high performing and low performing projects. The null hypothesis is that the means of each performance dimensions of the two groups is equal. Additionally I performed the Levene's test for Equality of variances in order to determine whether the variances of the two samples were equal, and thus which 2-tailed significance statistic was suitable.

An alternative to the t-test is the non-parametric Mann-Whitney U test which treats the dependent variables as ordinal data. In this test, the mean rank of the data is compared between the two groups. Some statisticians prefer this method of analysis with Likert-scales since the 5-point scale results are discrete and not truly normally distributed. However, the T-test is typically appropriate for samples so long as their distribution is generally mound-shaped, as this Likert-scale data set is.

Table 3-5: Comparison of the T and Mann Whitney U tests, both used to determine if there is a significant difference in the means of two groups in the variable of interest

Test	Scale	Compares	Distribution
T	Interval	Mean	Normal assumption (generally holds for mound-shape)
Mann-Whitney U	Ordinal	Mean-rank	No normal assumption

For the sake of robust results, I performed both the T and Mann-Whitney U tests and compared the results. The results of the two tests largely agreed, and it will be noted where they do not. Mann-Whitney U, T-test and Chi Square test statistics (p-values) are presented in full for each practice and each dimension in Appendix A.

3.3.2 Analysis of risks and mitigation measures

Through a separate analysis, I augmented the analysis presented in (Bassler 2011) using slightly different categories and a larger data set. I classified the 21 survey questions about the occurrence and impact of risk, and the 28 questions about the frequency of use and impact of mitigation actions into seven different categories:

1. **New technology**
   - Example risk: test plan schedule incomplete, or lacking dependencies
   - Example mitigation action: Engineering with redundancy or safety margins
2. **System integration**
   - Example risk: production readiness level for the system too low to meet delivery objectives
   - Example mitigation action: develop flexible product architecture
3. **Customer requirements**
   - Example risk: customer/stakeholders change or extend requirements or their priority
   - Example mitigation action: Help customer understand what their needs are and make trade-offs (e.g. MATE or other trade-off simulations and calculations)
4. **Company-internal**
   - Example risk: Resources are re-allocated or become unavailable
   - Example mitigation action: Define "standard work" or "standard processes" to increase process reliability
5. **Supplier**
   - Example risk: Supplier failure causing development delays, cost overruns or quality problems
   - Example mitigation action: Contractual sharing of cost overruns with suppliers
6. **Competitor**
   - Example risk: Activities of competitors disrupt project/program execution (e.g. aggressive pricing, new technology introduction)
   - Example mitigation action: Monitor activities of competitors (e.g. technology disclosures, bidding strategy, product launches, market entries, analysis of existing products, etc.)
7. **Market**
   - Example risk: Insufficient management of compliance leads to issues with regulatory policies.
   - Example mitigation action: Active lobbying with key stakeholders outside of direct customer/contractor relationship, e.g. regulatory agency or policy makers

I calculated a frequency of occurrence of risks as the number of times the risk did occur divided by the total number of question responses. Similarly, I calculate the frequency of use of mitigation actions as the number of times the mitigation was used divided by the total number of question responses. The respondent could explicitly state if the risk or mitigation did not occur or was not used. It is assumed that if the respondent entered an impact or reduction score, the risk or mitigation did occur.

For each risk, I averaged the impact scores (on a 5-point discrete scale) to give the average risk impact. Similarly for each mitigation action I averaged the reduction scores (on a 5-point discrete scale) to calculate the average mitigation reduction.

In each of the 7 categories, I averaged the individual frequencies and impacts to calculate overall frequencies and impacts for both the risks and the mitigations. To achieve a Risk Loss value, I multiplied the average frequency and average impact. To achieve a Mitigation Effort value, I multiplied the average frequency and average reduction.

3.4 Results

The results of the analysis of best practices as well as the risk loss – mitigation loss exercise are presented in this section.

3.4.1 Best practices

Of the 174 risk management variables of the survey, 36 variables were identified which showed a statistically significant difference between low and high performing projects in at least three of the four dimensions of performance. These variables are presented as best practices, and are presented below in Table 3-6 along with statistical outputs of either the Mann-Whitney U and Chi-Square test, whichever is applicable.

The differences of means are presented for each question in all four performance dimensions. Those dimensions are "Mind." (Mindset - Acceptance of the risk management process in the organization), "Satisf." (Satisfaction - Perceived value of risk management on project/program success), "Stab." (Stability - Stability of the development project/program) and "Target" (PD Target: Overall target achievement of the development project/program).

Following the table, Figure 3-8 to Figure 3-10 are presented to provide the reader with a better understanding of the significance of the various values presented in Table 3-6. For comparison, the means and distributions of three characteristics (1, 9 and 15) are plotted side-by-side for the high and low performing projects in each performance dimension.

Table 3-6: Statistical outputs of Mann-Whitney U and Chi-Square Tests for Significant Characteristics. Characteristics 35 and 36 were yes/no questions and so no difference of means is presented.

	Characteristic	Difference of Means			
		Mind.	Satisf.	Stab.	Target
1	Employees are motivated to perform/implement RM.	1.1**	1.08**	0.77**	0.79**
2	RM has available, qualified experts to help implement the processes.	1.25**	1.13**	1.03**	0.76**
3	There are sufficient resources and personnel to conduct RM.	1.29**	1.08**	0.95**	0.67**
4	RM explicitly addresses uncertainty.	1.06**	1**	0.95**	0.56*
5	RM is systematic, structured and timely.	1.69**	1.56**	1.18**	0.68**
6	RM is based on the best available information.	0.95**	0.88**	0.77**	0.4
7	RM is tailored to specific program/project needs.	1.14**	0.9**	0.95**	0.59**
8	RM takes human and cultural factors into account.	1.05**	0.99**	0.97**	0.86**
9	RM is transparent and inclusive towards all stakeholders.	1.34**	1.34**	0.96**	1.03**
10	RM is dynamic, iterative and responsive to change.	1.63**	1.28**	1.28**	0.53*
11	We coordinate and integrate RM activities of different functions and across the hierarchy.	1.08**	1**	0.81**	0.31
12	RM is integrated with higher-level RM process.	1.03**	0.78**	0.67*	0.55*
13	RM process is effectively integrated with project management processes.	1.32**	1.07**	0.94**	0.8**
14	RM teams are cross-functional and cross-organizational.	1.16**	0.94**	0.56*	0.46
15	Risk is assessed on scales of probability and impact	0.51*	0.61**	0.52*	0.08
16	Go/no-go decisions are made based on risk assessment.	0.92**	0.93**	0.66**	0.26
17	Resources are allocated to reduce largest risks as early as possible.	1.14**	1.06**	0.91**	0.6**
18	Risk assessments are used to set more realistic/achievable objectives.	0.79**	1.02**	0.85**	0.63**
19	Forecasts and projections are adjusted based on risk assessment.	1.32**	1.03**	0.68**	0.5*
20	The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs.	1.14**	1.09**	0.64**	0.35
21	Decisions are made based on risk-benefit trade-offs	0.69**	0.81**	0.68**	0.37
22	Risk-benefit trade-offs are used systematically to favor 'low risk - high benefit' options and eliminate 'high risk - low benefit' options.	0.75**	0.69**	0.58**	0.52*
23	Contracts are derived from detailed cost risk assessments.	0.91**	1.04**	0.57*	0.72**
24	Self-assessments, continuous improvement and best practices were used	1.31**	0.98*	1.07**	0.33
25	Standard work/processes were defined to increase process reliability	0.88*	1.12**	0.91*	0.59
26	Risks were escalated to senior management according to guidelines.	1.02**	1.03**	1.15**	0.07
27	Risks were regularly re-assessed according to guidelines.	1.3**	1.14**	0.69**	0.21
28	The RM process was regularly reviewed and improved.	1.67**	1.64**	1.14**	0.52
29	Execution of risk mitigation actions monitored by formal feedback system.	1.56**	1.27**	1.04**	0.15
30	An early warning system was used to track critical risks and decide on activating mitigation measures.	1.26**	1.15**	0.97**	-0.13
31	RM creates and protects value.	0.54**	0.96**	0.4**	0.37*
32	RM is an integral part of all organizational processes.	0.96**	1.1**	0.72**	0.58**
33	RM is central part of decision making.	1.08**	1.08**	0.61*	0.25
34	RM facilitates continuous improvement in the organization.	0.86**	1.25**	0.6**	0.44*
35	Risks and RM activities are communicated to stakeholders	*	**	**	
36	Before use, potential risk mitigation actions are evaluated to assess reduction of impact they would achieve	*	*	*	
	* : p < 5%, ** : p < 1%, RM: Risk management				

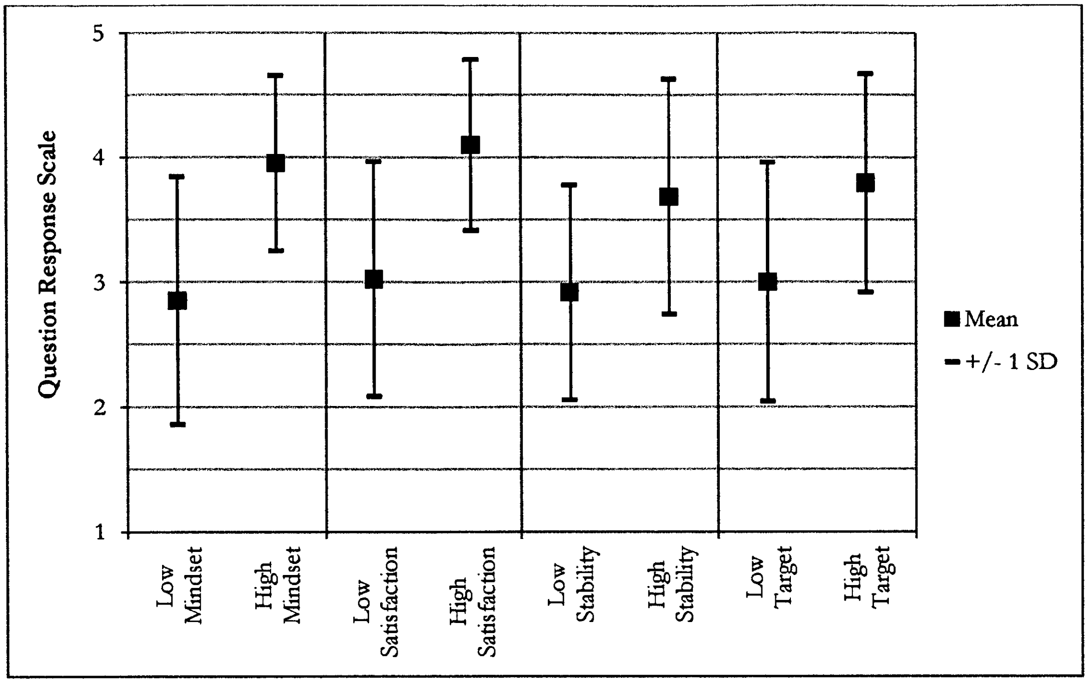

Figure 3-8: Responses of the high and low performing projects to the question "Employees are motivated to perform/implement RM" (#1 in Table 3-6) for each of the four performance dimensions.

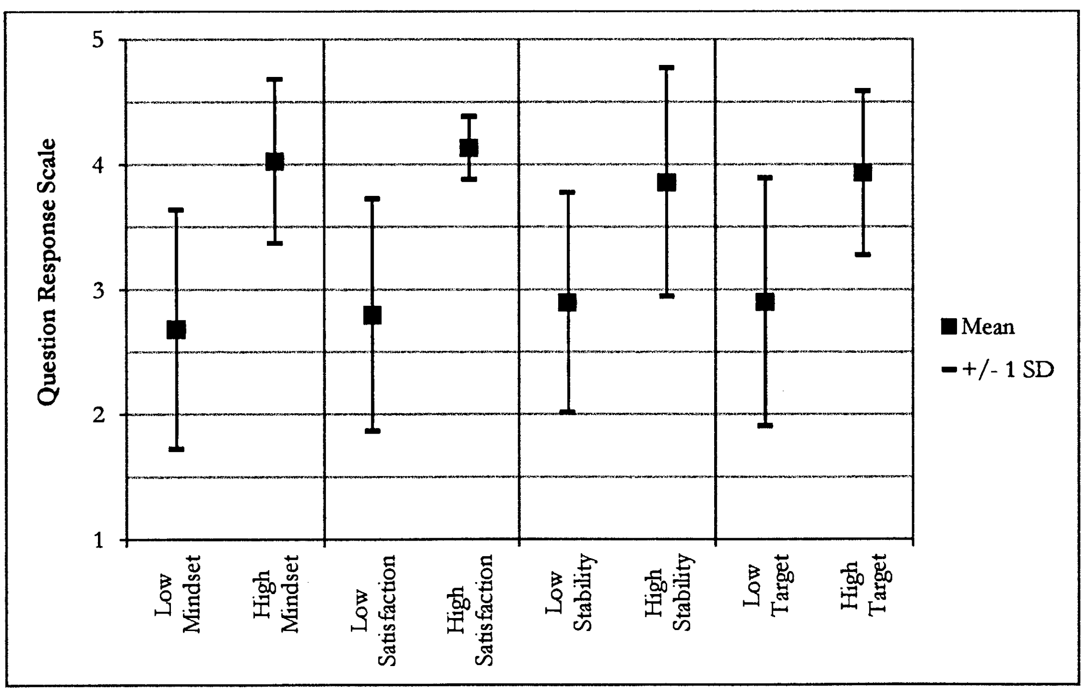

Figure 3-9: Responses of the high and low performing projects to the question "RM is transparent and inclusive towards all stakeholders" (#9 in Table 3-6) for each of the four performance dimensions.

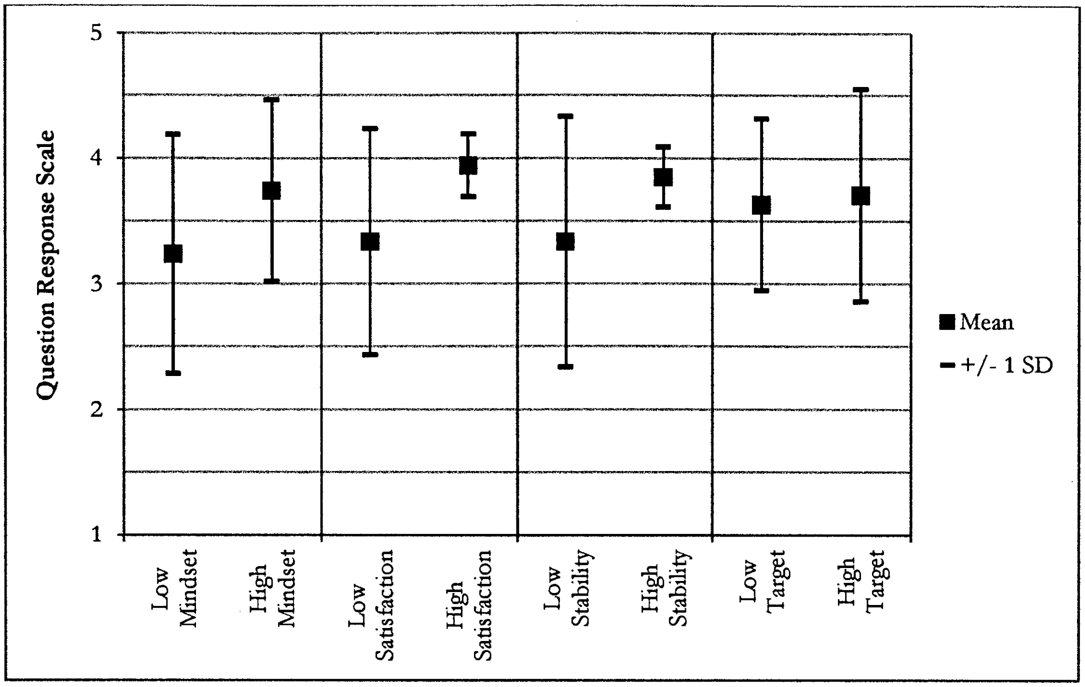

Figure 3-10: Responses of the high and low performing projects to the question "Risk is assessed on scales of probability and impact" (#15 in Table 3-6) for each of the four performance dimensions.

3.4.2 ISO principles and product development performance

Figure 3-11 below presents a different view of ISO 31000 and product development success from the survey. This data represents all 197 projects that answered both at least one question about adherence to the eleven ISO principles and at least one question about the project target achievement (therefore all four quartiles are considered). For each project, I averaged the responses for all ISO questions (Average ISO Score) and plotted those against the fourth performance dimension – PD Target Score. In general, it appears that a positive trend exists between adherence to the ISO principles and PD target achievement.

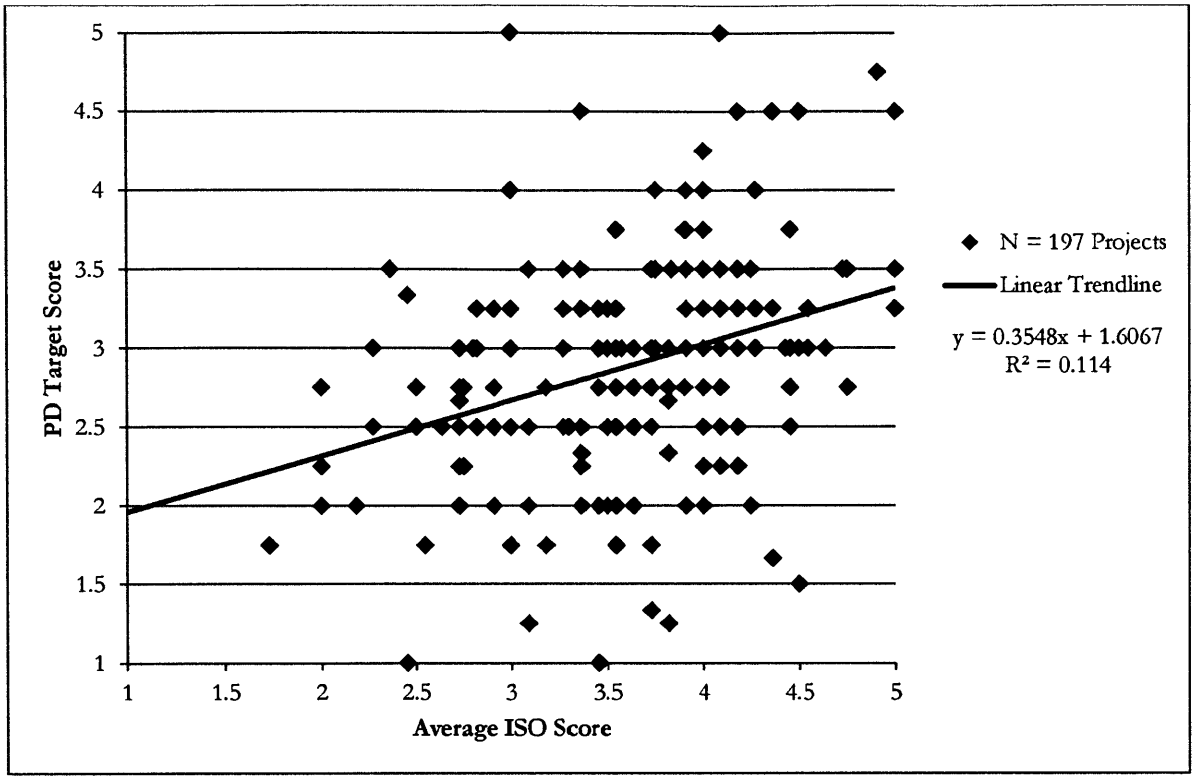

Figure 3-11: Average of responses regarding average of four responses regarding product development outcomes (cost, schedule, technical, customer satisfaction) versus adherence to ISO eleven principles for 197 projects. A linear trendline fit to the data is also plotted.

Although the plot and trendline imply a positive correlation between adherence to the ISO principles and Product Development Target Achievement, the R^2 value is very low and thus this data is not adequate to prove a relationship between the two measures.

3.4.3 Practices that were not significant

174 risk management practices were analyzed but only 36 were found to be significantly different between the high-performing and low-performing projects, and considered best practices. It is not useful to present and discuss all of those 138 practices which were not significant, but I will present general categories representing those practices.

These risk management characteristics included:

- The manner in which risk management is communicated (e.g. through a formal document, via a board).
- Use of sophisticated methods for quantifying the impact of identified risks (e.g. Probabilistic Risk Assessment, Monte Carlo simulations).

- Specific mitigation actions related to organizational efficiency, technological risks, and customers/contracting.
- Specific methods for monitoring risks.
- Specific Key Performance Indicators for use in risk management.

3.4.4 Loss from Risk and Mitigation Effort

Following the calculations outlined in section 3.3.2 above, Table 3-7 and Table 3-8 below present the risk loss and mitigation effort values calculated for all projects, and broken down into risk/mitigation category.

Table 3-7: Calculated frequency of risk occurrence, and average of reported impact of risk for each risk category. Loss is calculated as a product of frequency and impact for each risk category, and is also presented as a percentage of total loss.

Category	Risks			
	Frequency	Impact	Loss	Loss (%)
New Technology	0.84	2.8	2.4	15.4%
System Integration	0.81	2.7	2.2	14.2%
Customer Requirements	0.90	3.2	2.9	19.0%
Company-internal	0.87	2.8	2.4	15.7%
Supplier	0.84	3.0	2.6	16.6%
Competitor	0.58	2.3	1.4	8.9%
Market	0.67	2.4	1.6	10.2%

Table 3-8: Calculated frequency of mitigation use, and average of risk reduction achieved (impact) for each risk category. Effort is calculated as a product of frequency and impact for each risk category, and is also presented as a percentage of total effort.

Category	Mitigations			
	Frequency	Impact	Effort	Effort (%)
New Technology	0.91	3.4	3.1	19.3%
System Integration	0.84	3.0	2.5	15.7%
Customer Requirements	0.71	2.6	1.9	11.6%
Company-internal	0.79	2.8	2.2	14.1%
Supplier	0.81	2.7	2.2	13.8%
Competitor	0.81	2.7	2.2	13.6%
Market	0.72	2.6	1.9	11.9%

3.5 Conclusions from the Survey Analysis

Product design is a complex and intensely coupled process. It is not a surprise that the statistical analysis identified general features, philosophies, and attitudes which set apart low and high performing programs, rather than individual activities or methods for product design risk management.

3.5.1 Trends in performance dimensions

The statistical results indicate that there is a strong relationship between effective risk management and overall program performance. The trend of decreasing differences of means from dimension 1 to dimension 4 was expected since the four dimensions were ordered from that most dependent on risk management ("Mindset") to the least dependent on risk management ("PD Target"). Overall program success is dependent on far more factors than were possible to capture in the survey. Nevertheless, many of the characteristics presented above are significant in the "PD Target" dimension, indicating that risk management has a direct impact on overall program performance.

3.5.2 Significant risk management categories emerge

The 36 best practices are summarized and discussed in six categories: 1- RM Personnel and Resources; 2- Tailoring and Integration of the RM Process; 3- Risk-Based Decision Making; 4- Specific Mitigation Actions; 5-Monitoring and Review; and 6- Remaining ISO Risk Management Principles. The first five categories are collections of principles related to the same theme while the final category (6- Remaining ISO Risk Management Principles) is a collection of the remaining significant practices, which all happen to be ISO Principles which do not fit into the other five categories.

Table 3-9 and Table 3-10 below present the 37 best practices identified, grouped into those six categories. The categorizations were made for clarity by the author and verified by fellow subject matter researchers, but do not represent a scientific or statistical clustering of results. "ISO" in brackets following a best practice indicates one of the 11 ISO principles which is presented in its more appropriate category. The 11 ISO principles are further discussed in section 3.5.3 below.

Table 3-9: The 36 best practices of product development risk management grouped in six categories, with reference to the index in Table 3-6 where additional statistics for each characteristic are available.

	Table 3-6 Index
1- RM Personnel and Resources	
Employees are motivated to perform/implement RM. (ISO)	1
RM has available, qualified experts to implement processes.	2
There are sufficient resources and personnel to conduct RM.	3
2- Tailoring and Integration of the RM Process	
RM is tailored to specific program/project needs. (ISO)	7
We coordinate and integrate RM activities of different functions and across the hierarchy.	11
RM is integrated with higher-level risk management process.	12
The RM process is effectively integrated with other project/program management processes.	13
RM is transparent and inclusive towards all stakeholders. (ISO)	9
RM teams are cross-functional and cross-organizational.	14
RM is an integral part of all organizational processes.	32
Risks and RM activities are communicated to stakeholders	35
3- Risk-Based Decision Making	
Go/no-go decisions are made based on risk assessment.	16
Resources are allocated to reduce largest risks as early as possible.	17
Risk assessments are used to set more realistic or achievable objectives.	18
Forecasts/ projections are adjusted based on risk assessment.	19
The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs.	20
Decisions are made based on risk-benefit trade-offs	21
Risk-benefit trade-offs are used systematically	22
Contracts are derived from detailed cost risk assessments.	23
Risks were escalated to sr. mgmt. according to guidelines.	26
RM is central part of decision making. (ISO)	33
Identified risks are quantified on scales for probability and impact	15
Before use, potential risk mitigation actions are evaluated to assess achievable reduction of impact	36

Table 3-10: The 36 best practices of product development risk management grouped in six categories, with reference to the index in Table 3-6 where additional statistics for each characteristic are available (continued).

	Table 3-6 Index
4- Specific Mitigation Actions	
Self-assessments, continuous improvement and implementation of best practices were used.	24
Standard work/processes were defined to increase process reliability.	25
5 - Monitoring and Review	
Risks were regularly re-assessed according to guidelines.	27
The RM process was regularly reviewed and improved.	28
RM is dynamic, iterative and responsive to change. (ISO)	10
A formal feedback system was used to monitor the execution of risk mitigation actions.	29
An early warning system was used to track critical risks and decide on activating mitigation measures.	30
6 - Remaining ISO Risk Management Principles	
RM explicitly addresses uncertainty. (ISO)	4
RM is systematic, structured and timely. (ISO)	5
RM is based on the best available information. (ISO)	6
RM takes human and cultural factors into account. (ISO)	8
RM creates and protects value. (ISO)	31
RM facilitates continuous improvement in the organization. (ISO)	34

The results of category 1 (RM Personnel and Resources) indicate the need for motivated, qualified personnel on the risk management team, and sufficient resources to conduct risk management.

The significance of category 2 (Tailoring and Integration of the RM Process) clearly shows the importance of a customized and well-integrated risk management process throughout all functions, levels and processes in the organization. Successful risk management includes the internal and external stakeholders of the program in its processes and in on-going communication about the project. Risk management is not an external add-on function in the organization, nor is it a one-size-fits-all process. It must be tailored to the specific program environment and its stakeholders.

The analysis indicates that in high performing product development projects, decisions are much more likely to be made based on the results of risk management analysis (3- Risk-Based Decision Making). Decisions about forecasts, projections, contracts and other project decisions should be based on transparent risk trade-off information. Whether it is a fundamental idea of risk management (17: Resources are allocated to reduce the largest risks as early as possible) or more sophisticated decision method (23: Contracts are derived from detailed cost risk assessments), integrating risk management into the decision making process is a key factor in program performance.

Of the 32 different mitigation actions included in the survey, only the two presented in category 4- Specific Mitigation Actions correlate significantly with performance outcomes. The universality of this type of mitigation action likely explains why these two actions were found to be significant; continuous improvement, best practices, and standard work can all be applied to any project or process as a mitigation action. These two actions are not technology or project specific, unlike the other mitigation actions included in the survey.

The risk management process and its execution must be regularly monitored and reviewed, as suggested by the strong significance of the characteristics in category 5 (Monitoring and Review). This is important not only to the acceptance and impact of risk management throughout the organization, but to the stability of the program. Together with the characteristics in the preceding categories, this clearly shows that successful risk management is an on-going journey of tailoring, adaptation, integration and improvement, not a static process state.

3.5.3 Significance of all eleven ISO 31000 principles

The statistical significance of all eleven ISO 31000 Risk Management Principles indicates that the fundamental philosophies on which the standard is based are indeed applicable to product design. The standard states that "for risk management to be effective, an organization should at all levels comply with the principles" (ISO 2009b) and the results in this paper strongly support this statement. The 11 principles each have impact not only on effective risk management but also on the stability of the program and the overall achievement of cost, schedule, performance and customer satisfaction targets.

The eleven principles are generally high-level (for example "Risk Management creates and protects value"), and are more descriptors of an effective risk management process rather than specific risk management practices to implement. It is perhaps for this reason that they were all identified as significantly different between the high and low performing projects; they are, in fact, a set of risk management performance measures.

Nevertheless, this study confirms the assertion of the standard that compliance with the principles is necessary for effective risk management. The results of the study also suggest that the ISO 31000 standard is applicable to product development.

3.5.4 Agreement with relevant previous studies

These results agree with previous empirical studies (discussed in section 3.1.2) on the positive impact of risk management activities on product development outcomes. As was found in (Raz et al. 2002; Mu et al. 2009; Zwikael & Ahn 2011; Voetsch 2004), a positive relationship between risk management and the target achievement performance dimension was found for a number of categories and characteristics in this study. This paper goes beyond the previous studies by a) incorporating a much larger sample; b) addressing specific risk management practices instead of evaluating risk management as a whole; and c) differentiating the impact of risk management along four different outcome variables.

3.5.5 Transparency is highly associated with product development success

The single best practice which had the highest difference of means between the low performing and high performing projects in the PD Target dimension was "Our Risk Management is transparent and inclusive towards all stakeholders," one of the eleven ISO 31000 principles. This principle was in fact the only practice with a difference in means greater than 1 unit (1.03) in the fourth PD Target dimension, significantly higher than the next closest, "Risk Management takes human and cultural factors into account," with a difference of means of 0.86 (and also an ISO principle). Limitations to this finding are discussed in section 3.6.

Table 3-11 below presents a breakdown of the responses to the question "Our Risk Management is transparent and inclusive towards all stakeholders" with the corresponding average PD Target scores (the mean of the answers, asked on a 1-5 scale).

Table 3-11: Breakdown of 195 responses to the question "Our risk management is transparent and inclusive towards all stakeholders." For each group of responses to this question, the mean of the Product Development Target dimension is also presented.

	Our RM is transparent and inclusive towards all stakeholders.				
	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Number of Responses	7	33	55	83	17
Mean PD Target Dimension	2.46	2.59	2.82	2.94	3.55

The increasing Mean PD Target Scores presented in Table 3-11 indicates that indeed there is a trend in the degree of transparency/inclusivity and the product development target achievement.

3.5.6 Mitigation effort not aligned with expected risk loss

Figure 3-12 below presents the mitigation effort and total loss calculated for each risk type. These values are presented as percentages of total loss and total mitigation effort, in order to highlight relative differences in the level to which risks have impact and correspondingly are addressed with mitigation efforts. The plot also includes a line of equal percentage total loss and total mitigation effort for reference. The "equal line" can be seen to represent an effective risk management strategy, where the effort awarded to each risk type corresponds to typical loss caused by that risk.

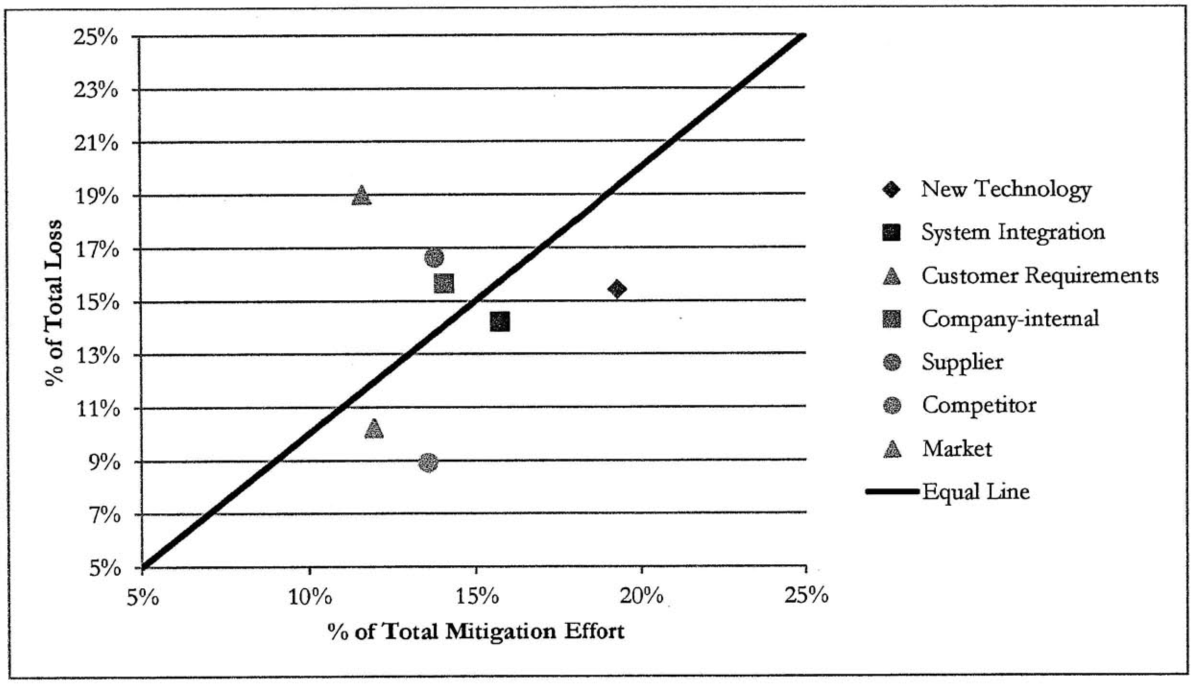

Figure 3-12: A plot of percentage Risk Loss and percentage Mitigation Effort for each risk category. These values reflect the average scores of 127 products. The equal line is included for reference, and indicates where an effort paid to a particular risk type would be in proportion to the typical loss from that risk.

Observational grouping would suggest that Market, System Integration, Company-internal and Supplier risks are generally appropriately addressed. New Technology and Competitor risks are allocated more mitigation effort than might be warranted. Customer Requirements related risks appear to be under-addressed, given a high risk loss but low mitigation effort paid to address those risks.

It can be seen in Figure 3-12 that the Customer Requirements '% of Total Loss' is the highest of all categories. This is due to both high frequency of occurrence (90% - the highest of all 7 categories) and high impact (3.2 on a 1-5 scale, also the highest of all 7 categories).

Yet Customer Requirements related risks have the lowest mitigation effort because of a low frequency (0.71 – the lowest of all categories) and a low risk reduction achieved (2.6).

New Technology risks have the highest "% Mitigation effort". This is a result of both a high frequency of mitigation (91% - the highest of all categories) and a high impact (3.4 – the highest of all categories).

As an extension of this analysis, the responses of those projects which self-identified as government-sponsored aerospace and defense were separated from the remaining projects (e.g. automotive, commercial aerospace, consumer goods, medical technology, etc.). These results are plotted below in Figure 3-13 and Figure 3-14. There are 73 government aerospace and defense products, and 52 commercial. Note this does not add to the 127 responses plotted in the Figure 3-12 because two projects did not identify the product industry.

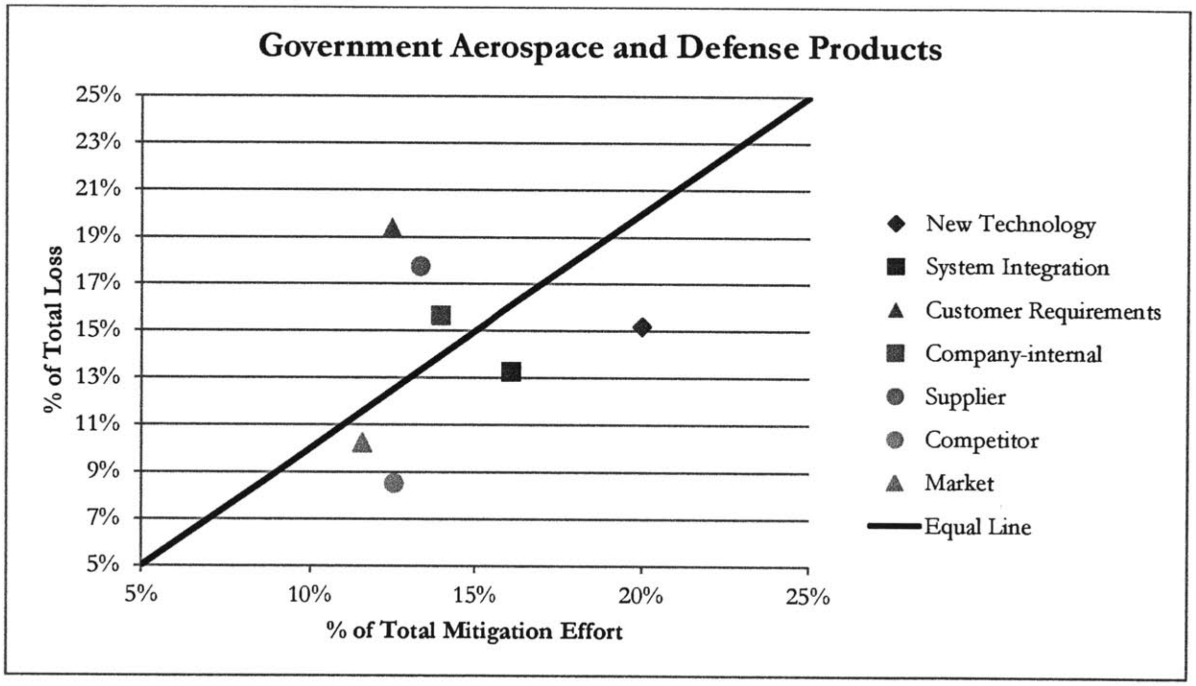

Figure 3-13: Similar to Figure 3-12, this plot represents the values calculated from the responses of the 73 government aerospace and defense products.

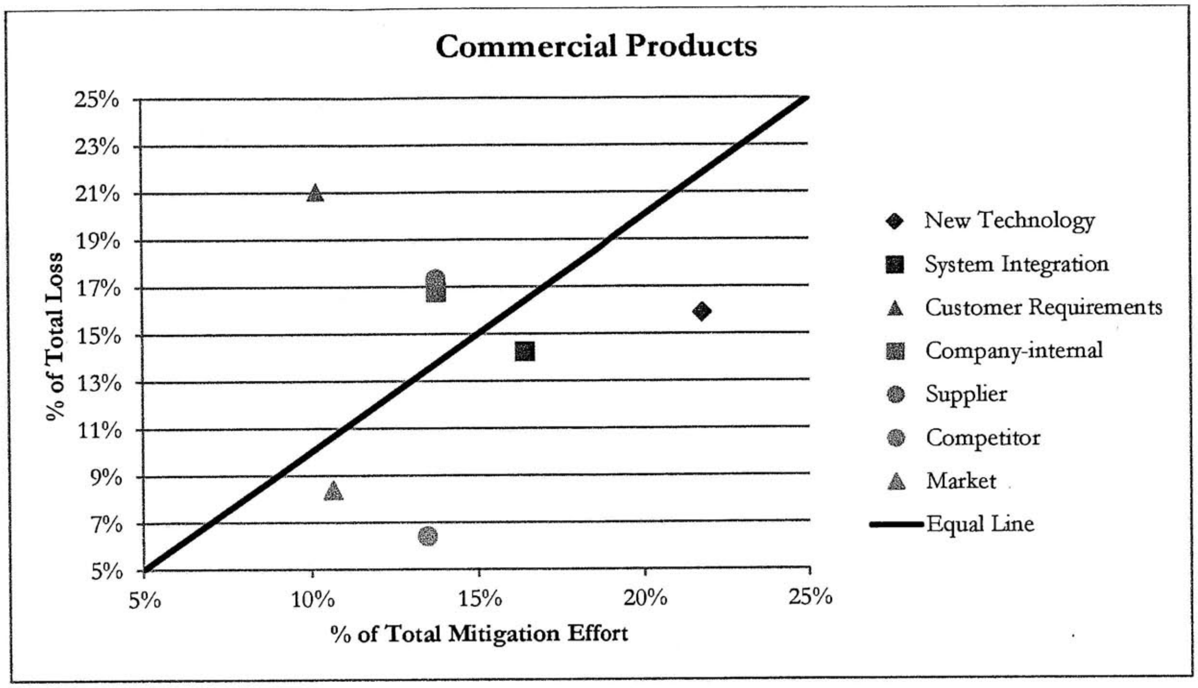

Figure 3-14: Similar to Figure 3-12, this plot represents the values calculated from the responses of the 52 commercial products.

Comparing the three plots, there is overall agreement, with relative relationships remaining consistent. This suggests that the first plot presenting the data for both types of projects is representative, and the two samples can be analyzed together. This result was surprising, given the differences in scale and scope of the projects, as well as differences in the customer-contract versus market relationship.

A possible explanation for the over-attention paid to New Technology risks is the widespread adoption of tools like the Failure Mode and Effects Analysis, Technology Readiness Level Assessments, and computer models and simulations. In terms of measurable, estimable uncertainties, technology risks tend to be more straight-forward to tackle, when compared to other less quantifiable risk types.

Additionally, many tasks which are typically considered key parts of the product development process can in fact be seen as risk mitigations, for example testing and prototyping or reuse of existing components. In the survey, we considered mitigations which are typically seen as design tools, but in industry this is not a common view. It is possible that in industry, when the risk management process is being designed and mitigation efforts are being considered, design tasks are not counted among technology mitigations. This leads to an over-attention paid to technology risks, and could explain the observed results.

Customer requirement related risks include, for example, the risk that the customer changes their priority or requirements (sometimes called "scope creep"), or the product development team does not understand the customer's requirements in the first place. These risks account for a great deal of the loss on a project, but are not addressed with a matching effort in mitigation actions. Tools for mitigating customer related risks include complex contracting structures, requirements elicitation techniques, and ongoing customer communication and transparency. There appears to be some attention paid to methods for elicitation of customer needs, but less to ongoing management of customer requirements. It can be concluded that customer-requirements risks – which result in significant risk loss to product development projects - are an under-addressed aspect of risk management theory and practice.

3.6 Limitations

The following limitations are important to consider when interpreting results. The survey is taken post-project and so accurate recollection of program details may be difficult. The analysis relies on self-reported outcomes which could be biased by the experience of the respondent. The survey was self-administered online; to address potential misinterpretation of the questions, clear descriptions and examples were included throughout the survey and opportunities were given to comment on ambiguity of individual questions.

There is the potential for self-selection bias, where those who chose to respond to the survey did so because of an already strong opinion about risk management, and others avoided the survey. A preliminary check to avoid a bias in the analysis due to various factors (e.g. industries, roles, project size) was performed for this analysis; extensive statistical analysis to control for these variables was not yet performed.

Although the sample included a diverse mix of product development projects, the statistical findings from this data set are not necessarily generalizable beyond this sample.

Low R^2 and high levels of correlation are generally found in this type of statistical study. This is because there are many interacting processes, capabilities, skills, and other factors contributing to product development. One specific correlation, for example, that between transparency and product development success, is likely to have a high number of covariates. An explanation for this is that if an organization is transparent with their risk management, they are likely also transparent in other processes. It is also possible that an organization that performs one process well, for example risk management, has also reached a level of excellence in the execution of many of their other processes. Therefore it is near impossible to isolate the effect of risk management alone to measure its contribution to product development success. For this reason, a further qualitative investigation of statistical findings is necessary.

4. Phase 2: Qualitative Investigation of Transparency in Risk Management

Informed by the statistical results of the previous chapter, this chapter narrows the scope and describes a qualitative investigation of one particular statistical finding: the role of transparency in product development risk management.

The single best practice which had the highest difference of means between the low performing and high performing projects in the PD Target dimension was "Our Risk Management is transparent and inclusive towards all stakeholders," one of the eleven ISO 31000 principles (ISO 2009b).

The standard *(ISO 2009b)* elaborates further on this principle:

> *Appropriate and timely involvement of stakeholders and, in particular, decision makers at all levels of the organization, ensures that risk management remains relevant and up-to-date. Involvement also allows stakeholders to be properly represented and to have their views taken into account in determining risk criteria*

A stakeholder is defined as "person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity" (ISO 2009c).

The statistical results suggest that there is a correlation between transparency/inclusivity with stakeholders and product development success, but does not indicate causation or provide explanation.

In order to conduct a sufficiently thorough investigation, I decided to focus specifically on transparency of risks and the risk management process in product development. Transparency in this context refers to the honest identification, analysis and reporting of uncertainties, risks and consequences to all stakeholders, regardless of the anticipated effect. Transparency therefore opens risk information and the risk management process itself to scrutiny as well as opportunity for collaboration.

I conducted interviews on the topic of transparency with twelve industry product development practitioners (from eleven different organizations). The aim of the industry interviews was to better understand the relationship between transparency and product development success, and to collect evidence to support the hypothesis that a transparent risk management process leads to improved product development performance.

The qualitative research interview method has been found to be an ideal way to examine topics where different levels of meaning need to be explored (Bouwen et al. 1994), as was the case in this study of transparency.

4.1 Literature on Transparency

Transparency is a popular topic in the academic worlds of monetary policy, international business and corporate governance, but this literature is not particularly relevant to product development.

Some literature has examined the role of transparency in risk management. Papers on the topic of risk management on the internet through transparency (Meijer 2005; Flinn & Stoyles 2004) and in the energy sector (Connors 2005) are not directly relevant because of the context of implementation but share the same general ideas and some vocabulary with this work.

Given our understanding of risk as the effect of uncertainty, where uncertainty can be a lack of information, the literature presented in section 2.1 on the topic of information adequacy is also relevant to transparency. Epistemic uncertainty – where information is lacking because it is not reported - would represent a specific instance of lack of transparency.

This facet of lack of transparency is explored by (Kutsch 2010) in a study of how choices are made on the relevance of risk information. A review of previous work on ignorance and certainty, as well as a taxonomy of ignorance is presented in this paper. The author concludes that traditional project risk management assumes "hyper rationality" of stakeholders and thus ignores aspects of managerial behavior, such as deliberate ignorance, and judgment of relevance. This work specifically explores deliberate ignorance of risks through a qualitative study of IT project managers.

Previously discussed in section 3.1.1, the work of (C. Chapman & S. Ward 2004) is also written on the topic of project management risk management, but the findings are particularly relevant to this discussion of transparency in product development risk management. Best practice in project risk management is said to be concerned with managing "uncertainty that matters in an effective and efficient manner." It also requires the elimination of "dysfunctional 'corporate culture conditions' like 'a blame culture' which fosters inappropriate blame." The authors argue that best practice cannot be achieved without understanding of - their term – risk efficiency and use of cumulative probability distributions to pursue it.

4.1.1 Transparency in product development

Two even smaller groups of literature address transparency in product development processes, and more specifically transparency in product development risk management. This work aims to make a significant contribution to the second group, regarded as an under-addressed research area.

There exists a large body of literature on the topic of information processing with management applications, as presented in the review of (Moorman 1995). This literature is informative and thought-provoking on the subject of transparency however not immediately applicable to transparency of risk management in product development.

In one of the very few instances of transparency in the context of product development, in an investigation of US defense acquisition program performance (Wirthlin 2009), the author identifies five key characteristics the acquisition system values: cost, schedule, performance, transparency and flexibility. This expands on the typical view of product development as a pure cost, schedule, and performance endeavor. The author identifies consensus building and desire for openness as the desirable effects of transparency. However it is pointed out that within the Department of Defense, this transparency comes with burdensome approval and accountability functions. These potential downsides of transparency were considered and addressed in this study's interviews.

In the same industry, a report on the Space-Based Infrared System (SBIRS) High satellite project (United States General Accounting Office 2004) further suggests an appreciation for transparency in defense product development:

> *Prior to the restructuring, the SBIRS High program office exerted no control over requirements changes, leaving many decisions on requirements to its contractors or within lower management levels of the program office. As part of the SBIRS High program restructuring, the Air Force established an advisory program management board to oversee requirements changes. The board's role is to ensure that new requirements are urgent and compelling, that they reflect an appropriate use of funds, and that decisions about requirements are more* ***transparent.***

In their book on project risk management, (D. F. Cooper et al. 2005) suggest that transparency and traceability of risk management decisions is often a requirement established by effective senior management. A case study is presented where increased transparency of risk management was achieved through online sharing of reports and studies to all stakeholders.

(Bendoly & Swink 2007) explore the effect of information (or lack thereof) on project managers' decision-making. The study concludes that greater visibility of situational information impacts project outcomes by affecting the decision maker's actions and perceptions regarding the behavior of others and the priority of the decision maker's task. These findings can be interpreted to suggest that transparency would work via a similar mechanism to impact product development outcomes.

4.1.2 Transparency in product development risk management

A well-integrated risk management process should affect the transparency of the product development process as a whole, and therefore those findings from the literature and presented above in section 4.1.1 apply to the concept of transparency in product development risk management.

(L. Cooper 2003) explores the role of knowledge management systems in product development risk management. Given that transparency means an accessible sharing of information, it would be expected that an improved knowledge management system would have an effect on increasing transparency. There are, however, no publications which specifically address transparency of risk management in the context of product development.

4.2 Method

Interview candidates were identified through mailing lists of professional organizations, the list of survey respondents from the previous chapter, and my professional and academic network. When possible, I used the snow-ball sampling method, whereby interviewees were asked to identify coworkers or contacts that might also be willing to participate.

The twelve interviewees are from eleven organizations, and represent a variety of stakeholders in the product development risk management process. Generalized details of the interview candidates are presented in Table 4-1 below.

Table 4-1: Anonymized identifiers of the twelve interview participants

Industry	Position
Defense	Program Manager
Commercial Aerospace	Engineer
Defense	Lead System Engineer
Air Force	Program Manager
Design Consultancy	Product Designer
Aerospace and Defense	Program Manager
Aerospace and Defense	Product Engineer
Aerospace and Defense	Risk Manager
Commercial Aerospace	Risk Manager
Sporting goods	Product Design Engineer
Telecom	Product Manager
Heavy Commercial Equipment	Engineering Lead

A semi-structured interview process was followed. As is accepted method, I developed a question protocol with alternatives and prompts (Bouwen et al. 1994). I first tested this protocol with three former practitioners, and through a spiral development technique, I selected the following five questions (with additional prompts and alternatives) for in-depth investigation:

1) Who are the stakeholders of the risk management process in your product development project?

2) To what degree is risk management transparent to these stakeholders? What is made transparent?
3) What are the benefits of transparency?
4) What are barriers to transparency? What are the limits of transparency?
5) Does transparency facilitate collaboration? Does transparency facilitate oversight and scrutiny?

All participants were informed that their responses would be made anonymous. Conversations were recorded and later transcribed.

I reviewed the interview transcripts to seek consistent themes and arguments. I extracted supporting quotations and present them with some discussion in the next section.

4.3 Results

Presented in this section are quotations from the interviews, grouped by topic. The quotations, elicited through the questions listed above, have now been sorted according to the following themes: How does transparency lead to better risk management? What minimum organizational characteristics are required for transparency to be effective? What are barriers to transparency? Additional quotations which were not particularly relevant to these questions are included in Appendix C, including a collection of quotations which elaborate on the current state of transparency in industry today.

4.3.1 How does transparency lead to more effective risk management?

There are a number of lenses through which to see the benefits of a transparent risk management system. This broad collection of benefits results not only from the wide array of functional roles which interact with the risk management system, but also the variety of risk management features which could be transparent; not only transparency of risk management results, but also of general risk management strategy, inputs into the risk management system and transparency of true uncertainties being reflected in the risk management process. Transparency of each of these elements individually and combined will lead to different benefits and obstacles, many of which are discussed below.

Shared representations

A transparent risk management process can be the vehicle for the establishment of an accurate shared representation of the uncertainties, risks and consequences in the development project for all project stakeholders. It is a mechanism for getting alignment of the "facts" of what is truly going on in the development process.

In this way, transparency allows engineers, designers and other non-managers to better understand the bird's eye view of the program and thus better understand management decisions and in particular resource allocation.

"[Transparency is important in] getting everyone on the same sheet of what the leadership and what the program really needs to worry about. If my engineers are really worried about burning down the technology risk, but when we all get together and look at it we realize the contract risk is so much higher, I can actually leverage a bit from those tech guys, and go 'don't feel like the leadership is abandoning you if we're spending all our time on contracting risks'."

- Program Manager, Air Force

A lack of transparency of uncertainty and risk on a large project, or from the managerial point-of-view, can lead to unnecessary pressures on the development team and less-than-optimal work planning and execution.

"Part of the problem was that the engineers perceived that there was something wrong that management wouldn't talk about. 6 months before scheduled first flight, it wasn't official. A lot of people thought that they were the only ones in trouble, and they were scrambling to get everything done to meet the deadlines. And then, boom – a delay is announced. And then, boom – another delay. And eventually we end up with a three year delay."

- Engineer, Commercial Aerospace

This shared representation not only helps in the top-down understanding of decisions, but also allows a channel for bottom-up communication of the uncertainties, risks and consequences, from the executers to the managers. Oftentimes there are very functional-specific risks, for example complex technical risks, which are difficult to communicate with management through other traditional processes.

"FMEA is something that's not generally communicated at a high level. And the risk assessment is something that can easily be done at a high managerial level. So when you're giving a program status update, every manager loves their red-yellow-green charts. Generally managers know red 'I cannot proceed until all my reds are gone'. Green is more of an 'I thought this is a risk but they apparently don't believe so.' It's really good from that high-level stand-point. When you throw an FMEA up in front of managers, they generally get glazed-over eyes."

- Engineer Lead, Heavy Commercial Equipment

"I want to know what the product guy thinks his biggest risks are, so that I can help him prioritize. There are never enough resources to do what you need. So as a tester, I want to know what the product development guy thinks the biggest risks are so that I can burn those risks down. If I'm the product development guy, I want my test team to understand what I believe my biggest risks are, because I want them to react to burning down my biggest risks."

- Program Manager, Air Force

The understanding through shared representation aids in team dynamics and motivation. The communication and connection which is made possible through a transparent risk management process allows all members of a team to see progress, focus and effort of the other teams.

"When you get everyone involved and everyone gets skin in the game you might say, they're all stakeholders, and they all know that their effort on the job is important."

- Program Manager, Aerospace and Defense

"[Transparency] really helps out by everyone understanding exactly why we're doing it, the process that we're doing, and what their role and responsibility in that process is. So not only is it transparent because of access but also the roles and responsibilities are clearly defined."

- Program Manager, Aerospace and Defense

"It helps with team cohesion and team dynamics because they understand why certain things are happening around the team that aren't just happening in their stove".

- Program Manager, Air Force

"In being part of the discussion, that process – what could happen, how do we anticipate certain issues – we use a lot of good lessons learned especially from the commercial world where teams got together to solve very technical challenges. It's not something we only think about when we have a meeting. I think the program leadership team think about it probably about 8 o'clock, 10 o'clock, and right after lunch! Because you're trying to minimize the surprises."

- Program Manager, Aerospace and Defense

Access to greater knowledge pool and fresh perspective for assessments and treatments

Transparency is not only important in reporting and assessing the uncertainties and risks within the development team and stakeholders, but often it is industry practice (particularly in the aerospace and defense industry) to bring in an independent oversight or auditing board that pays particular attention to risk. Although not always effectively utilized, transparency with these oversight functions can allow exposure of "fresh eyes" to identify and assess risks, and suggest effective mitigation actions or means of reducing uncertainty.

"We bring independent assessors in at the right times in the program that take an evaluation. Sometimes looking through another set of filters – an independent set – they'll come in and sometimes see something you didn't or have a suggestion on a mitigation."

- Program Manager, Aerospace and Defense

"The risk board is a structured and non-embarrassing way to say 'I need help'"

- Program Manager, Air Force

"The inclusion of diverse opinions, backgrounds, knowledge and experience that comes from full transparency actually enables better risk management in lowering the risk to the program. A few people can't know everything. Everybody is smarter together than a few people are alone. So that inclusion and transparency give you a much more robust and successful risk management for your program activities."

- Engineer, Aerospace and Defense

"The role [audit agencies] play… right now it's a little warped. The role they should play is as a resource to help me, as the leader, find out what I don't know."

- Program Manager, Air Force

With or without an independent oversight function, a transparent risk management process can facilitate organizational learning and effective knowledge transfer within the organization through the sharing of previously used mitigation actions and methods to reduce uncertainty and the occurrence of unanticipated events.

"Opening yourself up for risk management and having nothing to hide does allow criticism. If you're not open about it, you're never going to get help. A lot of guys think it's serendipitous. In a portfolio, everyone wants everyone to succeed. Being transparent in risk management is a way of saying 'look, these are my issues – I'm working them, they're not lying fallow – but any idea you have of moving these would be helpful. It allows your leaders who control resources who may be able to help you. It's a network or systems call for help throughout the stakeholder area."

- Program Manager, Air Force

"It helps out because there could be a risk already in the system, or another team is identifying a risk, and [the development team] can either benchmark off the mitigation plan, learn from it – because we do have a lessons learned database – or they could even say 'wait a minute, I don't want to duplicate this risk, this risk already mitigates the entire risk at hand so what I can probably do is coordinate with the person who is responsible to mitigate that risk so he can include a specific step where I could pretty much sign off and say I'm mitigating this risk.'"

- Risk Manager, Aerospace and Defense

"One of the things that a structured, transparent risk management system, coupled with a lessons learned system, or even organizational knowledge, does is allow access to intellectual resources. A lot of problems that we deal with are not cutting edge, they're something we solved in the 60s and then forgot. Opening up a risk and looking for relevant prior experience is a powerful way to burn down risk. If you're not transparent about it, you're never going to get that".

- Program Manager, Air Force

"At the end of a program, there is always a closure process – one that is required by contract, and one that we do as a company to try to capture that knowledge that you had. But we find that if you wait until the very end to start that process, you miss some opportunity. So at regular points in a program's lifecycle, where we have independent assessment reviews, we'll capture that knowledge and figure out a way to share it across. That's why we have these independent viewers and assessors come in because they'll say 'Have you thought about this – I saw it being done over here' or 'That's a good idea, I want to use it over here.' So the rotations and a lot of the cross-flow of information within the discipline – finance, engineering, program management - really helps transfer that knowledge around before we get to the end of the contract."

- Program Manager, Aerospace and Defense

Another dimension of transparent risk management is in the honest reporting of uncertainties, assessments and consequences passed on throughout the lifecycle, from early research and development to production and sustainment.

"I think it's important to identify those red risks early. There's a case where an incredibly high red risk emerged late in the process. There were advanced technology projects done on those technologies early on, but the risk assessment process was not part of that process at that time. The transparency and the communication of what was done were minimal. By the time it gets into our current product development path, we're essentially starting from scratch. By the time you learned about the risk and reduced the uncertainty, it's already very late in the program, and you don't have much time to fix it."

- Engineer Lead, Heavy Commercial Equipment

Additional benefits of transparent risk management

Transparent risk management will result in a thorough, honest report of the status of the uncertainties and consequences with reference to your objectives. This could lead to improved portfolio and resource allocation decisions.

"Transparency may not necessarily help your project, but it definitely helps the portfolio. Fully transparent risk management allows you to manage the resources better on those projects that are risky but winning, and allows you to cull those that are risky and unwinnable".

- Program Manager, Air Force

"We don't just [identify risks] for visibility purposes - and that's another pushback (one might say 'you already have it in the schedule, why are you going to create a risk to add more visibility') – that's not the case. We're not trying to just get the visibility but also be more aggressive in reaching that objective."

- Risk Manager, Aerospace and Defense

"As a portfolio manager of several programs or projects, with transparency into each one of their risks – if I see a common risk thread between them then I can bring company resources together to solve that one risk for a number of programs."

- Program Manager, Aerospace and Defense

There is also potential for a transparent risk management process, given more access and exposure to the stakeholders of the development project, to aid in the integration of the risk management system with the product development.

"You can't say 'OK, we've designed this program, now bring the risk management guys in and drives my risks down to zero'. It needs to be integrated into the whole thing. Transparency helps with that integration".

- Program Manager, Air Force

In another interesting observation, it was reported that transparency of risk management will allow team members to access and interpret project status and priorities on their own, thus leading to team self-direction.

"If everyone on the team is transparent and knows what's going on, it's easier for the team to self-level. One of the hardest parts about program management is there's only 24 hours in the day. As a single program manager it's very difficult to do everything yourself. You need your guys to understand that. I can see where being transparent in risk management would allow your team to self-direct a little bit to burn down those risks. I don't see why you would not do that".

- Program Manager, Air Force

4.3.2 What minimum organizational characteristics are required for transparency to be effective?

In order to be able to achieve the benefits of transparency, there are certain criteria which must exist. Transparency has a greatly diminished positive impact in the absence of these features.

Access to relevant stakeholders

As is stated in the ISO standard (ISO 2009b), a feature of transparency is "appropriate and timely involvement of stakeholders and, in particular, decision makers at all levels of the organization."

"I really want my end user to understand as much as possible in my world. That is a big barrier. They don't have enough time. I would not keep a risk from them – the barrier I see to that – even if I had the world's perfect risk assessment, with risks as low as possible – getting it into their cross-check, of all the stuff they need to know, is very difficult, because they're not acquisition or program management experts."

- Program Manager, Air Force

"Your ability to be transparent fades with some kind of distance – whether it's communication distance, desk to desk distance".

- Program Manager, Air Force

In order to have true and effective transparency, there should be a mutual understanding of risk management results. Ideal transparency would mean that the risk management results were a true representation of the state of the product development project.

"The management that you're reporting the risk assessments to aren't involved in the process – they see the final product. So you have a lot of control over what color to make a box, who's the champion, and what actions those people will do to go after the risk."

- Engineer Lead, Heavy Commercial Equipment

A just culture

The tools and methods for risk management are based on the assumption that risk identification and assessment are an honest reflection of the product development project. The system depends on each individual stakeholder, with their specific expertise and focus, truthfully informing the rest of the team on their risks and status. As reported in (C. Chapman & S. Ward 2004), if there are adverse consequences to identifying risks, or a "blame culture," a traditional risk management system will not work effectively. Whether in the defense or commercial industry, transparency will be avoided if the information exposed has the potential (or is perceived to have the potential) to reflect poorly on the project manager, individual practitioner or team. Product developers should not be worried about the threat to their personal reputation when honestly identifying and assessing risks.

"There's a timing piece here. If I was a leader and I walked in and realized my culture was bad – we didn't have a just culture – I'm not sure that risk management would be the first thing I'd work on. I'd need to build up the trust in the organization that 'you can tell me that there's a problem and you're not going to be punished for it.' Given a good culture, risk management being transparent: absolutely. Given a bad culture, I think that transparency would not be an on/off switch, I think it would need to be ramped, because people change slowly."

- Program Manager, Air Force

"As soon as you have an inkling that a risk has gotten bigger or your mitigation isn't working, you need to raise the flag. That's why we get paid the extra money – program managers need the moral courage to say 'you know, this ain't working – help'. You get that organizationally by trust. If a guy walks in and finds a problem, and you fire him, then why would you expect the next guy to raise the problem?"

- Program Manager, Air Force

"If you're in an organization where they fire you for saying the truth, your risk management will never work. It's a just culture. The risk management process is a structured way for people to raise their hand and say 'we have a problem here'. So if there's an organizational culture of blame and punishment based on risk management, you're never going to win. You've got to break that."

- Program Manager, Air Force

The decision to be transparent or not should not depend on the anticipated reaction to the honest reporting of information.

"In my mind being fully transparent goes back to confidence. If you're given a project that you know will ultimately fail, transparency becomes problematic at that point, because now you're just advertising your ability to complete the project. If you get personally tied to your project, I can see where an individual project manager would be hesitant to go fully transparent if he had doubts".

- Program manager, Air Force

"He only told me what I needed to know. We focused on our job, and, if the [stuff] hits the fan, it's not on us. There was this cover your tail mentality."

- Engineer, Commercial Aerospace

4.3.3 What are barriers to transparency?

There are a number of reasons why effective transparency may not be achieved at an organization.

Protection of intellectual property and sensitive materials

For many aerospace and defense organizations working with the government, there are strict regulations related to security and information permissions, for example the International Traffic in Arms Regulations (ITAR) regulations.

"One of the big barriers is classification (operational security, technology security). You can't open your risk management to everyone because you don't really want help from the Chinese".

- Program Manager, Air Force

"Besides security – because some risk registers are classified – and also some registers might be ITAR restricted, so somebody on the program might not have the full visibility of the entire risk register... other than that pretty much everyone has transparent access."

- Program Manager, Aerospace and Defense

In the commercial product development sector, Non-Disclosure Agreements are generally employed as an attempt to lessen the barriers to sharing intellectual and proprietary information, but barriers to transparency still exist in industries where large projects are undertaken by teams of (sometimes) competing companies.

"We have non-disclosure agreements with everyone we work with. Not that that's the be-all-and-end-all, but it certainly helps with communication."

- Engineer Lead, Heavy Commercial Equipment

"We do not share internal company profit/risk information with all project stakeholders since some of them are competitors on other projects."

- Project manager, Facilities control system (survey comment)

Avoidance of nonproductive management attention

An often repeated reason for avoiding transparency of risk management, especially between product development executer and management, is to avoid the attention and assistance that is awarded to the executer when a big risk is reported. Rather than additional resources or access to schedule or financial reserves, it was found that the most common response to high risks is increased management attention and increased meetings and milestones.

"[The manager] would have these meetings where there were green-yellow-red charts. You would have systems review, and – everybody was green. Everybody. 'Make it green'. Well when it was obvious that you couldn't be green, you would become red out in the open. Until the end, people were still pushing the 'I don't want to report that I'm doing bad because then I'm going to be micro-managed, management is going to come in and mop the floors, make my life impossible, and not let me do my work.' Not only did you not want to report reality because you were going to get demoted, but also because the way management reacted was 'what do you need', and you got swamped by the bean counters. It was really hard."

- Engineer, Commercial Aerospace

"You generally didn't want to share risks until you were in control of the situation. Managerial type people on the project team were generally avoided as far as risk information. The 'help' [that you get for raising a red risk] is not usually a good thing. It doesn't mean more staff, which would be a good thing. It's usually more meetings, more updates. An example – a colleague is responsible for a component in our current product line and there have been a lot of failures and risk with that component going to production. She gives daily updates with management and she gives at least weekly updates with our internal partners. She's basically come to the conclusion that all she does is update."

- Engineer Lead, Heavy Commercial Equipment

"Another problem with the full transparency of risks is that if you have a longer program, the pace at which you burn down risks – if you don't show any movement over a significant period of time, your transparency is going to attract attention. So when you go fully transparent – and I'm not saying this is a bad thing – you have to be proactive."

- Program Manager, Air Force

"I think there's a lot of value to [increasing management reporting frequency when a risk is being mitigated] – the people who are on the line and accountable for the overall program need to be aware of activities going on towards that risk. So the meetings are important. But the addition of these meetings and these responsibilities are not usually followed with additions to the team. So the person who is responsible for fixing it is generally also the one who is also attending these meetings, because they have the most knowledge. That's where the breakdown is. That person has to be fixated on reporting, and that person ends up spending more hours at work and getting more disgruntled because they get beat up in a meeting, and they have to work late to actually do their job. If it was a case where they added resources, so that somebody could either be reporting and somebody could be working on the problem, then that might make that process work."

- Engineer Lead, Heavy Commercial Equipment

"It can vary depending on the stage of the program. In the early stage, everyone wants to get everything out on the table, whether it's important or not. At later stages, people didn't want the extra 'help', mostly because usually it was not a good 'help'. And so they would really hold back on announcing potential risks until there was a better understanding, or if they had a solution ready to go."

- Engineer Lead, Heavy Commercial Equipment

Limits to stakeholder time and resources

Of course, given that product development is a resource-constrained process, transparency will be impeded by limits to stakeholder time and resources. True transparency does not only require reporting of availability of risk management information, but also the ability of those relevant stakeholders to process that information.

"The other barrier is just time. Even if I was in a totally unclassified environment, I don't have the time to look at everybody else's risk assessments to understand where I can help them and they can help me."

- Program Manager, Air Force

"It's one thing to make yourself transparent, but to be truly transparent you have to have the other people actually look at it. A barrier is - are those resources available to look at it at the right time. I can be transparent – I can put it in the window – but if nobody comes by and comments on it because they're not available... that's the only real barrier. There are only 8 hours in the day and 40 hours in the week to have somebody come look at it."

- Program Manager, Aerospace and Defense

The ISO standard clearly states that "appropriate and timely involvement" is recommended (ISO 2009b). In some instances, limited stakeholder time determines the appropriate degree of involvement in the risk management process.

"I wouldn't necessarily want the whole enterprise doing all of my risk assessment. I consider risk assessment to be a project leadership or project management role, not necessarily a line worker role. I want the risks from them – I want them coming up. I'm not a machinist – if my engineers design something that my machinist can't make, then I want him to raise that technical risk up. I just don't know if every part of every organization needs to know about every risk."

- Program Manager, Air Force

Likely due to limits on stakeholder time and resources, it is common practice to use risk ranking and a top-5 or top-10 cut-off when deciding on which risks to address and mitigate. This trucating of information means that the risk management system is no longer completely transparent since those risks below the cut-off are often no longer monitored or reported-on.

"We prioritize based on the risk settings, so we may actually talk about a top-5 or a top-10 or whatever the program has decided that threshold is going to be. All the information is captured and maintained and updated on a periodic basis, but it's not all equally addressed."

- Engineer, Aerospace and Defense

Warped oversight mentality

If oversight is not well-integrated into the product development process, an "us-versus-them" mentality can be created, discouraging team cohesion and resulting in limited communication and thus lack of transparency. The development team may feel that the oversight team does not have a full view of the process, and will make an uninformed decision on who or what is to blame, without full information.

"[People in the audit role] can't have a career there. You want the guy who was a program manager to take over the oversight function. Not someone who has grown-up in oversight. People who grow up in oversight tend to have a holier-than-though attitude – punishment complex. [...] they really should be experts in the area and not experts in oversight."

- Program Manager, Air Force

"Once you go into crisis mode – when you fess up 'Ok, you got me, I'm red. But I'm red because...' – the finger pointing starts."

- Engineer, Commercial Aerospace

"The best oversight system I've seen is [anonymous] where the guys in the safety office – it was a three year gig, that's it. They came right out of the test squadrons and went into the safety office. They were only there for three years and knew they'd have to go back after that. That was valuable, powerful assistance. A lot of times they caught things that you hadn't thought of. You never thought that you were going there to get beat up, or to pray to the gods of oversight."

- Program Manager, Air Force

"Scrutiny can also be good, as long as it is 'complete' scrutiny. An outsider coming in and examining part of a problem in detail can be damaging."

- Product design engineer, Sporting goods

Other barriers

For many, risk management is viewed as yet another administrative exercise. In these cases, risk identification and assessment can become a formulaic exercise, no longer a true reflection of the actual product development. This will sometimes be the case if the person who is charged with managing the risk management system is not perceived to be in touch with the realities of the development process.

"There are times when an employee will identify a risk but the customer will push back and will say 'I don't think it's a risk because of historical data' or 'yes it's a risk but since we're already managing it with the integrated master schedule. Since we already have a task that needs to be performed in the schedule, we don't need to raise it as a risk.' Yes, it's in the IMS but you need to be more aggressive."

- Risk Manager, Aerospace and Defense

"If your risks aren't moving, why are they not being burned down. Is it because of lack of effort, meaning you're not focused on this risk – well then, is it really a risk? You've shown me a risk, did you just pencil whip it to add... sometimes cultures build up where you have to have five risks. You really only have four but you've got to throw a fifth one out there. So you ask those questions."

- Program Manager, Air Force

"If the person facilitating [risk management] is not part of the project and has no knowledge of [product technology], it is an administrative process."

- Engineer Lead, Heavy Commercial Equipment

4.4 Conclusions from the Industry Interviews

A number of conclusions can be drawn from what was learned through the interviews. To begin with, a greater understanding of the benefits of, requirements for, and barriers to transparency of risk management in product development are known. Additional conclusions are presented below.

4.4.1 Transparent risk management is a key contributor to effective product development

In addition to being an important characteristic of successful risk management in itself, through its effect on information quality and availability, transparency is an assumed requirement for many principles, methods and tools of risk management.

Transparency is only one of the eleven ISO 31000 risk management principles, and so is only one facet of effective risk management. However upon further examination, many of the other principles (see Table 3-2) rely on a transparent risk management process, for example "risk management is based on the best available information" and "risk management is part of decision making" (ISO 2009b).

The linked nature of these concepts was repeatedly expressed in the interviews. The necessity for a "just culture" and thus honest reporting of uncertainties and risks, as well as the shared representation which can be attained from this information, will ensure that risk management is based on the best available information, and lead to better decision making.

Transparency is therefore not only itself a desirable feature of risk management, but is also an enabler of risk management best practices in product development.

Transparency of risk management is beneficial to product development as a means of ensuring there is opportunity for communication and collaboration between the project stakeholders. Risk information tends to be a reflection of those uncertainties which would have the greatest adverse effect on the product development outcomes, and thus those uncertainties which should be most immediately addressed. In many cases, these uncertainties haven't been addressed because they are novel, complex or challenging. Transparency of the risk management system allows all stakeholders the opportunity to work together towards risks, taking advantage of diverse experiences and expertise.

As a vehicle for an accurate shared representation of the current state of the product development project, transparency allows product development teams to better reason about uncertainties, risks and consequences. Transparency is a means of better understanding management decisions, and of aligning efforts towards critical tasks.

4.4.2 Potential to use transparency as an assessment metric of effective risk management

Given that transparency has been reported to be an integral part of effective risk management, it has the potential to be a powerful metric to assess the effectiveness of a product development organization's risk management.

There would be challenges to the measure of this metric; not only should risk management policy be examined (for example: who has access to the risk management reports? who participates in risk identification? etc.) but also the overall project culture regarding the reporting of risks should be assessed. If there is a "blame culture" or other disincentive to report risks and uncertainties, the risk management process may appear transparent when in effect it is not. Further, as discussed, transparency is not simply a matter of all information being disclosed and reported, but in order to achieve full transparency that information must be received and processed by the relevant stakeholder.

Although it would be challenging to assess these cultural and environmental factors, development of a transparency metric would potentially lead to a powerful means of assessing risk management effectiveness.

4.4.3 The multi-disciplinary and technically complex nature of product development introduces challenges to effective transparency

Product development is a complex process. It involves the collaboration of all functions of the organization, including design engineering, finance, marketing, manufacturing, and more. Not only are most projects cross-functional, they will also often involve many hierarchical layers of the organization, from upper-management and strategy to machinists.

Considering that there are uncertainties and risks associated with each of these stakeholders, a thorough risk management process will generate a great deal of information. There are also typically many competing management processes which require the stakeholders' time and attention. Although in an ideal world, all stakeholders would be able to process this information and consider it in their decision-making, in reality time and resources are limited.

The ISO standard suggests that transparency should be demonstrated through "appropriate and timely involvement of stakeholders" (ISO 2009b). Therefore a challenge of transparency in product development risk management is in determining what is appropriate involvement of stakeholders, i.e. who knows how much when.

As an example, if cycle time is short for a commercial product development organization, there is tension between the need to remain transparent throughout the development with the customer and the desire to cut-off transparency with the customer after initial needs elicitation and simply waiting until the next product definition to address new information.

In large projects, involvement, and correspondingly transparency, can be manipulated by certain stakeholders. The risk management system relies on individual stakeholders to honestly report on their areas of focus and expertise. Management may not be particularly technical, or privy to each and every detail, and therefore employees have the power to bias the interpretation of risk management results, leading to a lack of true transparency.

The degree of appropriate involvement for various stakeholders is sometimes deemed the responsibility of the project manager, or if it exists, the risk management function. Given the multi-disciplinary and complex nature of product development, this can be a challenging role. This person must be perceived to have a reasonable grasp in each of the disciplines in order to judge what is appropriate. He or she should also have a thorough understanding of the project itself in order to be able to detect biased information (explaining why the project manager is often charged with risk management).

4.4.4 A better reaction to high impact risk identification is needed

The quotations presented previously reflect the contrasting view of transparency in risk identification. One argument is that transparency regarding uncertainties and risks is good because you are able to seek the help of others, and better inform the other stakeholders of the true state of the project. The opposing view is that transparency regarding identified uncertainties, and in particular risks and consequences, is not good because it is not constructive help that you receive from senior management, but rather increased scrutiny, increased administrative and reporting duties, and ultimately you are left with less time and resources to tackle the risk that you have identified.

An effective risk management strategy must exist to incentivize honest reporting of risk, and effectively shift resources and "help" those who have identified high impact risks. Conventional management wisdom is to increase the frequency of meetings to increase the rate of information flow and enable rapid completion of tasks (Ulrich & Eppinger 2008). When these meetings are not intra-team but rather up the management chain, the increased information flow is not necessarily productive.

Interviewees expressed that in industry today, it does not appear that risk management results influence resource allocation. Therefore when a "red" risk is discovered, it is rare that additional staff or resources are provided to mitigate the risk and report to increasingly watchful management.

If the organization as a whole has an understanding of risk as "the effect of uncertainty on objectives" then the burden of action following the identification of risks will shift from that of blame to one of aggressively tackling inevitable uncertainty. It is understood that resources are required to mitigate risks to decrease the uncertainty or lessen the effect of the uncertainty on product development outcomes. Therefore when a "red" risk is identified, resources are deployed to address this risk, including accommodation for increased reporting expectations.

There is a clear need for a better reaction to high impact risk identification in order to clear barriers to transparency and therefore achieve effective risk management in product development.

4.4.5 Agreement with previous studies

Agreeing with the work of (Bendoly & Swink 2007) was the finding that a benefit of transparency is a shared representation and thus a better understanding of others' decisions and priorities.

As discussed by (Kutsch 2010), this study found that there are managerial and behavioral barriers to transparency, and thus risk identification and assessment is not likely to be perfectly rational.

This work found that a requirement for transparency and effective risk management is a just culture, which agrees with the arguments of (C. Chapman & S. Ward 2004), which emphasizes the elimination of "dysfunctional 'corporate culture conditions' like 'a blame culture' which fosters inappropriate blame."

4.5 Limitations

Some limitations should be considered when interpreting the results presented in the previously section.

There is the potential for self-selection bias, where those who agreed to participate in the interviews did so because of an already strong opinion about risk management or transparency.

The interviews were only conducted for one hour, and thus it was not possible to completely exhaust the entire area of transparency of risk management in product development. It is therefore possible that some information was omitted and a complete view of the topic was not achieved.

Although every effort was made to anticipate a variety of answers and thus prompts and alternatives were prepared, there is potential for some the questions to not effectively span the space of views, and thus some aspect of this topic was overlooked.

Every effort was made to avoid bias in the responses via the manner and order in which the questions were asked. The interview depends on self-reported observations, experiences and outcomes. It is possible that due to poor memory or other reasons, the interviewee was not able to recollect project details with complete accuracy.

Please also see the limitations of section 3.6 regarding the potential effect of un-captured covariates.

5. Conclusions

5.1 Overview

Risk management has become a common practice in product development organizations, often with its own dedicated function and staff. There is evidence in the literature to support the idea that effective risk management leads to improved product development outcomes, and this work has added to this evidence.

Of the 170 practices from the literature tested, 36 best practices in product development risk management were identified through the analysis of a survey of over 200 product development practitioners. The best practices in these categories show strong evidence not only for achieving effective risk management, but also the ability to positively affect overall project stability and the achievement of the project cost, schedule, performance and customer satisfaction targets. All eleven of the ISO 31000:2009 Risk Management Standard principles (ISO 2009b) were found to be best practices of product development risk management, suggesting the standard is applicable to product development.

The practice with the highest correlation with product development success was found to be one of the eleven ISO 31000 principles: "risk management is transparent and inclusive". The observed correlation between transparency and product development success was qualitatively validated through twelve semi-structured interviews with product development practitioners from industry.

Transparency was found to be an essential feature of product development risk management. Transparency of risk management is beneficial to product development in many ways: it is a vehicle for an accurate shared representation of the current state of the product development project; it facilitates stakeholder collaboration; it is a means of aligning efforts towards critical tasks. Requirements for and barriers to transparency were also explored.

5.2 Discussion

Other specific dimensions of risk management need to be further studied

The empirical correlations presented in this work are informative and suggest actionable findings. However it is important to remember that these statistical correlations do not necessarily indicate causation.

The investigation of transparency validates the statistical findings, and deepens our understanding of the relationship between transparency of risk management and product development performance. We now better understand the mechanisms by which transparency works, the requirements for transparency, and the barriers to transparency.

The risk management principles in the ISO 31000 standard, although high-level, appear to be applicable to product development, and correlated with product development success. With qualitative validation, this result would be much more powerful. Validation of the applicability of the ISO standard would encourage industry-wide standardization of risk management processes, thus encouraging the development of new tools and methods.

Risk management should be grounded in the concept of uncertainty

Early in this thesis we defined risk as "the effect of uncertainty on objectives," the same definition presented by the ISO 3100 standard (ISO 2009b). However when examining the risk management practices from the literature and common in industry (thus included in the survey), there is little reference to uncertainty or objectives. In the interviews with industry practitioners, risk was almost universally seen as the result of poor engineering, poor planning or poor management, and thus identifying or "owning" risks can be seen as a negative thing. A great deal of the discussion surrounding barriers to transparency focused on blame and responsibility for risks.

The requirements for transparency discussed previously in chapter 4 are non-trivial. In particular, the shift away from a "blame culture" and towards a "just culture" is a challenging undertaking. This blame would be avoided through a strict interpretation of the definition of risk, and therefore objective risk mitigation. There are uncertainties, which we try to anticipate, but are not always able to. We care about uncertainties when they have the potential to affect product development objectives, which should be unambiguous.

In this interpretation, many of the tools of product design and engineering are in effect risk management techniques, for example prototyping, detailed engineering drawings, re-use of existing components, design of a flexible architecture, postponement building. The goal of each of those exercises is to reduce either uncertainty or an adverse consequence.

Knowing that uncertainties are epistemic or aleatory, and that these uncertainties should be treated differently (by frequentist methods, for example Monte Carlo simulation, and by Bayesian probability combined with expert opinion, respectively) we can better mitigate identified risks.

Risk-driven design (Oehmen & Seering 2011; Bassler 2011) is a young methodology which could prove to re-focus risk management in product design on the effect of uncertainty. (C. Chapman & S. Ward 2004) have developed a concept for project risk management based on a definition of risk that is similar to that of (ISO 2009b). The application of their "risk efficiency" and probabilistic tool is a promising opportunity to conduct risk management that is grounded in the concept of uncertainty.

The nature of traditional risk management techniques is not structured to benefit from transparency

In the fourth chapter, we discussed a number of benefits to product development risk management that are achieved through transparency. The benefits are based on the assumption that information on uncertainties, risks and consequences exists, and this information is what is communicated through the transparency. However, this does not appear to be the case in industry today.

Based on evidence from the survey and confirmed in the interviews, it appears that there are certain risk management techniques which are near universal in industry today:

Risk identification is performed at the beginning of the project through team brainstorming. Risks are qualitatively assessed on a low-medium-high scale for impact and probability. These scores are mapped to a 3x3 square, with low scores indicated in green, medium in yellow, and high by red. These red-yellow-green scores are typically all that is monitored and reported by product development managers. There is then a pareto-like focus on either all risks which are red, or else the top 5 or top 10 risks measured by the product of impact and probability scores.

This one time (but thorough) risk identification and subsequent filtering of information, from identified risks with real impacts and probabilities to a short list of risks on a 3-point scale, is counter to fundamental transparency. The pressures of limited resources and competing management processes encourage this filtering and automating, but at the expense of transparency.

Given the uncertainty and complexity of product development, in order to achieve the benefits of a shared representation and collaboration through transparency, risk management information should be reported, shared and monitored in a greater level of detail.

Alternatives to the now common risk management techniques presented above should be explored. Risk information reported as a balance between over-filtered 3-point status information and detailed uncertainty and consequence assessments would allow greater benefits to be reached through transparency.

5.3 Suggestions for Future Work

Opportunities for future work are briefly described in this section.

5.3.1 Further survey statistical analysis

With such a large data set, there is a great deal of statistical analysis which can still be performed. (Forza 2002) discusses numerous statistical methods for analyzing survey data. Through exploratory methods, it is likely that deeper understanding of risk management and product development phenomena could be achieved by a principal component or clustering analysis. A test of associations would also be informative in identifying relationships between risk management characteristics and product development outcomes.

5.3.2 Stability

One of the four performance dimensions explored in Chapter 0, stability is a term that is often used in the context of product development. In preliminary interviews, this term was found to have a great deal of different meanings. For some, stability is seen as the exogenous budget and priority of the project. For others, it represents the internal perturbations in the development plan, and occurrence of unexpected events.

The concept of stability is briefly addressed by (Wynn et al. 2011) in their discussion of the evolution of uncertainty levels during design. They suggest that instability is an instance of context-uncertainty. Unstable descriptions of a model are said to be more likely to change, and therefore stability can influence how designers approach their tasks. A designer might be more likely to spend little time on the task if they think the input information is unstable. In this case, iterations will need to be frequent and numerous.

The survey analysis provides evidence to suggest that project stability can be improved by a "dynamic, iterative and responsive to change" (ISO 2009b) risk management system.

ISO 31000 defines this principle as:

> *Risk management continually senses and responds to change. As external and internal events occur, context and knowledge change, monitoring and review of risks take place, new risks emerge, some change, and others disappear.*

This description certainly appears to align with the definition of stability. However further research is required to confirm this finding, and to decide if risk management effects project stability, and further, if stability leads to more effective achievement of product development objectives.

An additional question to consider is what a practical measure of stability would be. Design specifications or customer requirements are two potential indicators, and could be tracked throughout the life of a project.

5.3.3 Specifications/customer requirements change

In analyzing the survey responses about risk impact and frequency of occurrence (plotted in Figure 5-1 below), the top three specific risks which account for the most risk loss were:

1) Supplier failure causes development delays, cost overruns or quality problems
2) Unrealistic objectives regarding cost, schedule or performance are set
3) Customers or stakeholders change or extend requirements or their priority

Academic research exists to address supplier risk management as well as optimal target setting. There are also accepted methods for requirements elicitation and establishment. There is very little literature or methods to address the occurrence of customer or stakeholders changing or extending their requirements or priority.

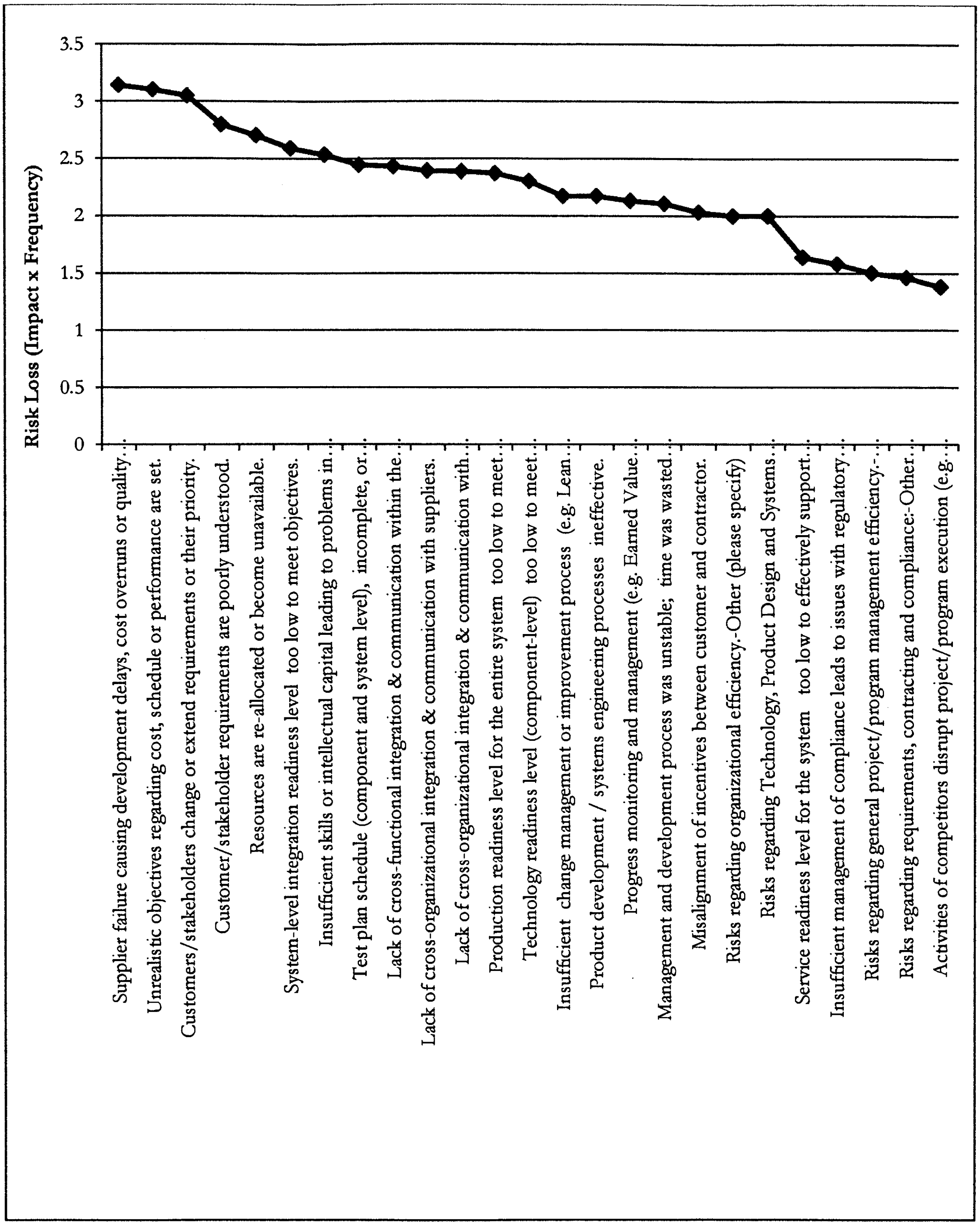

Figure 5-1: Average risk loss as calculated in section 3.3.2 for each individual risk addressed in the survey, based on 127 responses. See full survey in Appendix D for the complete descriptor of each risk.

Given that approximately half of the survey respondents were in the aerospace and defense industry, where projects are typically contracted and therefore customers have a great deal more influence to change requirements, I wondered if those responses were the reason for the high risk loss score. However, as seen below in Figure 5-2, the consumer customer and contract customer project responses follow the same trend.

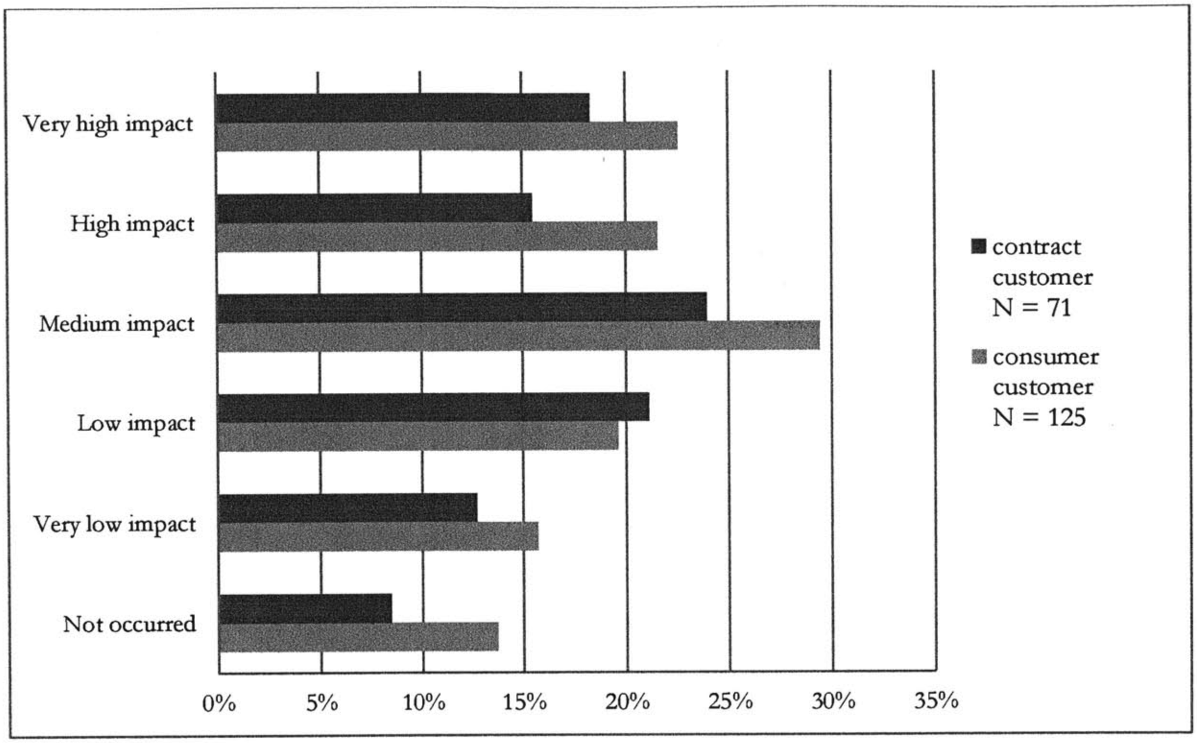

Figure 5-2: Percentage breakdown of responses regarding the risk "customer/stakeholders change or extend requirements or their priority."

This figure confirms that changing customer requirements or priorities is a real risk faced by product development organizations in industry.

I posit that a risk management perspective provides insight on setting and managing product specifications in large-scale complex product development projects.

Best practices from the development team with regards to quality of information can be applied to risk management, specifically filling the void of best practices for ISO Principle "risk management is based on the best available information". This principle states that:

> *The inputs to the process of managing risk are based on information sources such as historical data, experience, stakeholder feedback, observation, forecasts and expert judgment. However, decision makers should inform themselves of, and should take into account, any limitations of the data or modeling used or the possibility of divergence among experts.*

I argue that in product development, this principle is achieved (or there is the potential to achieve this principle) through the setting and managing of the product specifications by the development team themselves. Although not explicitly risk management, this practice can serve the purpose of effectively managing product risk.

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Appendices

Contents

A. Tables of Statistical Results

Table A-1: Test statistics (p-value) of Mann-Whitney U and T-tests, or Chi Square test (whichever is appropriate given the data type) for 36 best practices. Dark grey indicates a p-value greater than 0.05 (5%) and light grey indicates a p-value between 0.01 and 0.05 (1 -5%).

	Characteristic	Test	Test Statistic			
			Mindset	Satisf.	Stability	Target
1	Our employees are motivated to perform/implement risk management.	M-W	0.000	0.000	0.000	0.001
		T	0.000	0.000	0.000	0.000
2	Our risk management has available, qualified experts to help implement the processes.	M-W	0.000	0.000	0.000	0.002
		T	0.000	0.000	0.000	0.002
3	There are sufficient resources and personnel to conduct risk management.	M-W	0.000	0.000	0.000	0.009
		T	0.000	0.000	0.000	0.007
4	Our risk management explicitly addresses uncertainty.	M-W	0.000	0.000	0.000	0.027
		T	0.000	0.000	0.000	0.032
5	Our risk management is systematic, structured and timely.	M-W	0.000	0.000	0.000	0.009
		T	0.000	0.000	0.000	0.010
6	Our risk management is based on the best available information.	M-W	0.000	0.000	0.000	0.060
		T	0.000	0.000	0.000	0.052
7	Our risk management is tailored to specific program/project needs.	M-W	0.000	0.000	0.000	0.006
		T	0.000	0.000	0.000	0.007
8	Our risk management takes human and cultural factors into account.	M-W	0.000	0.000	0.000	0.002
		T	0.000	0.000	0.000	0.001
9	Our risk management is transparent and inclusive towards all stakeholders.	M-W	0.000	0.000	0.000	0.000
		T	0.000	0.000	0.000	0.000
10	Our risk management is dynamic, iterative and responsive to change.	M-W	0.000	0.000	0.000	0.036
		T	0.000	0.000	0.000	0.047
11	We coordinate and integrate risk management activities of different functions and across the hierarchy.	M-W	0.000	0.000	0.000	0.176
		T	0.000	0.000	0.000	0.161
12	Risk management is integrated with higher-level risk management process.	M-W	0.000	0.005	0.011	0.026
		T	0.000	0.005	0.010	0.022

Table A-2: Test statistics (p-value) of Mann-Whitney U and T-tests, or Chi Square test (whichever is appropriate given the data type) for 36 best practices. Dark grey indicates a p-value greater than 0.05 (5%) and light grey indicates a p-value between 0.01 and 0.05 (1 -5%) (continued).

	Characteristic	Test	Test Statistic: Mindset	Satisf.	Stability	Target
13	The risk management process is effectively integrated with other project/program management processes.	M-W	0.000	0.000	0.000	0.001
		T	0.000	0.000	0.000	0.001
14	Risk management teams are cross-functional and cross-organizational.	M-W	0.000	0.000	0.020	0.060
		T	0.000	0.000	0.021	0.056
15	Assessment of risk on scales, e.g. 1-5 scale for probability and impact.	M-W	0.025	0.010	0.035	0.355
		T	0.074	0.008	0.028	0.745
16	Make go/no-go decisions based on risk assessment.	M-W	0.000	0.000	0.003	0.206
		T	0.000	0.000	0.002	0.189
17	Resources are allocated to reduce largest risks as early as possible.	M-W	0.000	0.000	0.000	0.001
		T	0.000	0.000	0.000	0.001
18	Risk assessments are used to set more 'realistic' or 'achievable' objectives.	M-W	0.000	0.000	0.000	0.002
		T	0.000	0.000	0.000	0.002
19	Forecasts and projections (e.g. cost, schedule, performance) are adjusted based on risk assessment.	M-W	0.000	0.000	0.001	0.036
		T	0.000	0.000	0.001	0.030
20	The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs.	M-W	0.000	0.000	0.000	0.106
		T	0.000	0.000	0.000	0.098
21	Decisions are made based on risk-benefit trade-offs, e.g. larger risks are only acceptable for significant expected benefits.	M-W	0.001	0.000	0.002	0.097
		T	0.001	0.000	0.001	0.081
22	Risk-benefit trade-offs are used systematically to favor 'low risk - high benefit' options and eliminate 'high risk - low benefit' options.	M-W	0.000	0.001	0.005	0.016
		T	0.000	0.001	0.003	0.011
23	Contracts are derived from detailed cost risk assessments.	M-W	0.000	0.000	0.026	0.002
		T	0.000	0.000	0.022	0.002
24	Self-assessments, continuous improvement and implementation of best practices (e.g. Six Sigma, Kaizen) were used	M-W	0.000	0.019	0.004	0.256
		T	0.000	0.017	0.003	0.316

Table A-3: Test statistics (p-value) of Mann-Whitney U and T-tests, or Chi Square test (whichever is appropriate given the data type) for 36 best practices. Dark grey indicates a p-value greater than 0.05 (5%) and light grey indicates a p-value between 0.01 and 0.05 (1 -5%) (continued).

	Characteristic	Test	Test Statistic			
			Mindset	Satisf.	Stability	Target
25	Standard work or "standard processes" were defined to increase process reliability	M-W	0.012	0.009	0.012	0.085
		T	0.017	0.009	0.014	0.103
26	Risks were escalated to senior management according to guidelines.	M-W	0.001	0.000	0.000	0.929
		T	0.002	0.000	0.000	0.798
27	Risk were regularly re-assessed according to guidelines, e.g. after specific events or after a certain time interval.	M-W	0.000	0.000	0.005	0.505
		T	0.000	0.000	0.005	0.457
28	The risk management process was regularly reviewed and improved.	M-W	0.000	0.000	0.001	0.083
		T	0.000	0.000	0.000	0.094
29	A formal feedback system was used to monitor the execution of risk mitigation actions.	M-W	0.000	0.000	0.001	0.626
		T	0.000	0.000	0.002	0.615
30	An early warning system was used to track critical risks and decide on activating mitigation measures.	M-W	0.001	0.002	0.008	0.387
		T	0.001	0.002	0.008	0.659
31	Risk management creates and protects value.	M-W	0.000	0.000	0.008	0.017
		T	0.000	0.000	0.014	0.013
32	Risk management is an integral part of all organizational processes.	M-W	0.000	0.000	0.001	0.010
		T	0.000	0.000	0.001	0.005
33	Risk management is central part of decision making.	M-W	0.000	0.000	0.011	0.307
		T	0.000	0.000	0.003	0.257
34	Risk management facilitates continuous improvement in the organization.	M-W	0.000	0.000	0.002	0.034
		T	0.000	0.000	0.003	0.030
35	Risks and risk management activities are communicated to stakeholders (including management).	Chi	0.011	0.004	0.002	0.152
36	Before use, potential risk mitigation actions are evaluated to assess reduction of impact they would achieve	Chi	0.021	0.006	0.596	0.755

B. Phase 0: Immersion in Industry - Singapore

a. Motivation

As an exercise of immersion in industry, the author spent three months in Singapore meeting with industry practitioners from a variety of product development organizations. Through this experience, the author was calibrated on the reality of product development practice in industry: the differences between large companies and small companies, contract companies and customer-facing companies, and the degree to which academic work and industry practice are aligned. This experience was also an opportunity to explore current risk management best practices in product development.

b. Method

Interviews were conducted on the topic of product development with two separate groups: five Multi-National Corporations (MNCs) and six Small-Medium Enterprises (SMEs). The interviews were conducted in a semi-structured manner, and thus responses were not limited to a strict interpretation of the questions, and elaboration and interviewee-instigated discussion was encouraged.

Connecting with industry in Singapore

The interviews were conducted while the author was in Singapore as a visitor at the Singapore University of Technology and Design (SUTD).

To gain an overall view of the types of activities and companies doing product design and development work in Singapore, initial research was done through exploring company websites, investor information, corporate profiles, job openings and press releases. A number of companies were identified as being valuable to an understanding of the product development landscape in Singapore.

A two-pronged approach for connecting to companies was pursued: through the existing professional network of the industry liaison person at SUTD, and through Singapore government agencies. Rather than directly contact companies, I first approached Singapore government agencies for discussions. We met with five agencies through already existing SUTD contacts. At each of these agency meetings, I asked for a contact at anywhere from one to five companies. The snow-ball sampling method was employed for identifying further interviewees within the same organization, where the initial interview subject was asked to identify appropriate co-workers for further discussion. This resulted in a more comprehensive view of the organization.

c. Results

Table B-1 below presents general characteristics of the companies and practitioners interviewed.

Table B-1: Descriptors of companies and practitioners interviewed

	Company Type	2011 Revenue (USD)	Persons Interviewed
Multi-National Corporations	Information Technology (Printers and Accessories)	$120 bil	Design Strategist, Industrial Design Strategist
	Computer Technology	$60 bil	Program Manager, Experience Designer
	Commercial Aerospace	$60 bil	Project Leader, Research Team Leader
	Home Appliance	$100 bil	Design Director
	Product Design Service	Unknown	Director
Small-Medium Enterprises	Product Design Consultancy	Unknown	General Manager, Client Relations Manager, Account Manager
	Electrical and Household Appliances	$440 mil	Chief Technology Officer
	Product Design Consultancy	Unknown	Design Director, Engineering Manager
	Product Development Contractor	Unknown	Design Director
	Engineering and Manufacturing Contractor	Unknown	General Manager, Director, Engineer
	Laboratory Furniture and Healthcare Products	Unknown	Director

Use of product development processes

It was not surprising to see that most large product development organizations follow a variation of the conventional stage-gate development process, whether it is called a product development process, development roadmap, or product life-cycle process.

These large organizations must organize a large, globally located development team. The organizations face a highly competitive global market, and thus face time and budget pressures. They have well defined product platforms and tackle multiple product development projects at once. There can be a benefit to knowledge sharing across projects.

A structured product development process, and the standardization that comes along with it, can lead to improved efficiency, knowledge transfer, decision making and resource allocation (Rupani 2011).

The Small-Medium Enterprises with which product development process was discussed did not follow formalized product development processes. There were a number of reasons cited for this lack of formality: there is not enough time to formalize the ad-hoc process they follow; their small size means there are no economies of scale or efficiencies to be gained through standardization; standardization is best suited for iterative innovation and not applicable to projects involving new technologies; standardization and formalization will suppress creativity and innovation; standardization brings with it administrative and burdensome paperwork.

There is however a difference between company-client (design firm) and market-client organizations, even at the Multi-National scale, but especially at the Small-Medium Enterprise scale. Design consultancies and contract designers explained that they did not see a need to standardize their process, since it was frequently necessary as part of the project contract to follow the design process as stipulated by the client. In this way, the client is able to better track the progress of the project. When the client did not force the design firm to follow a process, it was common for the company to follow, at a high-level, the general stage-gate design process. In this case, check-in points with the client would coincide with gate-reviews. These firms tended to use structured methods, but not necessarily in a consistent or standardized way.

The author met with a number of "creative" design practitioners, for example, industrial designers, experience designers, brand designers and next generation (insight) designers. These practitioners play a key role in the product development process, but are often a separate siloed function at the large multi-nationals we encountered. These designers, whether they were part of a specific design group at a large Multi-National, or a key designer at a small design firm, tended to resist a standard design process, citing a trade-off between standardization and creativity. It is interesting to note, however, that the "creative" design teams at two of the Multi-Nationals studied were both undertaking a project to create a formalized corporate process to capture the early-stages and creative aspects of the design process.

Risk management

Small-Medium Enterprises and Multi-National Corporations again differ on the degree to which risk management was performed, whether formally or informally.

The Multi-National Corporations followed some form of the typical risk management process (identification, assess, analyze, evaluate, mitigate). Once risks are identified through brainstorming, most organizations assess risks with a red-yellow-green rating for impact and probability.

The computer technology multi-national follows a slightly different risk identification technique. In this process, those items that are new, unique, different or difficult about the specific product are identified and tracked. These "NUDD"s are then treated as risks in a typical risk management process.

This NUDD system also influenced the product development process itself. If a small enough number of NUDDs was identified, the first two stages of the product development process were combined.

The R&D team at a large Aerospace and Defense corporation explained their use of Technology Readiness Levels (TRLs) as a means of risk management. These levels make explicit the maturity of the technology for better information quality and less uncertainty surrounding technology performance and system integration.

The Small-Medium Enterprises interviewed acknowledged that they do not explicitly perform structured risk management. In some cases, it was again explained that there was not enough time or resources for an additional process and ongoing management of that process.

Those Small-Medium Enterprises which were design firms or company-client contractors repeatedly explained that risks were the customer's concern, and are not addressed in any internal way in their organization. This reflects a narrow view of the benefits of risk management.

Many of the small organizations interviewed rightly noted that a product development process, with frequent milestones and gates, is a certain form of risk management, providing some control to the development process.

d. Conclusions

Through immersion in the product development industry, I was able to better understand the reality of product development in a variety of organizations. Differences in uptake of formal product development processes were discovered between large and small corporations. The processes and attitudes of design firms with company-clients differed from those market-facing companies who perform their design and development internally. Risk management is practiced by large Multi-National Corporations but has not yet been pursued by smaller firms, for a variety of reasons, paramount being a lack of manpower and resources to manage this process. With such a large number of roles and functions within the organization participating in product development, it is not surprising that there exist different views within the same organization on the topics of process value, formality of process and methods, and obstacles in adopting certain processes.

A better understanding of the practicalities of product development in industry was achieved, and is valuable in interpreting the results of the next sections as well as in discussing these results with industry practitioners.

C. Additional Interview Quotations

The following are quotations which were captured in the interviews but not directly relevant to the questions explored in Chapter 0. The first set address the question: To what degree is risk management in product development transparent in industry today?

Intra-development team

It appears to be general practice to have all risk management processes and results available to all members of the product development team. If transparency is lacking across functions, it does not appear to be intentional.

"I think internal transparency is critical. Planning among teams in your own organization is critical."

- Product Design Engineer, Sporting goods

"There's no downside – as a matter of fact it's good to be transparent and to have a robust system that everyone can access, with the exception that you belong to the program. You don't want to give access to someone who doesn't belong to the program because of security purposes, there are some things that are confidential."

- Risk Manager, Aerospace and Defense

"I'm not being biased. I see who is in the tool, who is identifying risk, and I can tell you every department that supports [the program] has at least a risk in the system."

- Risk Manager, Aerospace and Defense

"If I think about functional direction, a lot of times it didn't even occur to us to speak about risks that did not seem to matter to their function. For example, electronics, software, etc. Although risk assessments were formally shared across functions, individually as you uncover something, you may or may not choose to communicate that to other functions."

- Engineer Lead, Heavy Commercial Equipment

In some organizations, all employees are trained in the risk management policy, facilitating transparency through an understanding of processes and roles.

"Every employee who has technical or management content on a program gets trained in risk. Finance... even contractors get trained on risk. Everybody gets a minimum of awareness, and it builds from there based on their role. The PM is going to have an extensive understanding of risk management."

- Program Manager, Aerospace and Defense

Customer

The relationship between the organization and the customer regarding risk management is complex. In aerospace and defense, full transparency with the customer is often mandated.

"I have a counter-part: the customer also has a risk manager and we're in constant communication. Everything is transparent. New risks or risks that are to be closed must be reviewed by him and I."

- Risk Manager, Aerospace and Defense

"Our program risk review tool – the customer has access to that. They have access to the reports, the characterization of the risks, the mitigation plan, and the costs to mitigate."

- Risk Manager, Aerospace and Defense

However some organizations will keep two separate risk catalogs, therefore reducing the transparency of the complete risk management system to the customer.

"For example [of an internal risk that is not shared with the customer] something that doesn't concern the customer, whether it's staffing, having enough personnel to conduct the testing... things that do not impact the government, we try to keep them internal. For example in the production line, a risk is probably something that we can take care of and there is no need to alarm the customer."

- Risk Manager, Aerospace and Defense

Supplier

There are differing views on the degree of transparency with the supplier. In some cases, intense communication and transparency are sought in order to improve collaboration and information sharing. For other organizations, there is a desire for transparency with the customer from an oversight and monitoring point-of-view, without the intention of collaboration.

"The company managed to send engineers on site, so to one of our partners in [country], we sent over a hundred engineers to oversee the processes and help. Rather than doing the lobbying and waiting game, it was daily communications with your people on site, we had people from the partners at [our company]. I really think that should have been done earlier."

- Engineer, Commercial Aerospace

"You don't always want to let your supplier know that you don't have faith or are planning an alternative ('external transparency'). They may get lazy or offended."

- Product Design Engineer, Sporting goods

Additional Miscellaneous Quotations

"Since we have the customer who is watching us, and helping us, and coordinating all activities with us, and because we're so dependent on contracts. If we don't execute to contract, we're not going to get awarded a second contract."

- Risk Manager, Aerospace and Defense

"[Commercial customers] look at risk not exactly the same way the DoD does, but they still look at risk. The company looks at reputation risk, risk of damaging future business, and that's more at the corporate level. And that's not exactly transparent to the people on the program or projects, from that perspective. There's a layer."

- Program Manager, Aerospace and Defense

"When you competitively bid things, as the project manager, you're handed this thing and told 'go execute this now' and the first thing you ask is 'OK, how much did we bid? Ok we negotiated for this much.' And right there is a big risk. And then you go look at the assumptions that were made in the proposal."

- Program Manager, Aerospace and Defense

"I'm dealing with programs that are early enough that our production dates are far enough out that you don't usually get 'help' [when you identify red risks]. One of the risk assessments I did a few weeks ago was for a technology that we've only tested once. We had an incredible number of red risks but it didn't really raise a lot of flags with people because it's just uncertainty – nobody knows – we don't know if it's going to impact this other system because we're never tested it before. So we're not getting any extra money for testing, we're not getting any management people reigning down on us, even though we have 20 red items."

- Engineer Lead, Heavy Commercial Equipment

"Just think about the difference associated with launching a satellite the way NASA does versus the risk associated with changing a mirror on a car. If I'm going to highlight a lot of risks in changing that mirror, I shouldn't be working for that auto company. [At NASA] if I don't, they don't want me working for them."

- Engineer, Aerospace and Defense

"The only times I've ever seen a failure to disclose a risk is normally a failure of imagination. There's nobody hiding a risk. If I found out somebody was doing that, I'd fire them in a heartbeat. But that's the culture of the military."

- Program Manager, Air Force

"One of the things I learned in flight test is that you need to put it in [end users] language. You can't tell them that there's a contract risk. It doesn't make any sense to them. You need to tell them 'I need your ideas to keep this as inexpensive as possible so that you can have more of them'. You need to phrase it in non-acquisition speak, non program management speak. The ability to tell that story to the end user is really critical. That's where communication skills pay off in spades."

- Program Manager, Air Force

"We know that a lot of people working in the company know the user because they were the user last year. So there's an informal way to get feedback and understand what risks are that way."

- Program Manager, Aerospace and Defense

D. Risk Management Survey

The online survey is reproduced in full in Figure D-1 to Figure D-22.

Risk Management Benchmarking Survey

MIT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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-KFUPM Center in collaboration with the Air Force Institute of Technology and Futron.

Direct benefit 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

Benefit 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 2604
Mail: Massachusetts Institute of Technology, Room 3-471, 77 Massachusetts Avenue, Cambridge, MA 02139

Q1.3. **This survey was developed by:**

MIT LAI ENABLING ENTERPRISE EXCELLENCE Futron AFIT

Q1.5. **This survey is supported by:**

INCOSE Risk Management Working Group

RiskSIG® "Advancing the State of the Art" Risk Management Specific Interest Group

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Figure D-1: First page of survey

Risk Management Benchmarking Survey

Q1.7. Program/project selection and structure of the survey

Q1.8. During this survey, we will ask questions regarding risks, risk management practices and the success of risk management in projects and programs.

For the purpose of this survey, we follow the definitions and guidance of the ISO 31000 standard. Risk is defined as the effect of uncertainties on objectives; risk management is defined as coordinated activities to direct and control an organization with regard to risk.

When you answer the questions, we ask you to observe the following rules:

- Please pick **one program or project** to use as a reference when answering the questions.
- Always use this one program/project as a **reference for all questions**.
- Please choose a **program/project with a focus on development** (not only production).
- Please choose the development program/project that **was finished most recently**, if possible within the last 6 months.

If you cannot or wish not to answer a question, please leave the answer blank.

The survey consists of four parts, as shown below:

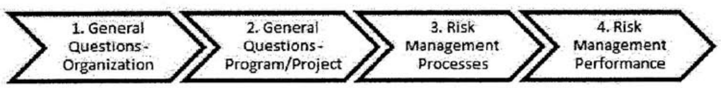

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Figure D-2: Survey – General Questions on your organization

Risk Management Benchmarking Survey

MIT MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Q1.10. General Questions on Your Organization
Please provide some information about your organization and yourself.

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

Q1.12. What type of organization do you work for?

- Government organization
- Company
- Non-profit organization

Q1.13. What is the yearly budget of your company or government equivalent?

- Less than $1 million
- $1 - $10 million
- $10 - $100 million
- $100 million - $1 billion
- $1 billion - $10 billion
- more than $10 billion

Q1.14. What area best describes your role during the program or project?

- General program/project management
- Planning, bidding, contracting
- Technology development, R&D
- Product design, systems engineering
- Dedicated risk management function
- Process improvement (e.g. Lean management, Six Sigma, CMMI)
- Executive decision maker / Senior executive

Q1.15. Did you spend a significant portion of your time (more than 20% or at least one day a week) on risk management related activities?

- Yes
- No

Q1.16. Did your project allocate a significant portion (at least 10% of yearly budget) to conduct risk management activities?

- Yes
- No

Q1.17. 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.

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Figure D-3: Survey – General Questions on your organization (continued)

Risk Management Benchmarking Survey

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Q1.18. **General Questions on Your Program/Project (1/2)**

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

Q1.20. Please provide some general information on the program/project you chose as the example for this survey:

	Less than $500k	$500k - $1m	$1m - $5m	$5m - $10m	$10m - $50m	$50m- $100m	$100m- $500m	500m - $1bn	more than $1bn	Do not know
Development budget for all contractors / suppliers for program/project.	○	○	○	○	○	○	○	○	○	○
Development budget within your organization for program/project.	○	○	○	○	○	○	○	○	○	○

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.

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Figure D-4: Survey – General Questions on your program/project

Risk Management Benchmarking Survey

○ Other (please specify).

Q1.24. What risk management models were relevant for the design of your risk management process?

- ☐ **Department of Defense** Risk Management Guide for DoD Acquisition
- ☐ **Project Management Institute (PMI)** project risk management process (part of the Project Management Body of Knowledge)
- ☐ Risk management process of **PRINCE2** project management framework
- ☐ **NASA** Risk-Informed Decision Making (RIDM) or Continuous Risk Management (CRM) process
- ☐ **INCOSE** risk management process from the Systems Engineering Handbook
- ☐ **ISO 31000** standard "Risk management - principles and guidelines"
- ☐ Do not know
- ☐ Other (please specify)

Q1.25. What development approaches or philosophies played a significant role in your project / program?

- ☐ Waterfall (e.g. Stage Gate, V-model, DoD 5000)
- ☐ Spiral development
- ☐ Agile development (e.g. Scrum, Extreme Programming)
- ☐ Design for Six Sigma
- ☐ Lean Product Development
- ☐ Do not know
- ☐ Other (please specify)

Q1.26. 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.

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Figure D-5: Survey – General Questions on your program/project (continued)

Risk Management Benchmarking Survey

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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:

	Very low	Low	Average	High	Very high
Technology experience: Familiarity of your organization with key technologies.					
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:

	Very low	Low	Average	High	Very high
Experience with customers or stakeholders: Familiarity of your organization with key customers and stakeholders.					
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:

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

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

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Figure D-6: Survey – General Questions on your program/project (continued)

Risk Management Benchmarking Survey

Experience with supply chain Familiarity of your organization with the supply chain needed to execute the project/program.	◯	◯	◯	◯	◯
Complexity of supply chain: Size, diversity and level of integration of the project's or program's supply chain.	◯	◯	◯	◯	◯

Q1.34. Please rate the challenge that the program/project posed for your organization regarding external factors:

	Very low	Low	Average	High	Very high
Experience with external factors: Familiarity of your company with the external factors (e.g. competitors, legal and regulatory environment).	◯	◯	◯	◯	◯
Complexity of external factors: Number and diversity of external factors (e.g. competitors, legal and regulatory environment).	◯	◯	◯	◯	◯

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.

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Figure D-7: Survey – General Questions on your program/project (continued)

Risk Management Benchmarking Survey

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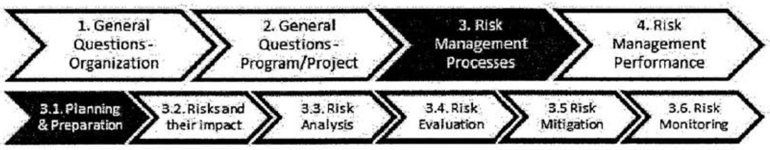
Q2.1. **Risk Management Process - Planning and Preparation**

Integration of stakeholders in communication and consultation of risk management activities. Choosing the right processes, tools and methods for risk management.



Q2.5. Please indicate your assessment of the way risk management was executed.

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

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.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
We **tailor the risk management process and the methods** to the specific program/project.					
We **coordinate and integrate risk**					

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Figure D-8: Survey - Risk Management Process – Planning and preparation

Risk Management Benchmarking Survey

We **coordinate and integrate risk management activities** of different functions and across the hierarchy.	○	○	○	○	○
Risk management is **integrated with higher-level risk management process**, 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.

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Figure D-9: Survey - Risk Management Process – Planning and preparation (continued)

Risk Management Benchmarking Survey

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Q3.1. Risk Management Process - Types of risk and their impact

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

3.1. Planning & Preparation | **3.2. Risks and their impact** | 3.3. Risk Analysis | 3.4. Risk Evaluation | 3.5 Risk Mitigation | 3.6. Risk Monitoring

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 occured, 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.

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

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

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

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Figure D-10: Survey - Risk Management Process – Types of risks and their impact

Risk Management Benchmarking Survey

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

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

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

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

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.

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Figure D-11: Survey - Risk Management Process – Types of risks and their impact (continued)

Risk Management Benchmarking Survey

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Q4.1. **Risk Management Process - Risk Analysis & Quantification**

Quantification of risks with sufficient accuracy

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

3.1. Planning & Preparation > 3.2. Risks and their Impact > **3.3. Risk Analysis** > 3.4. Risk Evaluation > 3.5 Risk Mitigation > 3.6. Risk Monitoring

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.

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

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.

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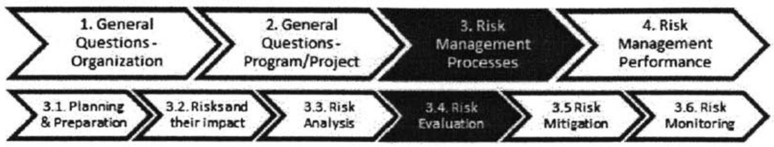
Figure D-12: Survey - Risk Management Process – Risk Analysis & Quantification

Risk Management Benchmarking Survey

Q5.1. **Risk Management Process - Risk Evaluation**
Prioritization of risks for proper treatment



Q5.6. How often did you use the following techniques to make decisions about risks in your project/program?

	Never	Rarely used	Sometimes used	Often used	Always used
Make go/no-go decisions based on risk assessment.					
Resources are allocated to reduce largest risks as early as possible.					
Risk assessments are used to set more 'realistic' or 'achievable' objectives.					
Forecasts and projections (e.g. cost, schedule, performance) are adjusted based on risk assessment.					
The results of the risk analysis are considered in making technical, schedule and/or cost trade-offs.					
Decisions are made based on risk-benefit trade-offs, e.g. larger risks are only acceptable for significant expected benefits.					
Risk-benefit trade-offs are used systematically to favor 'low risk - high benefit' options and eliminate 'high risk - low benefit' options.					
Contracts are derived from detailed cost risk assessments.					

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.

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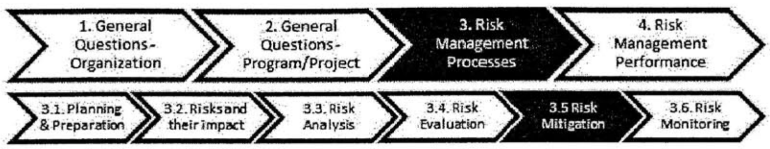
Figure D-13: Survey - Risk Management Process – Risk Analysis & Quantification (continued)

Risk Management Benchmarking Survey

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Q6.1. **Risk Management Process - Risk Mitigation**

Treatment of risks with effective mitigation actions



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:

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

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Figure D-14: Survey - Risk Management Process – Risk Mitigation

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

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

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

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

Q6.9. Mitigation actions to reduce technological risks:

	Not used	Very low risk reduction achieved	Low risk reduction achieved	Medium risk reduction achieved	High risk reduction achieved	Very high risk reduction achieved
Increased testing and prototyping activities.	○	○	○	○	○	○
Reuse existing components or off-the-shelf components.	○	○	○	○	○	○
Develop flexible product architecture (e.g. modular platform).	○	○	○	○	○	○
Strict configuration control to manage						

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Figure D-15: Survey - Risk Management Process – Risk Mitigation (continued)

Risk Management Benchmarking Survey

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

Q6.10. 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.

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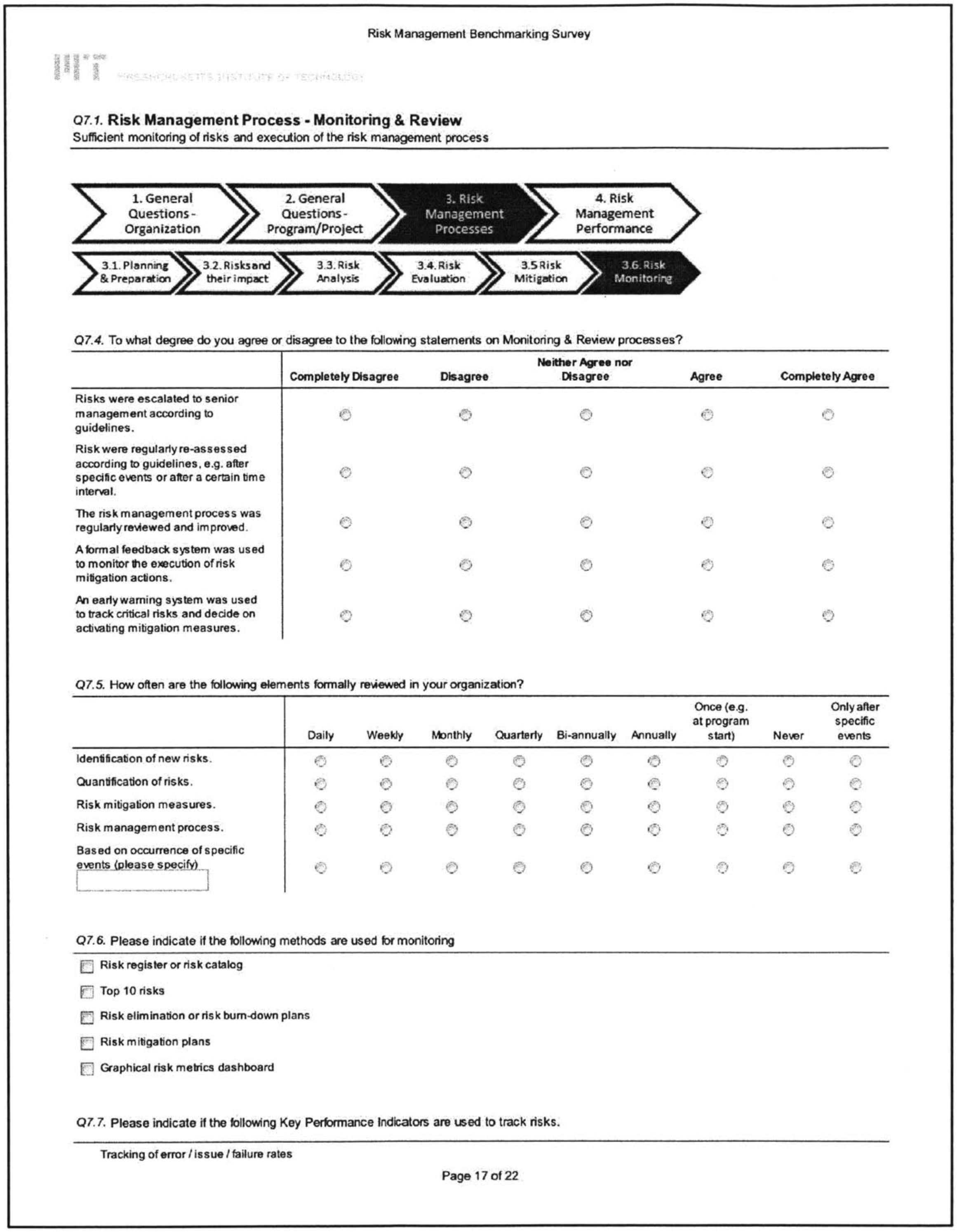
Figure D-16: Survey - Risk Management Process – Risk Mitigation (continued)



Risk Management Benchmarking Survey

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Q7.1. Risk Management Process - Monitoring & Review

Sufficient monitoring of risks and execution of the risk management process

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

3.1. Planning & Preparation > 3.2. Risks and their impact > 3.3. Risk Analysis > 3.4. Risk Evaluation > 3.5 Risk Mitigation > 3.6. Risk Monitoring

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

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

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

	Daily	Weekly	Monthly	Quarterly	Bi-annually	Annually	Once (e.g. at program start)	Never	Only after specific events
Identification of new risks.									
Quantification of risks.									
Risk mitigation measures.									
Risk management process.									
Based on occurrence of specific events (please specify)									

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

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Figure D-17: Survey - Risk Management Process – Monitoring & Review

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.

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Figure D-18: Survey - Risk Management Process – Monitoring & Review (continued)

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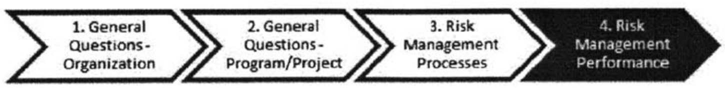
Q8.1. **Risk Management Performance**

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



Q8.3. Please indicate to what extent you agree with the following statements regarding the role and perception of risk management in the program/project:

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

Q8.4. Please indicate to what extent you agree with the following statements regarding the influence of risk management on the program/project:

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
Risk management creates and protects value.	○	○	○	○	○
Risk management is an integral part of all organizational processes.	○	○	○	○	○
Risk management is central part of decision making.					
Risk management facilitates continuous improvement in the organization.					
Risk management has a positive					

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Figure D-19: Survey - Risk Management Performance

Risk Management Benchmarking Survey

influence on program success.

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 chasing 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.

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Figure D-20: Survey - Risk Management Performance (continued)

Risk Management Benchmarking Survey

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Q8.8. **Option to receive copy of survey results**

Q8.9. If you wish to receive a copy of the results of this survey, please enter your contact details below (your details will be treated confidentially, and not correlated with the survey results; your email address will only be used once to send you a copy of the results)

Your email address

Q8.10. General feedback: If you have any general comments regarding the survey (too long or too short, too much or too less detail, etc.), please let us know here:

Q8.11. **Submit the survey by clicking the button below.**

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Figure D-21: Survey - Penultimate page of the survey

Risk Management Benchmarking Survey

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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 this survey reminded you of another project/program that you wish to comment on, please feel free to fill out a second questionnaire on a different project/program.

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Figure D-22: Survey - Final page of survey