APPROACHES TO CRISIS PREVENTION IN LEAN PRODUCT DEVELOPMENT BY HIGH PERFORMANCE TEAMS AND THROUGH RISK MANAGEMENT

Diploma Thesis

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September 2005

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ABSTRACT

This thesis investigates crisis prevention in lean product development, focusing on high performance teams and risk management methods.

Lean product development and the Munich Procedural Model (MPM) are the guiding frameworks for this thesis. From the MPM, team work and risk management are derived as important elements in crisis prevention, from lean product development, especially the notion of value is used to define basic types of crisis in product development and the failure modes of risks in product development.

High performance teams (HPT) are generally defined. Based on a literature review, 49 factors that describe HPT are identified and presented. They are characterized with Vester's Influence Diagram and categorized into four groups, enablers, drivers, critical elements, and indicators.

Risk and risk management are defined in the context of lean product development. Basic concepts are introduced to describe the axiomatic risk attributes (causal structure, failure modes, timeframe, cause-and-effect networks), resulting from the risk definition. Based on a literature review, a generic risk management process framework is defined, and a collection of methods for risk management in product development presented.

The relation of high performance teams and risk management is discussed and it is shown that the two are mutually beneficial.

A field study is conducted at a large North American company in the automotive sector. The theoretical findings from the literature are confirmed in large parts.

Keywords: Lean Product Development, Crisis Prevention, Risk Management, High Performance Teams, Literature Review, Field Study

ACKNOWLEDGEMENTS

I would like to extent my heartfelt gratitude to Prof. Warren Seering at the Massachusetts Institute of Technology for his invaluable guidance, advice, and for introducing me to the set-based approach of writing a thesis. My head is still spinning.

I would also like to thank Prof. Lindemann of the Technical University of Munich and the Lean Aerospace Initiative, especially Eric Rebentisch, for making this work possible. My deepest thanks also go to my supervisor Birgit Dick for her guidance and support.

I am also very grateful to the professionals at the industry partner for their extraordinarily friendly, insightful and generous support.

I would like to thank Günter Lessing for his cunning and irreplaceable guidance in the field of risk management and other areas.

My greatest thanks also go to Victor Tang, Jin Kato, Ryan Whitaker and Martin Graebsch for their ideas and friendly encouragement.

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1 Introduction

This chapter will briefly discuss the motivation for this thesis and its general context (section 1.1). The different areas that are taken into account are discussed in section 1.2. The goals of the thesis and the according research hypotheses are presented in the following section (section 1.3). The last section (section 1.4) gives a brief overview of the main part of the thesis.

1.1 Motivation and Context

Products and processes in product development are becoming increasingly complex. As a result, product and process failures are becoming more and more frequent, and the number of crises related to product development is increasing both in number and severity. Crisis prevention is thus becoming an increasingly important task in product development.

The goal of this thesis is to investigate approaches related to crisis prevention in product development. A special focus will be placed on risk management, as the traditional approach to prevent crises. In addition, high performance teams, that by definition successfully prevent crises in their development projects, are investigated.

1.2 Scope of Thesis

The scope of this thesis is research into crisis prevention in lean product development. The focus is on the factors defining high performance teams and risk management approaches for crisis prevention.

As a crisis in product development, we understand an unwanted situation with a high time pressure and pressure for results, occurring late in the development process. Crisis prevention aims at avoiding these situations (see section 2.5). High performance teams are teams that constantly outperform other teams in regard to stakeholder satisfaction (see section 2.3). As risk management, we understand all activities that proactively aim at minimizing the losses associated with risks (see section 2.4). Risk itself in this thesis is defined as a potential, time dependent loss of value, in a complex causal network (see section 2.4).

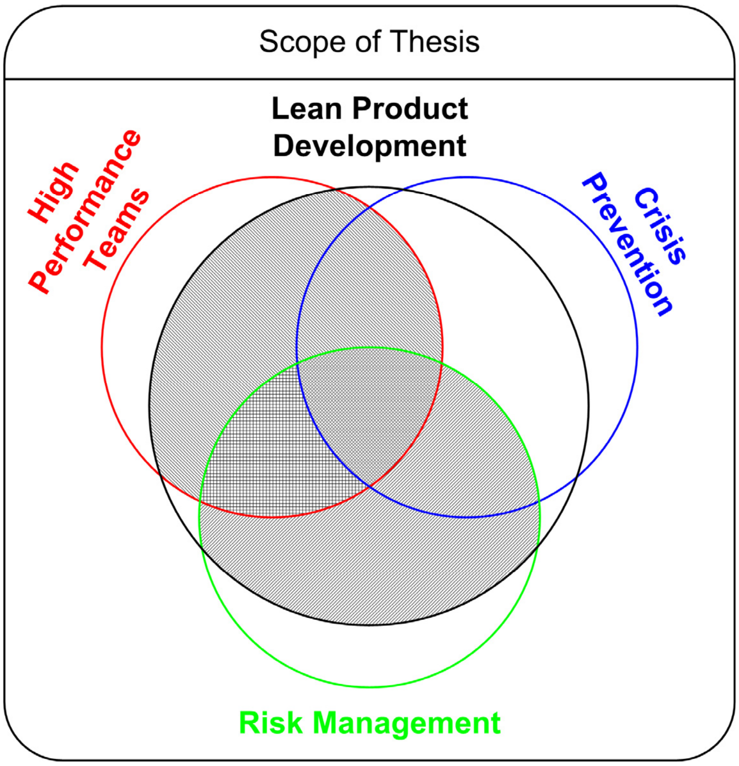

Figure 1-1: Scope of Thesis

In risk management, the scope includes both process framework and specific methods, with a focus on the methods.

The modes of research will both be a literature review and a field study. The focus will be on the literature review.

1.3 Research Goals and Hypotheses

The overall goal of this thesis is to deepen the understanding of crisis prevention in product development. The focus is placed on high performance teams and risk management methods.

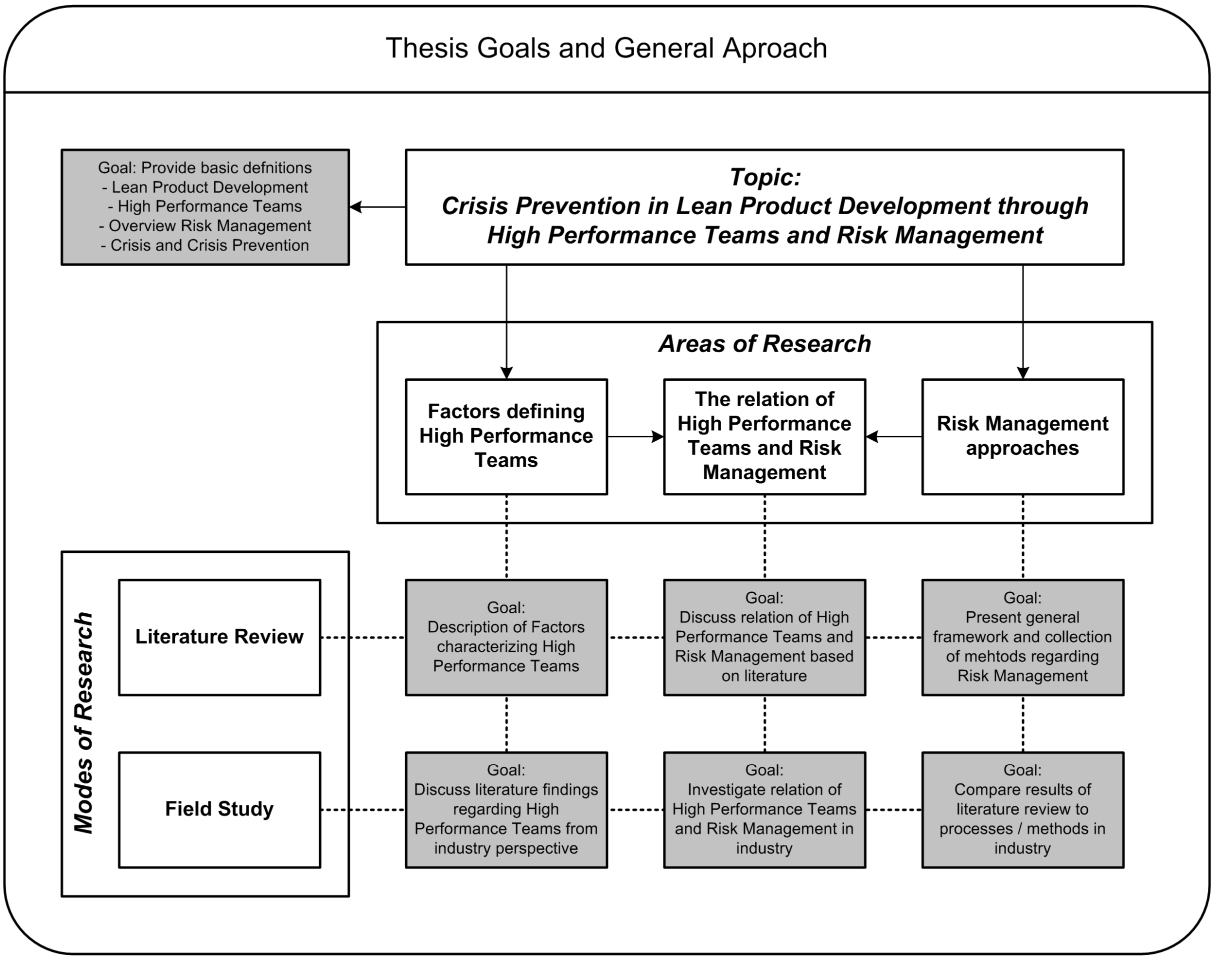

Figure 1-2: Thesis Goals and General Approach

The goals of this thesis are

- (1) Present the basic definitions and overview over the fields necessary to discuss Crisis Prevention in lean product development from a high performance team and Risk Management point of view,
- (2) Investigate in a literature review the factors defining High Performance Teams,
- (3) Research a general framework and a collection of methods applicable to Risk Management in Product Development, with a focus on the methods,
- (4) Discuss the relation of High Performance Teams and Risk Management, and
- (5) Discuss the literature findings from these three areas in the light of a field study.

The associated research hypotheses are that

- (I) As best practice examples, High Performance Teams in Product Development will show certain elements of Risk Management to prevent crises,
- (II) Risk Management in Product Development is an effective tool for Crisis Prevention,
- (III) The literature on Risk Management will offer a collection of methods on Risk Management, which are applicable to Product Development, and that
- (IV) The organizational structure of High Performance Teams and the processes of Risk Management are mutually beneficial
- (V) The field study will support and further illustrate the findings from the literature review.

1.4 Thesis Outline

The outline of this thesis proceeds from a general outline to a detailed discussion of the topic. This approach was chosen over a more “scientific” approach, which would present detailed definitions first in order to clarify and define the important terms of the thesis before starting to use them. It is hoped that with the chosen approach, the thesis will be easier to read by increasing the detail of the discussion step by step, and that the definitions will be more understandable once the general field of application has been discussed.

In chapter 2, the fundamental concepts for the discussion of the topics of this thesis are laid out. These are the discussion of the current challenges in product development in section 2.1 to put the thesis into the general context. Section 2.2 contains an introduction to lean product development. Section 2.3 discusses the fundamentals of high performance teams in Product Development, including the definition of high performance teams. Section 2.4 discusses the fundamentals of risk management, including a definition of risk and risk management. Section 2.5 addresses the basics of crisis in product development and includes a definition of crisis in product development.

Also, the sections presented above follow the approach of proceeding from a general to a detailed discussion. Especially section 2.4 on risk management (as the largest section in chapter 2) demonstrates this approach: Subsection 2.4.1 gives a general introduction to risk management, subsection 2.4.2 discusses different implementations of risk management, subsection 2.4.3 summarizes general trends in relation to the different implementations, subsection 2.4.4 discusses, more specifically, the risk management approaches in product development, subsection 2.4.5 defines risk based on the previous discussions, subsection 2.4.6 introduces, based on the definition of risk, general axiomatic attributes for risks and proposals for their description, subsection 2.4.7 defines risk management, taking the preceding outlines into account, and subsection 2.4.8 briefly presents some necessary mathematical fundamentals on probability.

Chapter 3 discusses high performance teams in product development in more detail. Section 3.1 outlines the research methodology employed, section 3.2 summarizes the literature base of the following discussion, section 3.3 describes the main factors that have been identified describing high performance teams, section 3.4 presents a characterization of these factors with Vester's Influence Diagram into the categories of Drivers, Critical Elements, Indicators, and Enablers, and section 3.5 discusses the result of the characterization.

Chapter 4 discusses the process and the methods of risk management in product development in detail. Section 4.1 outlines the research methodology employed, section 4.2 presents the literature base of the following discussions, section 4.3 briefly introduces a general process framework for risk management, and section 4.4 describes in detail a large selection of methods for risk management, along the process framework defined in the previous sections.

Chapter 5 gives a brief interim summary on the relation of high performance teams and risk management, based on the previous two chapters.

Chapter 6 contains a field study to discuss the results of the literature-based chapters 3 - 5 in the context of application in industry. Section 6.1 outlines the research method employed, section 6.2 describes the situation at the industry partner, and section 6.3 presents the results of the field study, in relation to risk management, high performance teams, and the relation of risk management and high performance teams.

Chapter 7 contains the overall conclusions, and chapter 8 an outlook and recommendations regarding possible future research.

2 Fundamental Concepts

This chapter establishes the fundamental concepts to discuss crisis prevention in lean product development through risk management and high performance teams. Section 2.1 discusses current challenges in product development, section 2.2 contains an introduction to lean product development, section 2.3 discusses the fundamentals of high performance teams, section 2.4 discusses the fundamentals of risk management, and section 2.5 addresses the basics of crisis in product development.

2.1 Current Challenges in Product Development

Products and the associated processes in product development are becoming increasingly complex. One answer to this challenge is advanced procedural models for product development, which offer a structured approach to complex problems while maintaining the necessary flexibility to adapt to changes.

2.1.1 The Munich Procedural Model (MPM)

One example of these process models is the Munich Procedural Model (MPM) [Lindemann et al. 2005].

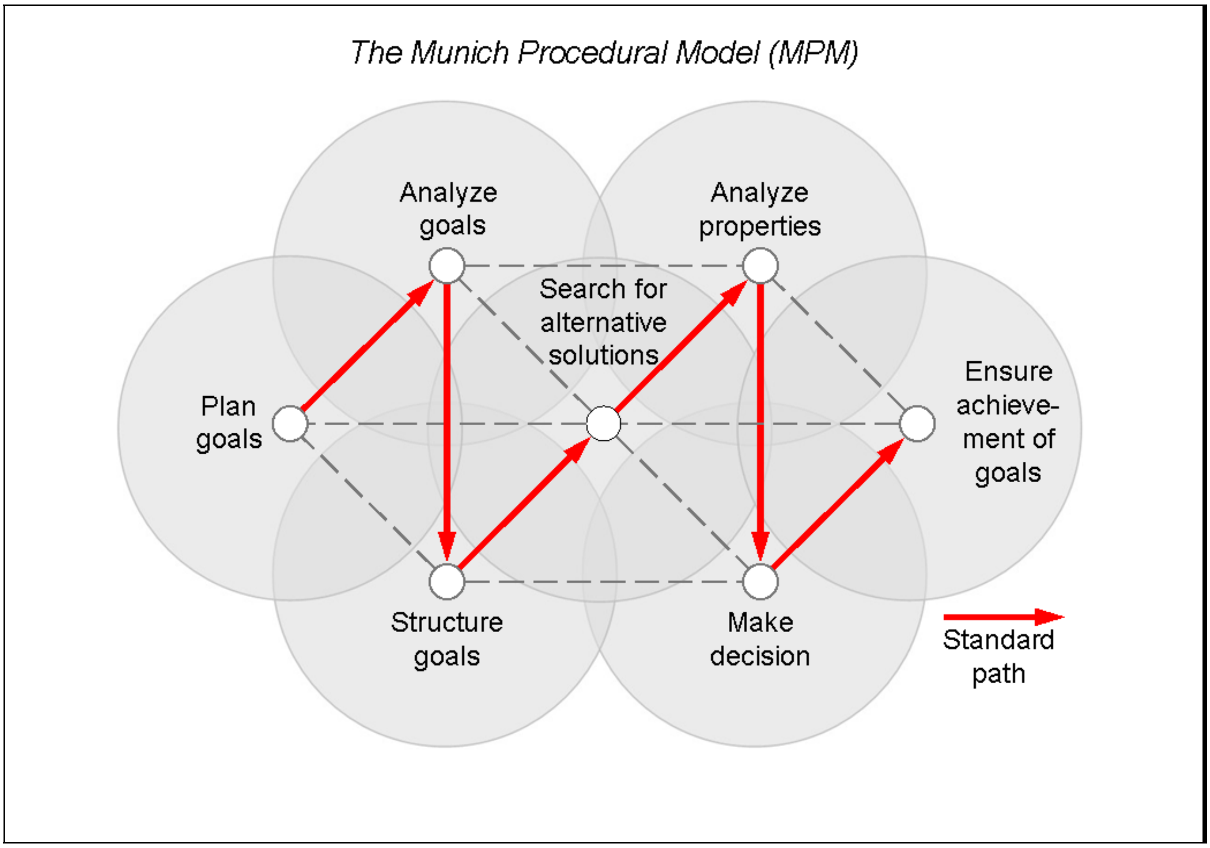

Figure 2-1: Overview of the Munich Procedural Model (MPM) [Lindemann et al. 2005]

Based on problem solving methodologies, it offers a structured yet flexible approach to address the complex situation faced in product development: It follows the basic problem solving approach of

- Clarify the problem,
- Search for alternative solutions, and
- Make decisions.

Its goals are to serve as a planning tool, give orientation on how to address complex problems, and support a division of a complex problem into manageable parts. It emphasizes the phase preparing a solution and provides procedural guidance for beginners as well as maintaining enough flexibility for experts. The model can be followed along the standard path, as well as being iterated along the indicated connections between the single steps.

The steps of the procedural model are:

- **Plan goals:** The general situation is analyzed regarding an existing product (if applicable) and the decisive influences on the product. Also, high level requirements are clarified and actions regarding product- and process planning are defined.
- **Analyze goals:** In this step, concrete and detailed requirements regarding the product are defined. High priority is placed on the identification and description of conflicts in the requirements and goals. The requirements are documented in a structured manner.
- **Structure goals:** The priority areas for actions are defined. Problems are divided into sub-problems. The prioritized customer requirements, technical conflicts and the degrees of freedom for the development are taken into account to define the areas of main focus.
- **Search for alternative solutions:** In this step, existing solutions are collected, new solutions generated, and solutions for sub-problems are completed, ordered and pre-selected. Partial solutions are combined in varying combinations to find optimal total solutions.
- **Analyze properties:** The properties of the proposed solutions and the resulting product are analyzed in regard to the main requirements defined earlier.
- **Make decision:** The analyzed alternative solutions are judged and decisions are made regarding their implementation.
- **Ensure achievement of goals:** This step aims at the minimization of risks in the implementation phase. If necessary, actions are defined and implemented accordingly.

2.1.2 Implications for Crisis Prevention from the MPM

An intrinsic goal of the MPM is to minimize the probability of a crisis situation. Crucial for the successful execution of a product development process according to the MPM is **teamwork** [Lindemann 2002]. Crisis prevention is explicitly addressed in the last discussed process step by **risk management** approaches, aiming at the minimization of risk. The MPM therefore suggests teamwork and risk management as the two important factors regarding crisis prevention.

Due to the increased complexity of products and product development processes, the number of product failures at the stage of customer usage has steadily increased. For example, the number of product recalls in the automotive sector in Germany has doubled from the years 1999 to 2004 ([KBA 2005] quoted from [Dick et al. 2005]). Recalls like these are examples for corporate crises, that in extreme cases can put a companies' future at stake ([Kendall 1998] quoted from [Dick et al. 2005]).

Recognizing the increasing importance of crisis prevention in product development, this thesis aims at further deepening the knowledge in regard to crisis prevention in product development. Following the elements suggested by the MPM, a special emphasize will be placed on **high performance teams** and **risk management**, as well as their relation.

2.1.3 An integral approach to Crisis Prevention in Lean Product Development

Crisis prevention in product development is not a one-dimensional activity. As has been discussed before, it is an emergent capability of a product development system based on different factors. In this thesis, crisis prevention will be discussed in an integral approach encompassing

- The guiding paradigm of Value-focus of Lean PD,
- The organizational structure-component of High Performance Teams, and
- The process- and method-component of Risk Management Methodology.

Lean product development and the associated value-focus will be discussed in the following section, section 2.2.

The organizational structure is addressed by the introduction to high performance teams in section 2.3, an in-depth analysis and discussion of high performance teams is presented in chapter 3.

The processes and methods of risk management are addressed in the general introduction in section 2.4, and chapter 4 containing a detailed discussion of a risk management methodology for product development.

The relation of high performance teams and risk management will be discussed in chapter 5.

2.2 Lean Product Development

2.2.1 General Introduction to Lean Thinking

Lean Thinking stems from the production and manufacturing area [Womack et al. 1990]. It is generally associated with a high increase in productivity and efficiency. The Lean Philosophy first developed at Toyota as the "Toyota Production System", with Shigeo Shingo and Taiichi Ohno being its foremost thinkers [Ohno 1988], [Shingo 1989].

Following the extraordinary success of Lean Production Systems throughout the world, Lean principles were starting to be applied in all functional areas of a company to increase productivity [Womack et al. 2003], [Murman et al. 2002], [Liker 2004].

At the heart of Lean Thinking lie the five principles of Value, Value Stream, Flow, Pull and Perfection [Womack et al. 2003].

Value is an attribute assigned to an object by its final customer (or, more generally, stakeholder), expressing this customers level of appreciation. For example, in a manufacturing setting, the customer is the ultimate judge of a products value, by taking all factors (like performance, price, and availability) into account. The opposite of Value is defined as Waste.

Value stream describes the generation of value throughout the company. It aims at identifying the activities that directly relate to the process of value generation throughout the company. This leads to the distinction of actions into three categories Value Adding (VA), Necessary, but non Value Adding (NNVA), and Non Value Adding (NVA). The goal is to optimize the Value Stream by eliminating or minimizing NVA and NNVA activities, and to support and optimize the VA activities.

Flow describes the easiness with which the Value Stream can cross organizational or other boundaries. The goal is to optimize the Flow of the Value Stream and thus minimize resource-consuming obstacles to the Value creation process.

Pull describes a basic control paradigm in which an upstream activity only starts after being triggered by a downstream activity. The goal is to minimize the complexity of the control system and thus increase efficiency by lowering throughput and reaction times.

Perfection describes the basic attitude that any technical or organizational system always can, and must be, continuously improved.

[Spear et al. 1999] focus in their analysis more on general guiding principles for process-setup and actions, as expressed in their "Four Rules" of the Toyota Production System:

Rule 1: All work shall be highly specified as to content, sequence, timing and outcome.

Rule 2: Every customer-supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses

Rule 3: The pathway for every product and service must be simple and direct.

Rule 4: Any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

[Spear 2004] carries forth this work into the area of management. Note that the two models mutually complement and reinforce one another.

2.2.2 Lean Product Development

In lean product development, an attempt is made to transfer the highly successful principles of Lean Thinking into Product Development. It aims at realizing similar increases in efficiency as have been witnessed in Production.

Work has been invested into developing overall process guidelines for lean product development [Morgan 2002], [Kennedy 2003]. While these works yield some general high-level principles, other research effort has gone into more detailed analysis of specific parts of Lean Thinking in Product Development.

The question of Value in Product Development is addressed by [Slack 1999] and [Chase 2001].

[Bauch 2004] addressed the concept of Waste in detail by systematically identifying waste drivers in Product Development. [Graebsch 2005] focuses specifically on waste in information transfer, while [Kato 2005] quantifies other waste types in Product Development, most notably Wasted Time and Information Inventory. In particular, the quantitative Waste analysis in [Graebsch 2005] and [Kato 2005] demonstrate the huge potential for optimization in Product Development and the ability of a Lean-based approach to locate this potential and make it transparent. [Graebsch 2005] shows for example that only about 12% of all information transfers in Product Development are truly value-adding, while [Kato 2005] e.g. discovered large inventories of information in typical Product Development projects, with a value decay of 6% per month.

[Oppenheim 2004] focuses on the application of the flow principle in Product Development.

In the area of Value Stream Mapping, [Millard 2001], [McManus et al. 2002] and [McManus 2004] demonstrate a tool to analyze and optimize the Value Stream in Product Development. Based on this notion of Value Stream, [McManus 2005] offers a Product Development Transition to Lean Roadmap, where he outlines and overall implementation approach.

[Browning et al. 2002b] and [Browning 2003] stress the fact that value adding in product development is not only about performing the right processes in the right way (or avoiding unnecessary and imperfect processes), but stresses that the quality of information on which the processes operate is also of great importance. Value can not only be added by processes that increase the performance level (or, in general, address form, fit, function) of a product, but also by processes that merely create information that increases certainty, i.e. reduces risk He argues for addressing the PD process as a system of processes, their systemic coordination, and the information they process. He demonstrates that there is a time lag between the creation and possible determination of value, as the value of a process is partly a function of not only the preceding, but also of those processes that follow.

A very interesting addition to the discussion of lean product development was made by [Liker et al. 1996] and [Sobek 1996], and in more detail by [Sobek et al. 1998], [Sobek et al. 1999] and [Liker 2004] by introducing the notion of Set-based design into lean product development. Set-based design aims at minimizing iterations and argues in favor of delaying decisions to the latest possible point instead of freezing designs early, and gradually narrowing down the set of alternatives by matching them with the different constraints from other functional areas. This concept is an especially interesting addition to lean product development, since it has no counterpart in the Production area. However, its feasibility has been hotly debated ever since its introduction (see e.g. [Bernstein 1998]), but research in this area has remained very active in recent years: Some fundamental concepts on Set-based design are developed in [Habib et al. 1997a] and [Habib et al. 1997b], an application example is provided in [Lee et al. 1999]. [Cristiano et al. 2001] integrates it with QFD. [Cavalucci et al. 2002] links the concept to TRIZ. A quantitative Simulation model is developed by Terwiesch and Loch in [Terwiesch et al. 1999], [Loch et al. 2001], [Terwiesch et al. 2002], [Terwiesch et al. 2004] and [Sommer et al. 2004], and mostly independent thereof of by [Fan et al. 2004]. A quantitative model based on real options theory is introduced by [Ford et al. 2004]. [Costa et al. 2003] present a discussion of iterations in the light of Set-based design.

2.2.3 The Concept of Value in Lean Product Development

Of particular interest to this work is the concept of Value in lean product development.

[Slack 1999] defines Value in Product development as "a measurement of the worth of a specific product or service by a customer, and is a function of (1) the product's usefulness in satisfying a customer need, (2) the relative importance of the need being satisfied, and (3) the exchange cost to the customer." [Womack et al. 2003] define Value as "a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer." [Browning 2002b] and [Browning 2003] argues that product value is a function of Performance, Affordability (Cost) and Timeliness (Schedule).

[Chase 2001] compiled an extensive list of Value definitions in Product Development.

Source	Value Definition
Miles, 1961	Value is the appropriate performance and cost.
Kaufman, 1985	Value is function divided by cost.
Shillito & DeMarle, 1992	Value is the potential energy function representing the desire between people and products.
Womack & Jones, 1996	Value is a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer.
Slack, 1998	Value is a measurement of the worth of a specific product or service by a customer and is a function of: (1) Product's usefulness in satisfying customer need (2) Relative importance of the need being satisfied (3) Availability of the product relative to when it is needed (4) Cost of ownership to the customer
LAI, 1998	Value is anything that directly contributes to the "form, fit, or function" of the build-to package or the buy-to Package • Form: Information must be in concrete format, explicitly stored • Fit: Information must be (seamlessly) useful to downstream processes • Function: Information must satisfy end-user and downstream process needs with an acceptable probability of working (risk)
Browning, 1998	[Value is] balancing performance, cost, and schedule appropriately through planning and control.
Deyst, 2001	Value is the amount by which risk is reduced per resource expended.
Stanke, 2001	[Value is] a system introduced at the right time and right price which delivers best value in mission effectiveness, performance, affordability and sustainability and retains these advantages throughout its life.
Site A	Value is anything that enhances performance (form, fit, & function) as measured by cost, schedule, and risk from the perspective of the customer, be they external and internal.
Site A	"Value is a balance between performance, schedule, and cost."
Site C	Value is a product design and manufacturing plan that enable the building and delivery to the customer of a product that meets the form, fit, and function requirements that the customer wants.
Site D	Value is the knowledge that adds form, fit, or function to the "design-to" package.
Site D	"Value happens when all of the stakeholders agree."
Site F	"Value is in the eye of the beholder. It must be tied to who is making that judgment and what the alternative is."

Table 2-1: Value Definitions in Product Development according to [Chase 2001]

Generalizing these definitions, I define: "The Value of an Object is a stakeholder-specific measurement proportional to the degree of fulfillment of said stakeholders goals related to the Object under discussion. The total Value of a System is the sum of the Values of all its Objects, for all associated Stakeholders, for all associated goals."

Here, Object is used in the widest sense and encompasses e.g. tangible elements as products or resources as well as intangible elements like processes or information.

This implies that Value is specific to the Object it is applied to, the Stakeholder, and the Stakeholders Goals related to a specific Object. From this follows that in order to specify Value, the Object(s) related to the Value must be specified, the Stakeholder(s) related to the Object(s), as well as the Goal(s) related to the Stakeholder(s) and Object(s).

As mentioned in the Introduction, this thesis focuses on Customers and Shareholders as the main Stakeholders. In order to operationalize the concept of Value, we need to define the Objects associated with these stakeholders in relation to Product Development. For the Customer, this Object is the Product, for the Stakeholder, it is the Product Development Process. The generic goals of the Stakeholders are summarized by the three main goals of engineering, being on time, on cost and on quality [Lindemann 2002].

With this information, the following matrix can be created, which yields the six main Categories of Value in Product Development:

			Generic Goals		
Stakeholders		**Objects**	**Time**	**Cost**	**Quality**
Customers	→	Product	1: (low) Lead Time	2: (low) Lifecycle Cost	3: (high) Performance
Shareholders	→	PD Process	4: (high) Schedule Adherence	5: (high) Budget Adherence	6: (high) Conformity to Standards

Table 2-2: The six Categories of Value in Lean Product Development

The categories are briefly explained in the following:

- Lead time: All activities that lower the lead time of the product are value adding.
- Lifecycle cost: All activities that lower the lifecycle cost of the product (including the cost of production, the operating cost, service cost and recycling cost) are value adding.
- Performance: All activities that increase the performance of the product in regard to the customer expectations and requirements are value adding.
- Schedule: All activities that support the schedule adherence of the product development process (and all activities that shorten the length of the process) are value adding.
- Budget: All activities that support the product development process staying on budget (and all activities that decrease the cost) are value adding.
- Process Standards: All activities that support the adherence of the product development process to certain standards (e.g. quality management) perceived as value adding by the stakeholders, are value adding.

Obviously, these categories are closely related to each other, reflecting the relation of the Goals, Objects and Stakeholders they are based upon. Also, the level of abstraction at which these categories are defined is somewhat arbitrary. The decision made in the selection above was based on the objective to provide as much detail on one level as possible, without sacrificing the overall general applicability.

The definition of the Categories of Value will play an important role when discussing crises in product development (see section 2.5) and the failure modes of product development for risk management (see section 2.4.6.3).

2.3 High Performance Teams in Product Development

2.3.1 Brief Introduction to teams and the role of teams

As discussed earlier (see section 2.1), teams play in important role in product development and crisis prevention in product development. Later, the important role of teams in risk management will also be discussed (see chapter 5).

Teams can be defined as a "small number of people with complementary skills who are committed to a common purpose, performance goals, and approach for which they hold themselves mutually accountable." [Katzenbach et al. 1993] (p. 45). Teams play a central role in modern product development organizations [Lindemann 2002] (p. 7-2). Team work has many different aspects: it addresses an increase of professional performance by increasing the ability to solve complex tasks and increasing productivity by utilizing synergy effects; it has social and emotional aspects due to the integration of humans into a larger group; and it has organizational aspects due to the differences in which individuals and teams solve tasks [Lindemann 2002] (pp. 7-2 – 7-6).

Due to its wide-ranging application and impact, the research in the area of team and team work is immense. [Newell 2000], [Hastings 1998] and [Belbin 2002] offer a brief introduction into the area, with further references cited therein. There are different types of teams. [Newell 2000] for example differentiates between informal, traditional, problem-solving, leadership and self-directed teams. Good teams are characterized with the attributes of small size, clearly defined goals, well-balanced skills, common approach and mutual accountability [Katzenbach et al. 1993]. For the practitioner, [Scholtes et al. 2003] offer a hands-on workbook for team leaders and team members.

2.3.2 Definition of High Performance Teams

High performance teams have been defined as teams that "consistently satisfy the needs of customers, employees, investors and others in its area of influence" with the result that "these teams frequently outperform other teams that produce similar products and services under similar conditions and constraints" [Kur 1996]. Sharp (cited in [Castka et al. 2001]) defines high performance teams as "a team of people who have unleashed their potential toward their stakeholder shared purpose".

Based on the understanding of crisis as an "unwanted state", these definitions of high performance teams implicitly state the crisis prevention capabilities of the teams.

Other definitions of high performance teams focus on specific factors of the teams. These factors will be discussed in detail in section 3.3. Based on these general definitions, the literature in the area of Product Development has been analyzed (see section 3.2).

2.4 Risk Management in Product Development

As discussed in section 2.1, risk management plays an important role in product development to ensure the achievement of goals in general and especially to support crisis prevention.

This section will first give a general introduction to risk management (section 2.4.1). The following section (section 2.4.2) will briefly discuss the broad spectrum of application and integration of risk management in the public and private sector. Section 2.4.4 will give a detailed overview of the areas of risk management in product development. The following section (section 2.4.5) will give a definition of risk, followed by a description of the axiomatic attributes of risk, resulting from this definition (section 2.4.6). Section 2.4.7 gives a definition of risk management in our context, and section 2.4.8 closes section 2.4 with a brief review of the fundamentals of probability and reliability theory.

2.4.1 General Introduction to Risk Management

The generic goal of risk management is to explicitly and in a structured manner address risks in order to minimize losses [Bernstein 1996]. For now, risk will be defined as a potential loss [Hall 1998]. For a discussion of the goals of risk management in product development, see section 2.4.4.2, for a proper definition of risk and risk management, see section 2.4.5 and 2.4.7.

In short, risk management is about handling the unknown and achieving robustness, i.e. guiding the rational decision-making process in the face of uncertainty, instead of resorting to mythical practices [Bernstein 1996].

"The revolutionary idea that defines the boundary between modern times and the past is the mastery of risk" argues [Bernstein 1996], and it goes along with the realization that "the future is more than a whim of the gods and that men and women are not passive before nature", and that risk management is "one of the prime catalysts that drives modern Western society".

The Hindu-Arabic numbering system forms the basis for the modern conception of risk, reaching the West 700 to 800 years ago. But it took until the Renaissance, before serious attempts were made at the studying of risk. Blaise Pascal was challenged in 1654 to solve a problem related to gambling that had not been solved for the past 200 years. Together with Pierre de Fermat, Pascal discovered the theory of probability [Bernstein 1996]. Bernoulli then advanced the theory of risk in 1738, introducing the concept of utility, a measure for consequences of risk, founding the Utility and Decision Theory. [Hall 1998]

The first "large scale" application of Risk management was in the financial sector, with the British government selling life annuities, and the establishment of marine insurance in London in the middle of the 17^{th} century. [Bernstein 1996]

In 1730, the structure of the normal distribution and the concept of standard deviation were discovered by Abraham de Moivre. Around 1750, Thomas Bayes developed a mathematical method on how to blend new information into old, allowing one to refine ones intuitive judgment of a situation as events actually unfold. In 1952, Harry Markowitz gave the mathematical demonstration on the principles that founded the theory of diversification, revolutionizing business theory. [Bernstein 1996].

2.4.2 Current Implementations of Risk Management

Risk management processes are employed in a wide variety of environments. This section aims at giving a very brief overview over the areas of application and pointing out some fundamental literature.

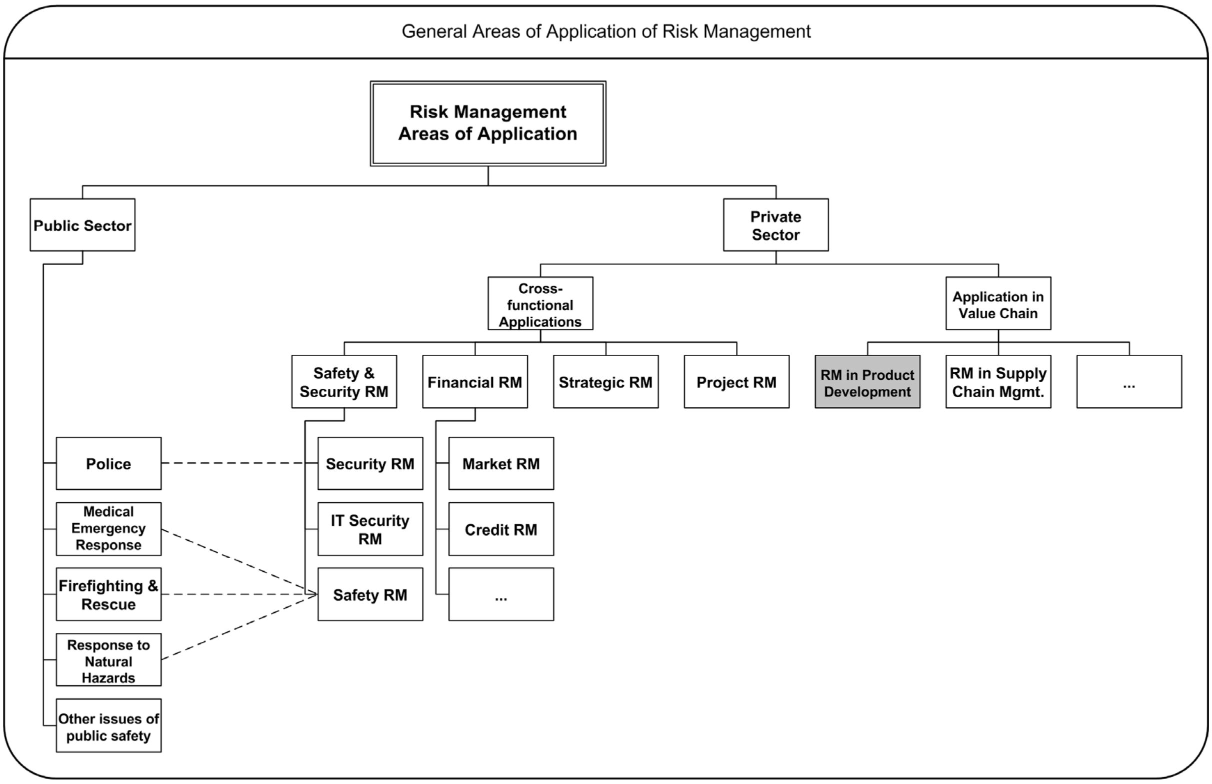

Figure 2-2: General Areas of Application of Risk Management

2.4.2.1 Risk Management in the public sector

In the public sector, risk management approaches are used both for military and civil applications. Application examples are the police, medical emergency response, firefighting and rescue, management of natural hazards like flooding and earthquakes, and large-scale issues of public safety, e.g. addressing industrial catastrophes and acts of terror [Steiner 2004].

The main relation to the private sector is through the police, natural hazard and public safety areas of risk management, which relate to security and safety risk management activities in the private sector.

2.4.2.2 Risk management in service functions

In the following, the risk management activities of the main service functions in a company will be discussed, as these might have an impact on the risk management activities in product development.

Financial Risk Management

Financial risk management is the usually most visible field. It evolved from insurance management in the mid 1970s, expanding to a much wider focus outside the classic insurance domain of covering natural disasters and other basic kinds of exposure [Heil 2000], and in detail [Field 2003]. Modern approaches are characterized by the convergence of insurance and financial instruments to minimize the negative impact of risk on a company [Doherty 2000]. Modern financial risk management faces strong regulatory constraints, and comprises the areas of Market Risk (changes in market conditions, price fluctuations, changes in interest and currency exchange rates), Credit Risk (delayed or no payments by debtors) and the financial components of the companies operation, mainly through insurances. [Dowd 1998], [Crouhy et al. 2001].

The methods employed in financial risk management are strongly quantitative and rely heavily on modern statistical methods and advancements in the area of data collection and processing [Field 2003]. Although they are very advanced, they are not discussed in this thesis explicitly. They are related to some methods encountered in reliability-oriented risk management, and are thereby addressed indirectly.

In financial risk management, risk management activities in other areas of the company are often referred to as “operational risk management”. [King 2001] for example defines operational risk management as being "concerned with adverse deviations of a firm's performance due to how the firm is operated as apposed to how the firm is financed". Unfortunately, the term operational risk management is also used in security- and safety oriented risk management applications, but there describes the security and safety activities [Steiner 2004]. In strategic risk management, operational risk management describes all risk management activities below the strategic level. Therefore, the term “operational risk management” is avoided in this thesis.

IT-Security and Security Risk Management

Security Risk management mainly addresses questions of the security of buildings (e.g. access, protection against fire and other hazards), personal security (e.g. security of executives and personnel traveling or working in unsafe countries) and IT-Security (confidentiality, integrity, availability and authenticity of data by addressing hardware, software and network-components) [Lessing 2004], [Steiner 2004].

Safety Risk Management

Safety risk management can be divided into process and product safety. Process safety addresses concerns related to the safety of production processes (e.g. in the chemical or mining industry, the nuclear sector or in aerospace applications), to avoid hazards to personnel, the surrounding community, the environment and the production process itself. [Bahr 1997] presents an engineering-focused approach to designing safety in large-scale systems in the chemical industry, [Jeynes 2002] offers an introduction to a company-centered view for managing safety-risks, [Kletz 1999] is an introduction to the HAZOP and HAZAN identification and analysis methodologies that are widely applied in all areas of process industries. Product safety focuses on safety-aspects of a single product.

Both risk management approaches are grounded on the fundamental principles of reliability of technical systems. These aspects will be discussed in detail in their relation to Product Development risk management in section 2.4.4.3.

Project Risk Management

Project risk management is a newly emerging discipline. It aims at making projects more resilient towards uncertainties. It has recently been included as one of the main pillars of project management by the Project Management Institute [PMI 2004]. Other important publications include [Chapman et al. 2002], [Chapman et al. 2003], [Kendrick 2003], [Cooper et al. 2005], [Wideman 1992] and [Schuyler 2001]. The project risk management literature will be discussed in the risk management literature review, see section 4.2.

Strategic Risk Management

Strategic risk management deals with issues of central importance to the operation of the entire company. It is strongly cross-functional orientated and tries to integrate the separate, low level risk management activities into an overall high-level view for the top management [Frame 2003], [Lessing et al. 2005]. Strategic risk management activities have become increasingly important in the last years. Corporate Governance initiatives are an important part thereof. They are cross-functional, top-down oriented measures on the border of strategic quality and risk management. They were initiated as a reaction to large-scale corporate crises in recent years and the resulting changes in legislation. They address a broad range of topics to holistically reduce the liabilities and threats to companies. See for example. the German Corporate Government Codex [DCGK 2003].

With the exception of the strategic risk management activities, all others follow a "silo approach" of addressing the Risk issues of specific functions within the company.

2.4.2.3 Risk Management in the value chain

The risk management activities along the value chain are relatively new developments, and are therefore not discussed in the same detail as the risk management activities in the service functions, although this surely would be a very interesting undertaking.

In many company functions, risk management activities have been emerging in recent years, for example in marketing [Romeike et al. 2003] or Supply Chain Management [Ziegenbein et al. 2004], [Peck 2003]. Risk management in Product Development is part of this trend, and will be discussed in detail in section 2.4.4.

2.4.3 Current Trends in Risk Management

In general, risk management has received a strong increase in management attention in the last years. This development has been driven by large-scale scandals (e.g. Enron) and the resulting new regulation (Basel-II capital accord, Sarbanes-Oxley Act) [Deloitte 2002]. An increasing number of companies introduce organizational changes to accommodate a risk management System, but most face tough challenges by the integration of processes, data and IT-systems [Deloitte 2002]. The area of Operational Risks (to which many Product Development Risks belong) is receiving increasing attention, but the area is still in its infancy and processes have only been implemented rudimentary (this information comes from the financial sector; there was no data found for other industries) [Deloitte 2002].

A survey in Switzerland showed that only 30% of all companies have an institutionalized risk management System, and significant problems exist in the area of documentation and communication of Risks [KPMG 2004]. [Marsh 2004] showed that German companies have a head-start in risk management and are more likely to utilize their risk management Systems to manage opportunities as well. [KPMG 2004] sees European companies generally ahead in risk management implementation. As the biggest risks are regarded international competition, shifts in demand and changes in core markets by European small and medium sized companies in different business areas (up to 300 Million EUR turnover) [Marsh 2004]. In the sector of Financial Services, image risk emerges as the dominant risk [PWC 2004a]. Taking a more general look at a broader industry base worldwide, [PWC 2004b] concludes that fierce competition, loss of qualified personnel, over regulation, exchange rate fluctuations, and to a lesser degree, international terrorism are the major risks. [PWC 2004a] argue that quantifiable risks are being addressed in too much detail, while qualitative risks are being neglected. [PWC 2004b] comes to the conclusion that about 75% of all CEO in companies with an integrated risk management system think that risk management significantly contributes to the value creation. The notion of equal attention to both quantifiable and unquantifiable risks, as well as Risk management contributing to value creation is also strongly supported by [PWC 2002].

For risk management in product development, the following implications can be derived thereof:

- The Basel-II capital accord forces especially small and medium sized companies to list and manage in detail the risks and uncertainties they are facing in order to acquire capital at low cost [Wolf 2005]; this also involves risk associated with product development.

- Product Development plays an important role in several of the main risks listed in the discussion above, for example strong international competition and adaptation to changing markets.

2.4.4 Approaches to Risk Management in Product Development

2.4.4.1 The relation of Risk Management and Lean Product Development

In the introduction, the relation of risk management and product development has already been briefly discussed along the Munich Procedural Model 2.1.

Alternatively (but not in contradiction to the view discussed previously), risk management in product development can be understood as properly handling the uncertainties that the PD effort faces, minimizing their negative impact, and exploiting them where possible. [Browning et al. 2002b] compares a value adding process in product development with a process decreasing the risk surrounding the product being developed. Not only do processes in Product Development add value that address form, fit, function (or influence its performance directly), but also processes that reduce the uncertainty surrounding the product's performance. [Browning et al. 2002b], [Browning 2003]. In this thesis, this approach is broadened to include the organizational processes in Product Development as well, since they constitute the enabling framework.

It has been noted that risk management in Product Development supports a cross-functional and proactive orientation [Smith et al. 2002] (pp. 8-10), and that risk management is an effective approach to prevent "firefighting" in later phases of the development process [Smith et al. 2002] (p. 11), [Thornton 2004] (p. 21). [Greenfield 2001] and [Griner et al. 2000] (pp. 40-44) identified a working risk management system in development as one of the main factors for the successful execution of a NASA Faster, Better, Cheaper mission.

Thus, risk management in Product Development can be considered a value adding activity and seamlessly integrates into the lean product development school of thought.

2.4.4.2 Goals of Risk Management in Product Development

The goal of risk management, in general, is to

- Explicitly, in a structure manner and proactively address risks in order to minimize the associated losses.

In product development, as discussed above and in section 2.4.6.3, this includes:

- Manage and decrease the uncertainty surrounding product attributes (Lead Time, Lifecycle Cost, Performance)
- Manage and decrease the uncertainty surrounding process attributes (Schedule adherence, Budget, Quality)

Which ultimately leads to

- Less firefighting
- Crisis prevention
- Reduction of surprise problems in late development phases
- Avoidance of reoccurrence of known problems
- Addressing of root cause
- Retaining of best practice solutions / organizational learning
- Cross functional integration

Figure 2-3: Goals of Risk Management in Product Development

(adapted from [Hall 1998] and [Smith et al. 2002])

2.4.4.3 Risk Management approaches in Product Development

This section will briefly discuss the risk management approaches which have been identified in the area of Product Development and which have been included in the detailed analysis in chapter 4.

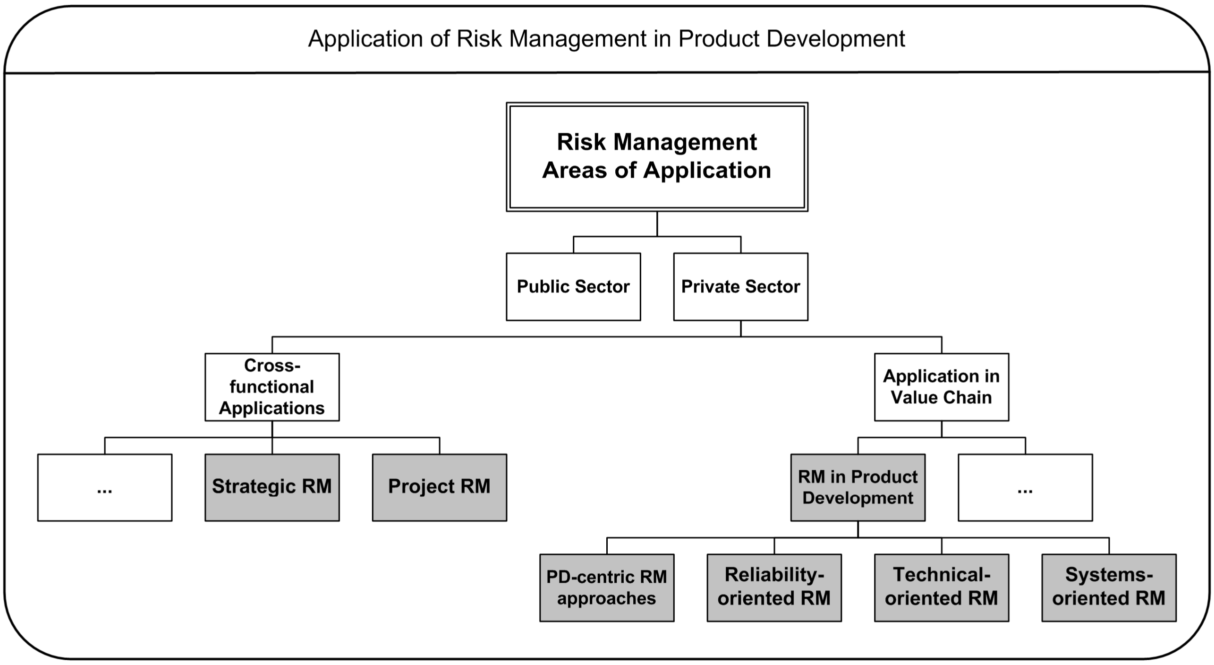

Figure 2-4: Areas of Application of Risk Management in Product Development

The following risk management methodologies in regard to service elements have been selected for further analysis (explanation given below):

- Strategic Risk Management
- Project Risk Management

Safety and Security-related approaches have been excluded due to the very specific nature of the risks they address. Financial risk management approaches have been excluded because they rely heavily on large amounts of quantitative, historical (but still applicable) data. This situation is seldom encountered in product development.

The approaches specific to product development risk management which have been identified and included in the further analysis are:

- Existing product development centric risk management approaches (including software development risk management)
- Reliability-oriented risk management
- Technical risk management

- Systems-oriented risk management

Brief descriptions of the different risk management approaches as listed above now follow:

Strategic Risk Management

It must be assured that a risk management System for Product Development can be seamlessly integrated into an overall corporate risk management System. This work addresses this issue twofold. Firstly, general risk management approaches are reviewed in the definition of the process structure for risk management in Product Development to assure that the requirements regarding its functionality are met. Secondly, a broad interdisciplinary and cross-boundary approach will be taken when identifying risks to assure that the operational interfaces to other risk management activities are clearly defined. [Wolf 2003], [Lessing et al. 2005], [Frame 2003]

Project Risk Management

Product Development projects and programs depend on project management. Thus, the newly emerging field of Project risk management will be taken into account..

Existing Product Development-centric Risk Management approaches

In the current literature on risk management in Product Development, only one work could be identified that addresses the Risks on a project level [Smith et al. 2002].

There is additional literature which focuses on the management of software development programs [Dorofee et al. 1996], [Hall 1998] and references therein.

Reliability-oriented Risk Management

[Evans et al. 2000] offer a design-focused introduction to product reliability. One of the main works in this area is [Birolini 2004], which covers the topic from probability theory to engineering methods. [Blischke et al. 2000] approach the subject from a business and engineering perspective. [Andrews et al. 2002] provide detailed mathematical descriptions of common methods, along with application examples. [Modarres et al. 1999] and [Ayyub 2003] give hands-on descriptions of common analysis methods. [Stamatelatos 2002] gives an overview from an aerospace point of view.

Technical-oriented Risk Management

[Browning et al. 2002b] connect risk management with lean product development by defining the reduction of performance risk as value creation. Based thereon, they introduce the risk value method, based on Technical Performance Measures and their Probability Density Function.

Another view on technical-oriented risk management focuses on the management of variation on products dimensions and features as a way to guide performance, cost and safety. The concept links Product Development and Production and has strong ties to Quality

Management, SPC, Six Sigma and Robust Design. They focus strongly on quantitative methods to address quantifiable variations in dimension and product performance, based on Key Characteristics which have been derived from the critical system requirements. See [Thornton 2004] (contains extensive references), [Parkins 1999] for an application example with management-oriented lessons learned.

Systems-oriented Risk Management

This approach to risk management in Product Development is from a whole-systems perspective. [Hastings et al. 2004a] present a framework to understand Risk in large-scale systems (e.g. in aerospace applications), which reads "Uncertainty" causes "Risk" handled by "Mitigation" resulting in "Outcome". For each of these four categories, they present general subcategories. They then continue to show how different approaches in handling risks combine different elements out of these categories. This approach offers value on a Systems level (which it was developed for), but their definitions become too inconsistent and fuzzy when applied to more detailed levels. [Hastings et al. 2004b] (chapter 12 therein) offers an interesting application example. Through industry studies, they identified “Risk in conceptual design” as the most important element.

2.4.5 Definition of Risk

In the general language use, risk is defined as “possibility of loss or injury” [MWOD 2005].

In the context of product development, [Smith et al. 2002] defines “uncertainty, loss and its time component” (p.5) as the three essential facets of risk. Risk is defined as the” possibility that an undesired outcome – or the absence of a desired outcome – disrupt the project.” [Hall 1998] defines risk as “the possibility of loss”. [Kaplan et al. 2001], focusing on reliability and safety applications, define risk as a triplet of a risk scenario, probability of the scenario, and the damage vector associated with the risk scenario. [Browning et al. 2002b] defines risk associated with technical product performance as the “uncertainty that a product design will satisfy technical requirements and the consequences thereof.”

For the definition of risk in this thesis, these definitions were combined and risk defined as

- an uncertain,
- time-related
- loss of value,
- being part of and influenced by complex dynamic networks of factors and/or events.

The first element captures the concept of uncertainty and probability of the risk definitions, the second element explicitly notes the time-related nature of risk, the third element integrates the definition of risk with the Lean school of thought (see section 2.2.3 for a discussion of the concept of value in lean product development), and the fourth and final element addresses the complex nature of risks as being part of causal networks rather than simple single cause-and-effect relations, as discussed in length by [Kaplan et al. 2001].

2.4.6 Axiomatic attributes of Risks and basic concepts for their description

Based on the definition of risk given above, four basic attributes are derived to describe any given risk. These are

- The probability of occurrence, based on a (more or less complex) causal structure,
- The timeframe of the risks development,
- The type and magnitude of the risks impact, and
- Causal networks describing the causes and effects of the risk (e.g. scenarios).

The first three attributes are elements that can be assigned to a single risk. The forth attribute is a meta-attribute that allows for the placing of a risk into a complex network of causes and effects, possibly containing a multitude of other risks.

2.4.6.1 Cause structure – the basis for deriving the probability of occurrence

Risks are usually caused by more than one single event, and can be caused by events from a wide variety of sources. The proper identification of the events leading to a risk is the first step in properly assessing its probability of occurrence. Maybe more importantly, it is also the key to understanding how to prevent the risk from occurring.

In order to facilitate this process, a generic causal structure is introduced. It is a general proposal and must always be customized to a companies situation (it is therefore never "complete"). The proposal presented here is based on [Milberg et al. 2002], [Zäh et al. 2002] and [Lindemann 2002]. It consists of four tiers that cover the spectrum of levels of influence the team might have on the causal factors.

The four tiers are:

- Program or project level
- Company level
- Supply Chain or Business to Business level, and
- Environment Level

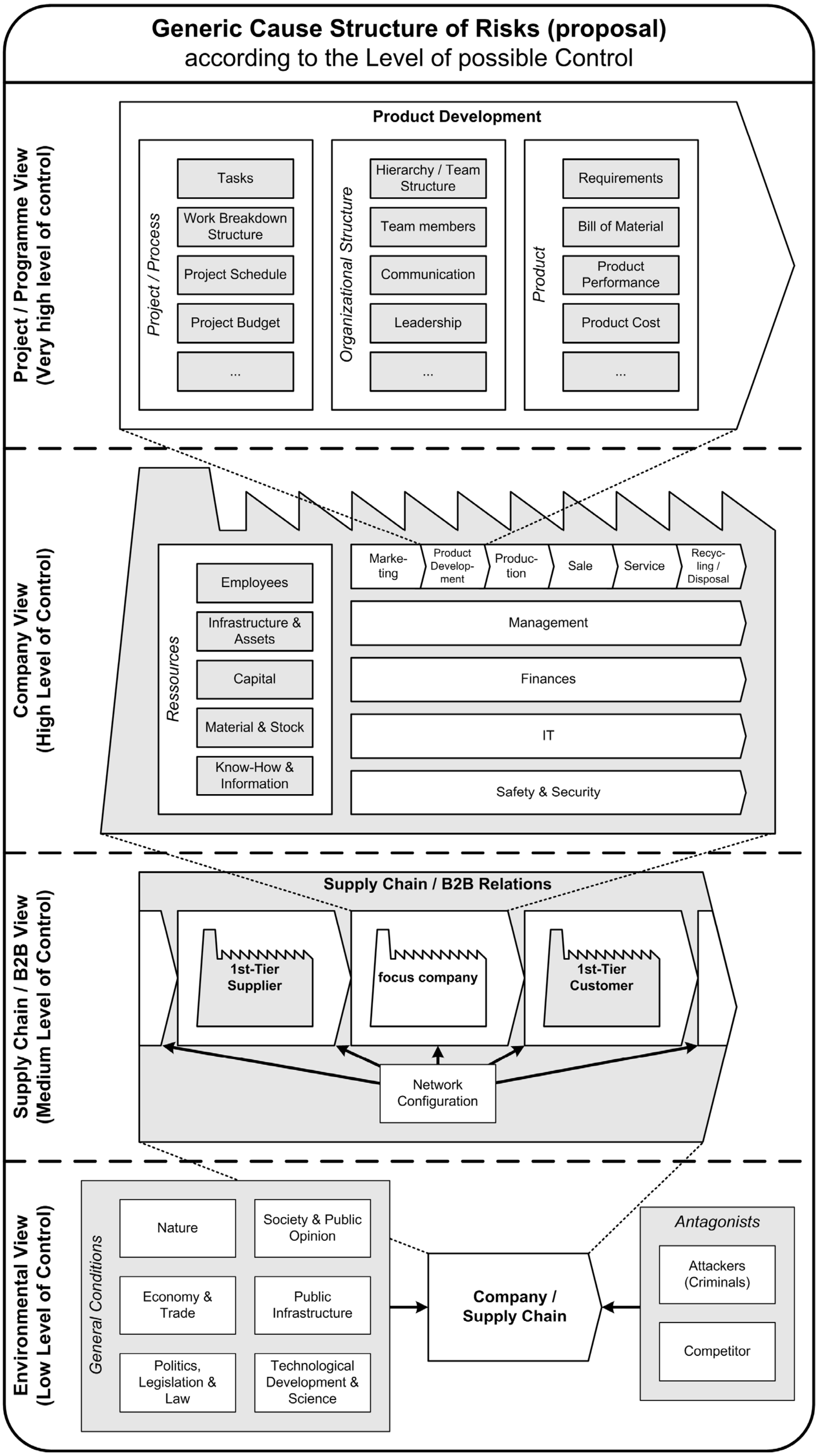

Figure 2-5: Possible structure for categorizing the sources of risk

The program or project level represents the highest level of control. It encompasses all factors that are directly under the control or associated with the development project or program. As an example, three categories are defined:

- Project / Process: This category includes all factors that relate to the project or process itself, for example the tasks, work breakdown structure, schedule, budget, generic processes, process requirement (e.g. quality management) etc.
- Organizational Structure: This category includes all factors that are related to organizational elements, for example the hierarchy, team structure, and other team factors (see section 3.3 for a detailed discussion of these factors).
- Product: This category includes all factors that are directly related to the product, for example the technical requirements, bill of material, parts geometry and definition, product performance, product cost, product lead time etc.

On the company level, there exists still a relatively high level of influence on the factors, as they are located within the companies direct sphere of influence. This level can for example be modeled with two groups of factors [Milberg et al. 2002], [Zäh et al. 2002]:

- Resources: This category includes the different types of resources, for example Employees, Infrastructure & Assets, Capital, Material & Stock, and Know How & Information, etc.
- Company functions: This category includes the processes along the value chain as well as the supporting processes, for example Marketing, Research, Product Development, Production, Sale, Service, Recycling & Disposal, Management, Finance, IT, Safety & Security, etc.

On the Supply Chain level or Business to Business level, the influence decreases as it can only be indirectly and through a dialogue be exerted on the partners. The following categories are proposed:

- Supplier: This category very broadly describes the suppliers of the company. It can further be refined, for example by splitting the supplier up into different tiers, or along attributes of the product they supply.
- Customers: This category describes the customers of the product. In case of an OEM, it might directly address the final customer, but also different tiers of customers are possible in case of a parts supplier. Similar to the supplier base, the category describing the customers can also be defined on a more detailed level.
- Network Configuration: This category includes the factors that describe in general the way that the supply network is set up and operated.

On the Environmental level, the influence that can be exerted is very small, as the factors are beyond the direct and indirect sphere of control of the company. It can be modeled along two main categories:

- General conditions: This category describes broadly the factors exist as boundary conditions for the company and play an important role, for example nature (including e.g. weather hazards and natural catastrophes), economy & trade (including e.g. economic cycles), politics, legislation & law (including e.g. labor regulations), society & public opinion (including e.g. the public perception of the company), public infrastructure (including e.g. transportation infrastructure), technological development & science (including e.g. new innovations), etc.
- Antagonists: This category describes the factors that work against the company, for example competitors or criminal attackers (including e.g. hackers, disgruntled employees, thieves, espionage and terrorism)

2.4.6.2 Description of the Timeframe of a Risk

The timeframe of the development and impact of a risk is seldom addressed explicitly (see section 4.4). It is therefore sufficient in a first step to arbitrarily define three categories, short term, medium term, and long term, to describe the timeframe of a risk (as done for example in [Hall 1998]).

Timeframe of risk	
Timeframe	**Description**
Immediate	immediate attention necessary
Short term	Needs attention in the near future
Medium term	Must be addressed at a later stage of the project
Long term	Only needs to be addressed in late stages of the project

Table 2-3: Description of the timeframe of a risk

2.4.6.3 Failure Modes – basis for describing losses

Similar to the causal structure that defines a basic structure to categorize causal factors influencing a risk, the Failure Modes provide the basic structure to discuss possible losses that might be incurred by a risk. Failure modes is a term borrowed from the FMEA literature. It describes the possible ways in which the functions of a system can fail [Zäh et al. 2002]. The application in risk management has been described, in addition to the FMEA literature, for example in [Rice et al. 2003].

The categories of possible losses are closely linked to the definition of value. A “loss of value” can by definition only occur for a pre-defined category of value, similar to the way a Failure Mode is being linked in FMEA to the system’s functions.

In analogy to the definition of the categories of value in lean product development (section 2.2.3), the categories of possible losses due to risks, or failure modes, are defined as follows:

	Generic Goals		
Objects	**Time**	**Cost**	**Quality**
Product	1: Increase of Lead Time	2: Increase of Lifecycle Cost	3: Reduction of performance
PD Process	4: Schedule overrun	5: Budget overrun	6: Non-Conformity to Standards

Table 2-4: The six Failure Modes in Product Development

2.4.6.4 Cause and Effect networks

In order to understand and describe a risk, the complex network of causes and effects surrounding the risk needs to be understood and described [Kaplan et al. 2001].

Generally speaking, every risk is part of three different networks of events and factors:

- A network representing causal relations and influences on the probability of occurrence
- A network influencing and defining the timeframe of the risk
- A network representing the relations influencing the type and magnitude of impact.

These three types of relations can be regarded as three layers of one large network of factors and events. One event can have multiple relations on any layer to any other events. Also, the risk itself is a central piece of the network, not its "end", as the risk for example might have a large influence on the network of events that define its impact, and which occur after the occurrence of the risk itself. Also, other risks can be part of the network.

Scenario methods are best suited to describe these networks. They are discussed in more detail in section 4.4.

2.4.6.5 A Brief discussion of possible Risk Taxonomies

After defining risk and introducing the basic attributes of risk, possible risk taxonomies are briefly discussed. A mutually exclusive and exhaustive categorization of risks is very difficult to achieve due to the network character of the causes leading to a risks and the network character of the impacts being possibly caused by a risk. Nevertheless, a categorization can always be logically stringent and as mutually exclusive and exhaustive as possible. In the literature, generic categories of risks are often presented that do not follow any logical stringency (e.g. defining Market risks (cause), Schedule Risks (impact) and Long-Term risks (timeframe) as generic categories for structuring risks). Every risk can at all times be categorized by any of the following categories (this list is not complete, but aims at outlining the general idea of stringent risk categorization):

Cause-oriented categorizations:

- Categorization by Causes of Risk (Schedule, WBS, etc…)
- Categorization by Likelihood of Risk

Impact-oriented categorization

- Categorization by type of impact (e.g. Budget overrun)
- Categorization by magnitude of impact

Time-oriented categorization

- Categorization by urgency of risk
- Categorization by dynamics of risk

Meta-oriented categorizations:

- Categorization by overall Risk Rating
- Categorization by Owner of Risk
- Categorization by Owner of Counteractions
- Categorization by …

The leading categorization of Risk and risk management for this work will be along the type of impact, i.e. the failure mode realized by the impact. The decision regarding the main categorization is somewhat arbitrary; however during the course of the research this type of categorization proved to be easily understandable and accessible by all dialogue partners.

2.4.7 Definition of Risk Management

The definition of risk management in the literature usually strongly emphasizes the process aspects of risk management. For example, [Hall 1998] defines risk management as “a general procedure for resolving risk”, or [Smith et al. 2002] defines risk management as “the activity of identifying and controlling [risks] proactively”.

In the context of this thesis, a broader definition of risk management is adopted which not exclusively focuses on the process but also acknowledges other elements necessary to discuss risk management.

In this thesis, risk management is therefore defined as a system consisting of the elements

- Risk Definition with the axiomatic attributes,
- Risk Management Process Framework,
- Risk Management Methods, and
- Organizational Structure associated with Risk Management.

The risk definition and the associated axiomatic attributes are discussed in sections 2.4.5 and 2.4.6 respectively. The risk management process framework is discussed in section 4.3, the risk management methods are addressed in section 4.4. This thesis does not explicitly address in detail the organizational structures for the implementation of risk management processes into a project. This question is addressed in the introduction to the discussion of risk management process frameworks (see before).

2.4.8 Fundamentals of probability and reliability theory

The following offers a very brief summary of some fundamental principles of probability and reliability theory from [Birolini 2004] (pp.363-409). A mathematically strict introduction can be found in the literature.

2.4.8.1 Probability

The probability of the favorable outcome (or event) A can be understood as

$$\Pr\{A\} = \frac{number\ of\ \ favorable\ outcomes}{number\ of\ \ possible\ outcomes}$$

Two events A and B are independent, if the information about the occurrence or the nonoccurrence of one event does not influence the probability of occurrence of the other event. In this case, the probability of A and B occurring can be calculated as

$$\Pr\{A \cap B\} = \Pr\{A\}\Pr\{B\}$$

For totally independent events A_i, the probability of all events A_i occurring is calculated as:

$$\Pr\{A_1 \cap A_2 \cap ...\} = \prod_i \Pr\{A_i\}$$

Two events A and B are mutually exclusive, if the occurrence of one event excludes the occurrence of the other event. In this case, the probability for event A or event B occurring is:

$$\Pr\{A \cup B\} = \Pr\{A\} + \Pr\{B\}$$

For totally exclusive events A_i, the probability of any event A_i occurring is:

$$\Pr\{A_1 \cup A_2 \cup ...\} = \sum_i \Pr\{A_i\}$$

Conditional probability for two is defined as the probability of and event B occurring under the condition of A having occurred:

$$\Pr\{B|A\} = \frac{\Pr\{A \cap B\}}{\Pr\{A\}}$$

Applied to arbitrary events A and B, this yields the probability of A or B occurring as:

$$\Pr\{A \cap B\} = \Pr\{A\}\Pr\{B|A\} = \Pr\{B\}\Pr\{A|B\}$$

In its generalized form for events $A_1 \ldots A_n$, this function becomes the multiplication theorem:

$$\Pr\{A_1 \cap \ldots \cap A_n\} = \Pr\{A_1\}\Pr\{A_2|A_1\}\Pr\{A_3|(A_1 \cap A_2)\}\ldots\Pr\{A_n|(A_1 \cap \ldots \cap A_n)\}$$

For arbitrary events A and B, the probability of occurrence of at least one of the events can be calculated as:

$$\Pr\{A \cup B\} = \Pr\{A\} + \Pr\{B\} - \Pr\{A \cap B\}$$

The distribution law of a random variable τ (in the following always a continuously random variable, not discrete) as a function of t is usually described by defining a distribution function F(t) as the probability of τ being smaller or equal to t:

$$F(t) = \Pr\{\tau \le t\}$$

The probability of τ taking on a value within the interval (a,b] thus is

$$\Pr\{a < \tau \le b\} = F(b) - F(a)$$

For continuous random variables τ, the distribution function F(t) is:

$$F(t) = \Pr\{\tau \le t\} = \int_{-\infty}^{t} f(x)dx$$

With f(t) being the probability density function of τ satisfying the condition:

$$\int_{-\infty}^{\infty} f(t)dt = 1$$

The expected value or mean E[τ] of the random variable τ is defined as

$$E[\tau] = \int_{-\infty}^{+\infty} tf(t)dt$$

In reliability applications, the mean E[τ] is identical with the mean time to failure (MTTF).

The variance Var[τ] is a measure of the spread of the random variable around the mean. It is defined as:

$$Var[\tau] = E[(\tau - E[\tau])^2] = E[\tau^2] - E[\tau]^2 = \int_{-\infty}^{\infty} (\tau - E[\tau])^2 f(t)dt$$

The standard deviation of τ is defined as

$$\sigma = \sqrt{Var[\tau]}$$

2.4.8.2 Reliability and Failure Rate

If the chance events are interpreted as component failures, the reliability function R(t) of an item gives the probability of a component working failure free in the interval (0,t] and is defined as:

$$R(t) = \Pr\{\tau > t\} = 1 - F(t)$$

The failure rate λ(t) of a component is the failure rate of a component at t. λ(t)δt is the ratio of items failed in the time interval (t,t+δt] It is defined as

$$\lambda(t) = \frac{f(t)}{1 - F(t)} = \frac{\frac{dR(t)}{dt}}{R(t)}$$

2.5 Crises and Crisis Management in Product Development

2.5.1 Crisis Management

A crisis can be understodd as a sudden event or set of circumstances that could

- threaten health, safety and well-being of employees, customers, neighboring communities or the public at large,
- significantly threaten the environment,
- significantly interrupt the business processes and / or
- significantly damage the company's reputation

(according to [Oehmen 2004]). Crisis Management is usually divided into different process elements, e.g. contingency planning, crisis recognition, containment, and crisis resolution [Barton 2004]. Often, business continuity management (or business continuity planning) is introduced to the mix as a subset of crisis management processes focusing on security aspects with the aim of providing a functional infrastructure (i.e. physical workspace and information technology) during crisis situations [Elliott et al. 2002]. [Callan 2002] offers a very detailed guideline, including checklists and forms, to cover the business continuity management part of crisis management.

There exists a host of literature on Crisis Management in Business: [Barton 2004] gives a broad overview over crisis management in a broad range of industries (airlines, chemical companies, food processors and financial service companies), addressing accidents, natural events, tampering, technological breakdowns, economic and market forces and rogue employees, outlining a systematic crisis prevention and management process. The planning phase of his model fits very well into the risk management process framework presented in this thesis. Similarly, [Mitroff et al. 2001] take a very broad look at crisis management, and also discuss ethical and psychological aspects of crisis management.

[Rosenthal et al. 2001] give an overview of the current academic research in the field of crisis management, but with a focus on crisis situations due to natural disasters, large-scale technical failures, criminal or terrorist activity, and failures of public bodies.

Throughout the Crisis Management literature, the internal and external communication during a crisis situation is always regarded as especially important. [Coombs 1999] is one of the main works dealing with the aspect of communication throughout crisis management, from the detection of early warnings regarding a crisis situation to postcrisis actions. [Seeger et al. 2003] similarly stresses the role of communication in crisis management.

[Töpfer 1999][1] introduces a typology of crises along its life cycle. He differentiates between potential, latent and acute crises. According to this model, he defines a phase model of crisis management consisting of the five phases of prevention, early detection, crisis containment, recovery as restart, and learning from the crisis. Töpfer further differentiates crisis prevention into crisis avoidance and preparation for eventual crisis. He also divides crises into foreseeable and unforeseeable crisis. Foreseeable crises can be avoided, unforeseeable crises can, in the best case, only be prepared for. In this sense, this thesis deals with crisis avoidance in Product Development for foreseeable crises.

Töpfer also introduces five levels of Crises Management:

- Process and subject level: Events before, during and after a crisis situation, in their dynamic and thematic relation.
- Internal and external information level: Type and source of information, especially related to an early and comprehensive detection of possible causes of a crisis.
- Organizational Level: Processes and structures for crisis management
- Internal and external communication level: Communication of information regarding the incident and the initiated response to all stakeholders, including the media, customers, employees, management, stockholders and the general public.
- Psychological Level: Effects of the events, actions and information in the course of the development of the crisis on directly and indirectly affected people.

2.5.2 The relation of Crisis Management and Risk Management

In general, crisis management applies to risks with a high potential impact. Planning for crisis management and crisis prevention can therefore be seen as specific actions initiated to reduce the likelihood of occurrence (crisis prevention) and the magnitude of the impact (crisis management) of crises due to high impact risks. Risk management provides the framework for identifying these risks and tracking the measures taken as part of the crisis management planning efforts.

[1] All terms related to this work have been translated by me from German, and I am to blame for inaccuracies therein.

In the case of crisis prevention, risk management also serves to eliminate the root causes of potential crises. In this form of application, the risk management approaches discussed in the following relate to crisis prevention.

This work relates to crisis management along the previously discussed structure in the following way:

Level	Phase in Crisis Management
	Prevention
Process and subject level	Cause structure of risks (see above) and according risk scenarios (see section 4.4)
Internal and external information level	Risk Identification and Assessment
Organizational level	Team Structure (structures) and risk management processes and methods (processes)
Internal and external communication level	Only internal communication applies during Prevention-phase. Directly addressed by Team Structure, indirectly by Risk Management process
Psychological level	Indirectly by giving the agents of crisis management confidence due to the structured analysis and preparation process

Table 2-5: Relation of this work to Crisis Prevention

2.5.3 Crises in Product Development

Crises in Product Development represent a specific subset of these generic cases. According to [Lindemann 2004], they are typically characterized by

- Unexpected and / or unwanted event
- Occurrence late in development process
- High degree of necessary changes
- Very high time pressure and pressure for results

He discerns three generic crisis scenarios in product development:

- Scenario 1:During the product development process itself, no problems become apparent and the situation seems under control. Only after the market introduction of the product, grave problems become visible that needs to be resolved quickly in order to sustain the product in the market.
- Scenario 2: During the testing of system components, large performance gaps become apparent that threaten a timely market introduction of the product. With the

help of preventive measures, the performance gap can be closed until the scheduled market introduction of the product.

- Scenario 3: A performance gap in the product is only detected shortly before the market introduction. The performance gap cannot be closed until the scheduled market introduction, and the introduction has to be postponed.

In this thesis, an additional dimension of structuring crises in product development will be introduced, namely by the type of impact of the crisis. The crisis types are derived from the definition of value in product development (see section 2.2.3), and the subsequent definition of failure modes in product development related risk management.

	Generic Goals		
Level	**Time**	**Cost**	**Quality**
Product	Large scale increase in product lead time	Large scale increase in product lifecycle cost	Large scale decrease in product performance
PD Process	Large scale schedule slippage	Large scale budget overrun	Significant derivation from process standards

Table 2-6: Crisis types in product development according to type of impact

The six generic types of crisis, according to the type of impact, can be defined as:

- Large scale schedule slippage: The schedule of the product development process cannot be held, which ultimately leads to a later market introduction of the product
- Large scale budget overrun: The planned budget for the product development process is exceeded to a significant degree
- Significant derivation from process standards / requirements: Important process standards are neglected with potentially serious consequences (e.g. documentation of the testing of medical products is not available in a lawsuit)
- Large scale increase in product lead time: The product cannot be provided fast enough to the customer after the development process is complete, potentially resulting in the loss of significant market shares.
- Large scale increase in product lifecycle cost: The product lifecycle cost is significantly higher than accepted by the market, potentially resulting in the loss of large market shares.
- Large scale decrease in product performance: The product performance does not meet the customer expectations in important aspects, potentially resulting in the loss of significant market shares.

2.6 Summary of this chapter

In this chapter, the fundamental concepts were introduced needed to discuss crisis prevention in lean product development through high performance teams and risk management.

It was shown that, based on the Munich Procedural Model, both high performance teams and risk management play an important role in crisis prevention (section 2.1).

Lean product development was introduced (section 2.2). Especially important for this thesis is the definition of the categories of value as

- Lead time: All activities that lower the lead time of the product are value adding.
- Lifecycle cost: All activities that lower the lifecycle cost of the product (including the cost of production, the operating cost, service cost and recycling cost) are value adding.
- Performance: All activities that increase the performance of the product in regard to the customer expectations and requirements are value adding.
- Schedule: All activities that support the schedule adherence of the product development process (and all activities that shorten the length of the process) are value adding.
- Budget: All activities that support the product development process staying on budget (and all activities that decrease the cost) are value adding.
- Process Standards: All activities that support the adherence of the product development process to certain standards (e.g. quality management) perceived as value adding by the stakeholders, are value adding.

High performance teams were defined as teams that “consistently satisfy the needs of customers, employees, investors and others in its area of influence” with the result that “these teams frequently outperform other teams that produce similar products and services under similar conditions and constraints” (section 2.3). This implicitly states their crisis prevention capabilities.

For risk management, an overview was given over the different areas of application. The different approaches to risk management in product development were derived from the literature (section 2.4.4), being

- Strategic Risk Management
- Project Risk Management
- Existing product development centric risk management approaches (including software development risk management)
- Reliability-oriented risk management
- Technical risk management
- Systems-oriented risk management

Risk was defined (section 2.4.5) as

- an uncertain,
- time-related
- loss of value,
- being part of and influenced by complex dynamic networks of factors and/or events.

Based on this definition, axiomatic attributes of risk were derived and basic concepts for their description introduced (section 2.4.6). These are

- The probability of occurrence, based on a (more or less complex) causal structure. A model for a causal structure was proposed consisting of the four levels of influence “Project or program level”, “Company level”, “Supply Chain or Business to Business level” and “Environmental level”.
- The timeframe of the risks development, with the four levels of “immediate”, “short term”, “medium term” and “long term”.
- The type of the risks impact, categorized along the six generic Failure Modes in product development, „Increase of Lead Time“, „Increase of Lifecycle Cost“, „Reduction of performance“, „Schedule overrun“, „Budget overrun“, and „Non-Conformity to Standards“
- Causal networks describing the causes and effects of the risk (e.g. scenarios).

risk management was defined (section 2.4.7) as a system consisting of the elements

- Risk Definition with the axiomatic attributes,
- Risk Management Process Framework,
- Risk Management Methods, and
- Organizational Structure associated with Risk Management.

Crises and crisis prevention in product development were discussed, and the relation of risk management and high performance teams to „classical” crisis prevention frameworks discussed (section 2.5).

Crises in product development (section 2.5.3) were defined as

- Unexpected and / or unwanted event
- Occurrence late in development process
- High degree of necessary changes
- Very high time pressure and pressure for results

3 High Performance Teams in Product Development

As has been discussed in section 2.1.2, high performance teams can be an important factor in crisis prevention. This chapter looks at high performance teams in product development in more detail. Section 3.1 outlines the research methodology employed, section 3.2 summarizes the literature base of the following discussion, section 3.3 describes the main factors that have been identified describing high performance teams, section 3.4 presents a characterization of these factors, and section 3.5 discusses the result of the characterization.

The overall goal of this chapter is to better understand the factors determining high performance teams.

3.1 Research Methodology

3.1.1 Identification of Product Development Programs and Projects

Based on the definition of high performance teams as teams that "consistently satisfy the needs of customers, employees, investors and others in its area of influence" with the result that "these teams frequently outperform other teams that produce similar products and services under similar conditions and constraints" [Kur 1996] (see section 2.3), an extensive literature research was conducted to

- identify examples describing high performance teams in product development and
- identify general literature on high performance teams.

As a starting point, interviews were conducted with professors and experts in the field of product development at MIT. From these interviews, companies, products, programs and other key word where identified, in addition to concrete literature recommendations.

From there, books and papers where identified and detailed forward and backward searches were conducted (based on keywords, authors and references) for all these elements, utilizing the following resources:

- MIT's Barker Library Database (books and conference proceedings)
- Engineering Village 2 (large database for engineering-related papers and articles)
- Proquest Database (large database for economics and management related papers and articles)
- Google (large Internet search engine)
- Amazon.com (large database for books, especially the citation-features where used for forward and backward tracking)
- Company and other specialized internet sites

3.1.2 Identification of main factors of High Performance Teams

The identification of the main factors was done in two steps, analysis and synthesis.

3.1.2.1 Holistic and systematic analysis of literature

In the analysis step, the literature cited above was systematically analyzed to identify the factors that were cited as facilitating the workings of high performance teams.

The goal was to take a holistic and systematic view at the situation of high performance teams. The holistic view calls for an analysis not only of the team itself, but of its relation to the environment and environmental processes. The systematic analysis was achieved by defining a general structure for the analysis of the literature (see Figure 3-1), taking the Product Development process, the associated company internal processes of the value chain and the associated external processes of the value chain into account.

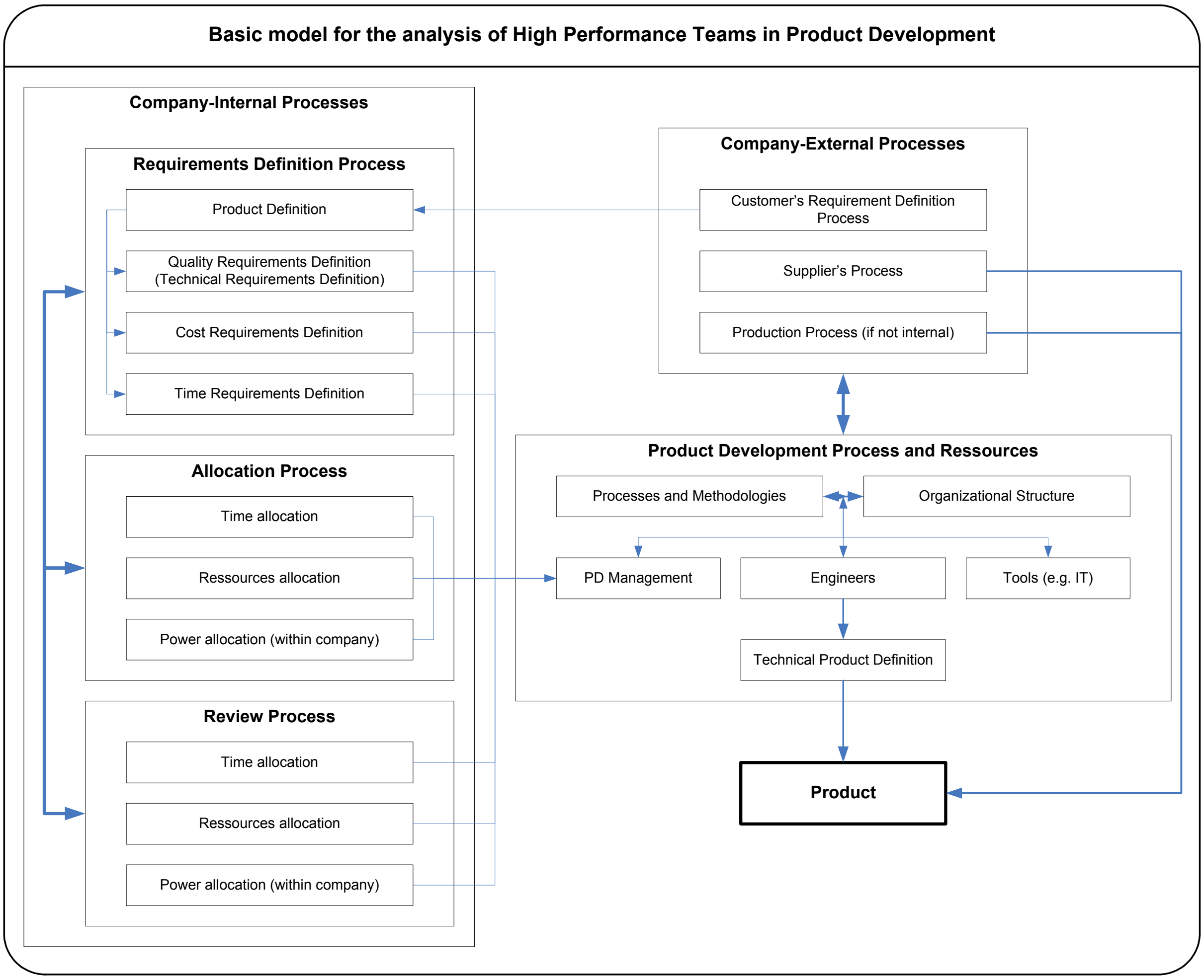

Figure 3-1: Basic model for the analysis of High Performance Teams

3.1.2.2 Synthesis of main factors of High Performance Teams

The results of the analysis where synthesized to a manageable number of factors by grouping them along a simple system model of team workings, describing attributes and processes on the levels of the individual member, the team, the member-to-member relation and the team-to-environment relation. The multitude of factors were grouped according to this structure, and, where possible, summarized. Also, only factors where taken into account that had been identified by several different sources.

3.1.3 General description of Influence Diagram (according to Vester)

3.1.3.1 Background, goal and reason for application

In order to analyze and characterize the complex relationship between the factors determining high performance teams, an Influence Diagram according to Vester was utilized. The following introduction is based on Vester's fundamental work [Vester et al. 1980] and the updated presentation of his method in [Vester 2002]. The literal translation of his systems analysis method is "sensitivity model", but in order to avoid confusion with other systems engineering methods, it will be translated as "Influence Diagram (according to Vester)" in this thesis.

The goal of this method is to analyze and characterize the relationship between elements of a complex system. This method is especially well suited for application, because it

- Aims at complex socio-technical systems
- Assesses of the role of system components
- Can be performed with reasonable effort
- Can be communicated to and understood by others with reasonable effort

(according to [Vester 2002])

3.1.3.2 Process Outline

Simplified, the method consists of four steps:

- Defining the system and the elements of the system for analysis
- Assessing the influence that the system elements exhibit on each other
- Calculating Active Sums and Passive Sums as basic characterization of elements
- Plotting of system elements in the Influence Diagram
- Assessment of system elements

In the following, every process element will be discussed in more detail. The theoretical discussion will be illustrated by an example related to this thesis.

3.1.3.3 Definition of System and system elements

The system being analyzed is usually roughly defined by the problem definition. Systems Engineering offers methods to refine and clarify the definition (e.g. System definition and analysis in [Züst 2000] (pp. 74-86), or methods in [Haberfellner et al. 2002] like Black Box (p. 443), Input-Output Models (p. 483), network thinking (p. 549) and others.

Vester himself offers a broad approach to identify possible system elements by checklists which address possible physical and dynamic basic characteristics of elements, as well as possible relations of the elements amongst each other and the environment [Vester 2002] (pp. 218 – 222).

In this thesis, the system analyzed was a "generic" high performance team, and the system elements are represented by the different factors identified describing High Performance teams.

As an example, let's assume that our analysis yielded the four factors as defining high performance teams:

Factors defining High Performance Teams (Example)
Quality of Results
Coaching of inexperienced by experienced team members
Performance Incentives
Motivation of Team Members

Table 3-1: Example of definition of system elements

3.1.3.4 Assessment of influence System elements exhibit on each other

In the next step, the mutual influences, which the system elements have on each other, are analyzed. [Vester et al. 1980] proposes using a complex system model to quantify the influences, [Vester 2002] additionally proposes the usage of Influence matrices, which greatly simplify the assessment process. Influence matrices are also described in other systems engineering resources, e.g. [Haberfellner et al. 2002], (pp. 558-559). In an influence matrix, the system elements are represented in the first row and column. Then, the strength of the influence of the system elements on other system elements is assessed on the basis of the system model defined in the step before. The strength of the influence from a row-element on a column-element is noted in the according intersection in the matrix.

In our example, the four factors "Quality of Results", "Motivation", "Coaching" and "Performance-based incentives" have a multitude of mutual influences. We could say that "Motivation" strongly influences the "Quality of Results", helps "coaching", and also makes the application of "Performance-based incentives" a bit easier. On the other hand, "Motivation" itself is influenced by the "Quality of the results", as well as strongly by "coaching" and a bit by "Performance-based incentives". Representing no influence by a zero, some influence by a 1, and a strong influence by a 3, the complete matrix is as follows:

Influence …	**From (right)**	Quality of results	Coaching	Performance I.	Motivation
To (below)					
Quality of results			3	0	3
Coaching		0		0	1
Performance Incentives		0	0		1
Motivation		1	3	1	

Table 3-2: Example influence matrix

3.1.3.5 Calculating Active Sums and Passive Sums as basic characterization of elements

For a basic characterization of each element, the active sum and passive sum are calculated. The active sum describes how strongly an element influences other elements in the system, the passive sum describes how strongly a system element is influenced by the other elements. The calculation is done by summing up the values of the matrix for every element along the column to derive the active sum, and along the rows to derive the passive sum.

Additionally, for every element the product and quotient of active and passive sum can be calculated. A high product value implies that changes of this element will also result in strong feedbacks into the system, if the product is small, a neutral behavior can be expected from the element. The quotient of active sum divided by passive sum indicates how strongly an element is defined by other elements: A high quotient indicates that an element can relatively easily influence the system, without experiencing feedbacks. A low quotient indicates that the element itself is mostly governed by other elements in the system. [Haberfellner et al. 2002] (pp.558-559).

In our example, the active and passive sums are as follows:

Influence …	From (right)	Quality of results	Coaching	Performance I.	Motivation	Passive Sum (PS)
To (below)						
Quality of results			3	0	3	**6**
Coaching		0		0	1	**1**
Performance Incentives		0	0		1	**1**
Motivation		1	3	1		**5**
Active Sum (AS)		**1**	**6**	**1**	**5**	
Product (AS * PS)		**6**	**6**	**1**	**25**	
Quotient (AS / PS)		**0,18**	**6**	**1**	**1**	

Table 3-3: Example influence matrix with active and passive sums

3.1.3.6 Plotting of system elements in the Influence Diagram

In the next step, the factors are plotted in a diagram according to their active and passive sum.

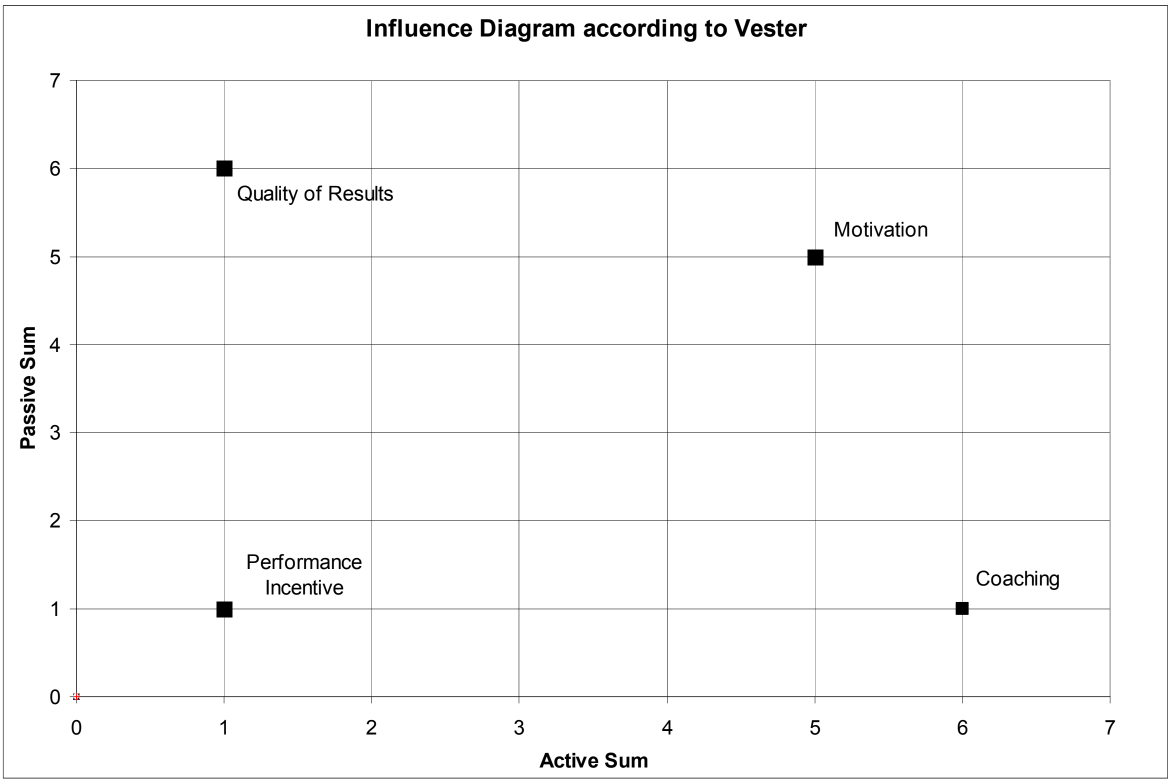

Figure 3-2: Simple influence diagram (example)

3.1.3.7 Assessment of system elements and their roles

The elements can now be assessed in regard to their role in the system [Vester et al. 1980] (pp. 142-143), [Vester 2002] (pp. 234-238), [Haberfellner et al. 2002] (pp.558-559). For this assessment, the

- Active and passive sum, as well as the
- Product and quotient thereof

can be used.

In this work, we define four different roles of elements:

- **Drivers:** Drivers are elements that have a strong influence on the system, but are themselves not strongly influenced by the system. They represent the ideal control element, because changes can easily be achieved due to their strong influence, but unpredictable feedback loops which could potentially lead to unwanted results can be minimized. Drivers are characterized by a high active sum and a low passive sum, or a high quotient and usually mid-range product value.
- **Critical elements:** Critical elements are elements that both have a strong influence on the system, but are also strongly influenced themselves by the system. They can possibly cause complex effects in a system which might be difficult to control and therefore have to be watched and treated very carefully. The are characterized by a high active and passive sum, or a high product and mid-range quotient value.
- **Indicators:** Indicators are elements that are strongly influenced by the system, but they do not strongly influence the system itself. They are very well suited to display and make transparent the current state of the system, but are unsuited to exert any influence on the system. Indicators are characterized by a low active and high passive sum, or by a high quotient and mid-range product.
- **Enablers:** Enablers are elements that seem to have weak links with the system and are neither strongly influenced by the system, nor influence the system strongly. However, this does not imply that these factors are "unimportant". They might be necessary for the proper working of other factors, hence the naming "enablers". They are characterized by low active and passive sums, or small product values. The quotient is arbitrary.

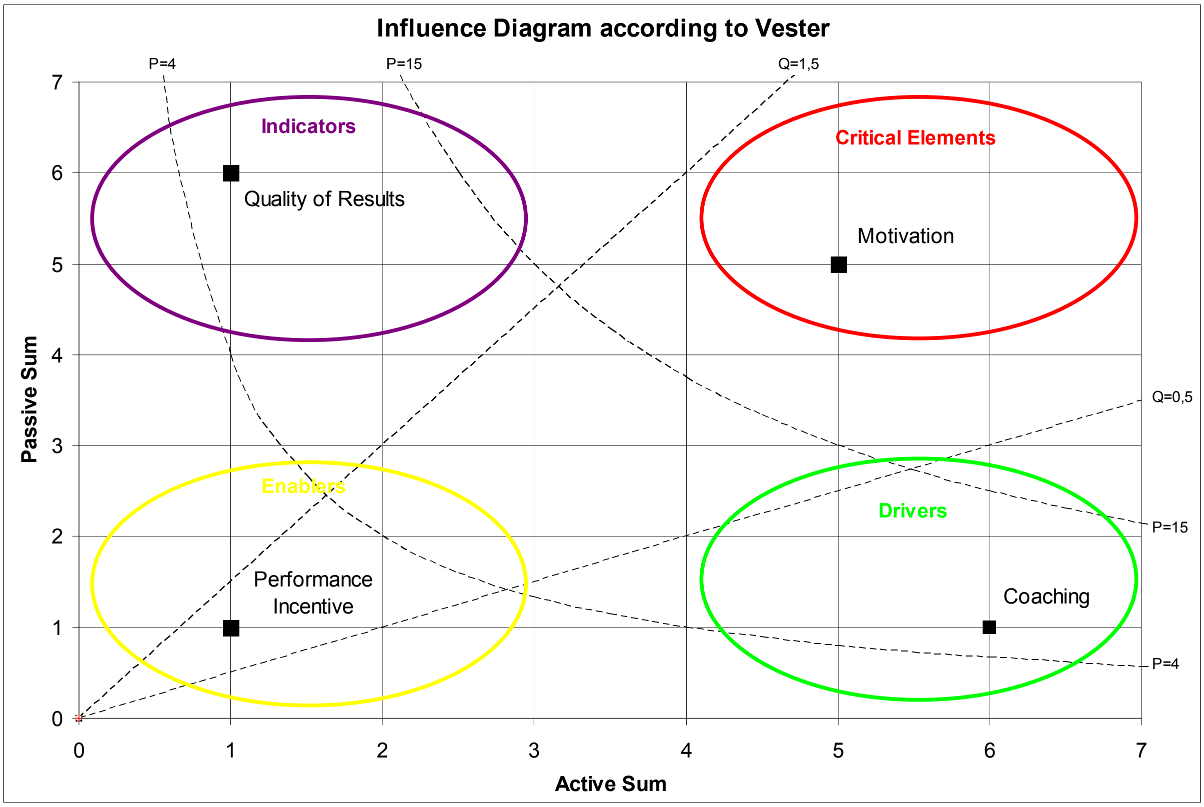

Figure 3-3: Influence diagram with assessment of system elements (example)

3.1.4 Specific Application of Influence Diagram (according to Vester)

For the application of the method in the context of this work, the most important specific characteristics are the following:

- As the system elements on which the analysis is based, the factors identified by the literature as important for high performance teams are used. This does not strictly follow a classic system analysis process, although elements of system analysis were used in the definition of the factors.
- The mutual influences of the elements were quantified with an influence matrix, as explained with the example in the section before, not a complex system model. An exponential scale of 0 – 3 – 9 was used to reflect the assumed non-linear nature of the relationship. [Lindemann 2002] (chapter 4).

Scale Value	Description
9	Very strong positive influence, influencing factor is necessary for influenced factor
3	Noticeable positive influence, influencing factor noticeably supports influenced factor
0	There is no influence from the influencing to the influenced factor
-3	Noticeable negative influence, influencing factor noticeably constrains influenced factor
-9	Very strong negative influence, influencing factor effectively disables influenced factor

Table 3-4: Definition of scale values for influence matrix

- In order to assure that a coherent system is discussed, all factors causing a "-9" influence were eliminated. A "-9" influence basically points out a contradiction in the model, as two factors seem to be incompatible to each other. This was done in such a way as to eliminate all "-9" influences with dropping the smallest possible number of factors.

- The quantification was first done by the author. Due to the high number of nearly 2500 influences, the matrix could not be discussed in its entirety with others. Excerpts of the matrix were discussed with partners at MIT and industry. No significant deviations in the assessment could be found. The matrix was then updated by the author to reflect some minor differences in the assessment, and an effort was made to apply the rationale behind the different assessments of the factor to other factors as well which were not explicitly discussed.
- Thus, the robustness of the assessment could be demonstrated by punctually verifying the results [Lindemann 2002] (chapter 4).
- One positive side effect of the large number of influences is the robustness resulting from the Gaussian distribution of possible errors. Due to the high number of assessments, the effect of wrong assessments is relatively likely to be cancelled out by other wrong assessments.

3.1.5 Field Study

A field study was conducted to discuss and possibly verify or falsify the findings of the literature review and analysis. Please see chapter 6 for a detailed discussion.

3.1.6 Limitations of approach

The limitations of the research approach regarding the selection of the projects and programs under consideration is that the process prefers "popular" examples which are well covered in the literature (e.g. Mars Pathfinder and Lockheed Martin Skunk Works).

Regarding the application of Vester's Influence Diagram, only a simplified system model was used where contradicting and limiting factors were eliminated. Also, the quantifications of the relations were discussed, but cannot be considered 100% objective. It is also important to note that the factors who might be very important from an engineering point of view do not necessarily emerge as a driver or critical element in this analysis, as the focus put on team performance.

3.2 Literature base of discussions

The following resources represent the selection from the results of the literature search which were included in the review:

3.2.1.1 General papers on High Performance Teams:

[Ancona et al. 1992], [Ancona et al. 2002]	Introduction to the concept of X-teams as high performance teams in business
[Quinn 1985]	Discussion of mechanisms that large corporations can use to stay competitive and encourage behavior similar to small entrepreneurial ventures
[Castka et al. 2001]	Introduction to and discussion of high performance teams
[Pearce 2004]	Stresses shared responsibility, team design and boundary design and discusses the according preconditions
[Gustafson et al. 1994]	Specific summary of attributes of high performance teams
[Ranney et al. 1995]	Discussion of industry example of high performance teams in new product development
[Ehlen 1994]	Discussion of obstacles for high performance teams and steps to build such teams
[Kur 1996]	General model to describe high performance teams, including a review of the literature
[Peters 2004]	Definition of Performance from a high performance team point of view, special emphasis on the problems resulting from a hostile environment
[Eggensperger 2004]	Discussion of high performance teams in the military sector, only partially applicable to this analysis
[Hyman 1993]	Industry example of high performance team in software

	development
[Katzenbach et al. 1993]	General discussion of high performance teams in business environments
[Labich 1996]	Discussion of high performance teams in non-business environments (military, sport, music, healthcare, firefighting)

3.2.1.2 Books and papers on Lockheed Martin Skunk Works

[Johnson et al. 1985]	The personal account of Kelly Johnson, the legendary founder and manager of the Lockheed Martin Skunk Works, of his work
[Rich 1994]	Ben Rich, the manager to follow Kelly Johnson, discusses his experiences with Johnson and his leadership style.
[Rich et al. 1994]	Summary of Johnson's and Rich's management philosophy (the famous "14 rules").
[Vasilash 1992]	Discussion of high performance teams in aerospace development
[Webb 1998a] and [Webb 1998b]	Short biography of Kelly Johnson and his management style
[Harwood 1993]	History of Lockheed Martin, contains some information on Skunk Works
[Sawyer 2001]	Brief discussion of the Skunk Works working style

3.2.1.3 Books and Papers on Mars Pathfinder and other Faster, Better, Cheaper missions

[Shirley et al. 1999]	Donna Shirley, manager of the rover development for Mars Pathfinder, gives her account of the development of the Sojourner mars rover
[Muirhead et al. 1999]	The account of Brian Muirhead, flight system manager, of the Mars Pathfinder mission
[Mishkin 2003]	Andrew Mishkin, a systems engineer for the Sojourner rover, describes the Mars Pathfinder mission
[McCurdy 2001]	Detailed discussion of NASA's Faster, Better, Cheaper programs
[Spear 1998]	Summary of Tony Spear, project manager, of the Mars Pathfinder mission, including important lessons learned
[Spear et al. 2000]	Discussion of the status and future work regarding the implementation of the Faster, Better, Cheaper philosophy at

	NASA
[Paté-Cornell et al. 2001]	Detailed analysis of the success factors of Faster, Better, Cheaper missions
[Marcopulos 1998]	Description of Faster, Better, Cheaper development from a supplier's perspective
[Young et al. 2000]	Young report analyzing the causes of Faster, Better, Cheaper mission failures
[Goldin 2000]	Remarks by Daniel Goldin, NASA administrator, to the JPL development team addressing Faster, Better, Cheaper challenges
[Griner et al. 2000]	Framework for NASA to increase mission success presented by a task force led by NASA chief engineer Brian Keegan.
[JPL 2000]	Results of a special review conducted at the Jet Propulsion Laboratory after the loss of the Mars Polar Lander and Deep Space 2 missions.
[Greenfield 2001], [Cornford et al. 2001]	Description of the role and approach towards risk management in successful JPL teams

3.2.1.4 Books and Papers on other highly successful product development teams

[Kidder 1981]	Description of a very successful development of an early microcomputer at Data General
[Rhodes 1986]	Description of the Manhattan project, where a nuclear weapon was developed in record time
[Hiltzik 1999]	Describes development processes at Xerox' Palo Alto Research Center (PARC), famous for its far-reaching innovations
[Westrum 1999]	Description of the development of the sidewinder missile

3.3 Description of main factors

The following briefly describes the main factors identified in the analysis of high performance teams. All the factors discussed are closely related to each other. The relations will be investigated in the systems analysis of the next section, and are not part of the following description. The factors are described according to the different levels, in alphabetic order.

3.3.1 Individual Team Member Level

3.3.1.1 Hand-picked members

All team members are hand-picked by the project manager. Ranney notes that this selection process should be repeated in preparation of every new project phase. This ensures that the team members perfectly reflect need for expertise as seen by the project manager and it ensures that team members have at least a "basic fit", since they went through the same selection process

[Johnson et al. 1985], [Rich et al. 1994], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Shirley et al. 1999] (p.150), [Hiltzik 1999], [Rhodes 1986], [Kidder 1981], [Quinn 1985], [Mishkin 2003], [Westrum 1999], [Rich 1994], [Pearce 2004], [Gustafson et al. 1994], [Ranney et al. 1995]

3.3.1.2 Hands-on work on product

Encourage and enable engineers to hands-on work and experience with the product they are designing, with the idea of supporting an improvement in design quality and to support a quicker and more reliable error correction.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Muirhead et al. 1999], [McCurdy 2001], [Hiltzik 1999], [Rhodes 1986], [Kidder 1981]

3.3.1.3 High degree of motivation

A high degree of motivation of all team members is regularly identified as an important factor. This factor describes the degree of willingness of the team members to utilize all their abilities to the highest possible degree. The literature review shows that motivation is a complex factor, which is subject to many different influences.

[Peters 2004], [Castka et al. 2001], [Gustafson et al. 1994], [Ranney et al. 1995], [Katzenbach et al. 1993], [Shirley et al. 1999], [Kidder 1981], [Hiltzik 1999]

3.3.1.4 High degree of qualification

The qualification of a team member describes the degree to which she or he is able to fulfill the demands that she or he faces throughout a project. In this analysis, qualification addresses both technical or engineering qualifications as well as social and organizational qualification, depending on the role of the team member. It also includes the notion that the potentials and qualifications of team members are realized and utilized accordingly.

[Castka et al. 2001], [Peters 2004], [Katzenbach et al. 1993], [Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [[Shirley et al. 1999], [McCurdy 2001], [Kidder 1981], [Hiltzik 1999]

3.3.1.5 Identification of members with team goals

All team members identify with common time, cost and quality goals and with the greater vision driving the project. This results in a higher motivation and is a key enabler for team members to act responsibly.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Muirhead et al. 1999], [McCurdy 2001], [Goldin 2000], [Hiltzik 1999], [Rhodes 1986], [Kidder 1981], [Quinn 1985], [Gustafson et al. 1994], [Ehlen 1994]

3.3.1.6 Proactive solving of problems

Team members proactively try to discover and solve problems. They do not try to hide or obscure problems, or blame them on others. Instead, problems are openly discussed and a constructive way of solving them is sought. This element is sometimes “hidden” within descriptions of a “positive team culture”.

[Castka et al. 2001], [Shirley et al. 1999], [Hyman 1993], [Spear 1998], [Kidder 1981]

3.3.1.7 Seamless Employment / Sequential Multitasking

The idea of Seamless Employment or Sequential multitasking is that a engineer is responsible for the product throughout its life-cycle, changing functions accordingly (e.g. from requirements definition, through different design phases, in production, assembly, and operation). It aims at creating a learning effect and deep understanding of the product and the associated processes, a retaining of knowledge, and fosters a feeling of “ownership” and responsibility.

[Johnson et al. 1985], [Rich et al. 1994], [Muirhead et al. 1999], [McCurdy 2001], [Kidder 1981], [Spear 1998], [Ranney et al. 1995]

3.3.2 Team Level

3.3.2.1 Alignment of responsibility and freedom of execution

The team is held responsible for the proper execution of a task. At the same time, it is given the freedom to execute the task in the way the team sees fit. This increases the motivation of the team and minimizes the amount of micro management.

[Greenfield 2001], [Spear 1998], [Pearce 2004], [Gustafson et al. 1994], [Ehlen 1994], [Muirhead et al. 1999], [McCurdy 2001], [Goldin 2000], [Shirley et al. 1999] p.149], [Hiltzik 1999],

3.3.2.2 Capturing of Lessons Learned

The problems and errors occurring during a project are documented along with their causes and strategies for avoidance or corrections (once they occurred) for following projects.

[Johnson et al. 1985], [Spear 1998]

3.3.2.3 Clearly defined, short and long term goals

The short and long term goals must be clearly defined. The short term goals must be well aligned with overall long term goals. This includes the general overall purpose definition as well as specific performance targets to provide clear directions for the team members.

[Katzenbach et al. 1993], [Gustafson et al. 1994], [Castka et al. 2001], [Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Shirley et al. 1999], [McCurdy 2001],

3.3.2.4 Collocation

The team is physically collocated at one office location, with all necessary support functions in the vicinity. This approach greatly eases communication among team members.

References:

[Johnson et al. 1985], [Rich et al. 1994], [Harwood 1993], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Hiltzik 1999], [Rhodes 1986], [Kidder 1981], [Quinn 1985], [Paté-Cornell et al. 2001], [Hyman 1993]

3.3.2.5 Common approach

All team members follow the same overall approach in solving the problem. This includes social, administrative and economic aspects. The administrative and economic aspects imply that all team members do about the same amount of work, have a common project schedule, a common understanding of responsibilities for tasks and a common decision making process. The social aspects imply agreement on the persons assuming different roles, e.g. leadership and social roles within the team.

[Katzenbach et al. 1993], [Ancona et al. 2002], [Johnson et al. 1985], [Rich et al. 1994], [Rich 1994],

3.3.2.6 Employment of best-practices model as overall process model

An overall process model for requirements definition, strict reviews of schedule, budget, and performance, as well as to define the development phases etc. is established and followed through to allow for a transparent and professional control of the project.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Harwood 1993], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Kidder 1981]

3.3.2.7 Explicit Risk Management approach

A risk management process is set up to allow the project manager and team members to identify and manage the most critical aspects of the project and the product. This is especially useful when the product development process is taken to its limits in regard to the workload of the team members and the resource utilization. The project manager needs to be highly selective in deciding on the focal points of attention, and has very little room for error

[Greenfield 2001], [Cornford et al. 2001], [McCurdy 2001], [Young et al. 2000], [Griner et al. 2000], [Spear et al. 2000], [Spear 1998]

3.3.2.8 Flexible Membership

The team is open to accept members on different levels of commitment or involvement with the team, take up new team members from outside, and allow members to leave the team when there skills are no longer needed. The team size can be kept as small as possible, and new expertise can be integrated into the team easily.

[Ancona et al. 2002]

3.3.2.9 Internal mechanisms for execution

These mechanisms describe basic procedures to facilitate an efficient operation of the team. They comprise integrative meetings, transparent decision-making using real-time-data and scheduling tools. The meetings aim at integrating new information from the external activities into the core activities. Transparent decision making ensures that members understand the reasons behind decision and thus create a deeper understanding of and buy-in into the common goals. Scheduling supports the coordination of internal and external activities.

[Ancona et al. 2002]

3.3.2.10 Isolation

The team is physically and organizationally separated from the mother organization. This prevents interruption through non-related work, allows the establishment of a new working atmosphere, and fosters a feeling of total responsibility for success. [Peters 2004] especially stresses the negative impact a "hostile environment" can have on a team.

[Johnson et al. 1985], [Rich et al. 1994a [Hiltzik 1999], [Rhodes 1986], [Kidder 1981], [Quinn 1985], [Peters 2004]

Issue: Extensive ties, see below.

3.3.2.11 Minimum process, maximum resource constraints

Minimum constraints regarding the process are imposed on the team. The team is allowed to decide in which way the tasks should be executed (also referred to as task autonomy). On the other hand, resource constraints (e.g. cost and schedule) are strictly enforced. The understanding of "minimum constraints" regarding the process can differ greatly. The review process is usually the strongest process constraint. The idea is to foster innovation through the freedom in the execution of the process, and to bound the resulting uncertainties with the resource constraints.

[Greenfield 2001], [Ehlen 1994], [Shirley et al. 1999], [McCurdy 2001], [Kidder 1981]

3.3.2.12 Mixture of high potential young and experienced senior engineers

All group leader positions within the team are staffed with Senior Engineers. The junior engineer positions are filled with relatively inexperienced, but high-potential young engineers. This ensures high degree of "practicable" quality and transfer of "Lessons Learned" by senior engineers, but at the same time offers the possibility to establish a new work atmosphere, get an influx of new ideas by junior employees and create a high degree of motivation.

[Kidder 1981], [Quinn 1985], [Hiltzik 1999], [Westrum 1999], [Johnson et al. 1985], [Rich et al. 1994], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Shirley et al. 1999] (p. 148)

3.3.2.13 Performance-based incentives

Incentives are given based on performance, not on headcount. There can also be a career-oriented incentive, i.e. that the membership in a high performing team earns the team member credit in the organization. This avoids behavior that would not directly support value creation (often resulting in an unnecessary increase of team size), and increase motivation.

[Johnson et al. 1985], [Rich 1994], [Ranney et al. 1995], [Castka et al. 2001]

3.3.2.14 Positive but strict time, cost and quality reviews and monitoring

A strict system is set up to review the level of achievement in regard to time, cost and quality goals.

[Spear 1998], [Rich 1994], [McCurdy 2001], [Muirhead et al. 1999], [Spear et al. 2000], [Shirley et al. 1999]]

3.3.2.15 Quick and reliable error correction

When errors are discovered, they are quickly and reliably corrected. It is not focused on the question of who caused the error, but how it can be resolved. This element is sometimes "hidden" within descriptions of a "positive team culture".

[Kidder 1981], [Johnson et al. 1985], [Rich et al. 1994], [Shirley et al. 1999]

3.3.2.16 Replication of team structure in sub-teams

The organization of the team is cascaded downwards through all sub-teams that might form, and possibly even extended towards suppliers or other external partners.

[Shirley et al. 1999] (p.151), [Kidder 1981]

3.3.2.17 Reuse of existing technology

Whenever possible, existing technology is reused, either from previous programs or from existing off-the-shelf hardware to minimize the complexity and scope of the task.

[McCurdy 2001], [Muirhead et al. 1999], [Young et al. 2000], [Spear et al. 2000], [Shirley et al. 1999]

3.3.2.18 Small team size

The team is kept small in size. Teams of 2 to 25 people are regularly described, with a maximum of 40 people having been encountered in the literature (larger groups are generally split up into teams of this size). The main intentions are to foster constructive interaction through a personal atmosphere, avoid logistical issues, avoid the "herd behavior" of large groups, and foster a personal identification with team. This factor is often implicitly assumed when factors as trust, mutual respect or other "group culture" elements are described.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Katzenbach et al. 1993], [Muirhead et al. 1999], [McCurdy 2001], [Shirley et al. 1999], [Kidder 1981], [Hiltzik 1999], [Castka et al. 2001]

3.3.2.19 Strong Project Manager

The project manager has the total control over resources in the project and disciplinary power over the team members. This supports a quick and transparent decision making processes, clear goals, and a common overall approach.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Muirhead et al. 1999], [McCurdy 2001], [Kidder 1981], [Quinn 1985]

3.3.2.20 Utilization of specific IT Tools

The use of specific IT tools has been investigated in the literature. There is no definite proof regarding the employment of special IT tools. Teams utilize simple, off-the-shelf software (e.g. Excel).

3.3.2.21 Well-balanced skills

The skills of the team members are complimentary. This includes the areas of technical or functional expertise, Problem-solving and decision-making skills, as well as interpersonal skills.

[Katzenbach et al. 1993], [Castka et al. 2001]

3.3.3 Team Member to Team Member relation level

3.3.3.1 Coaching of young through experienced team members

Experienced team members are encouraged to coach (and thereby supervise) inexperienced team members. This is a measure to assure quality of results and transfer the lessons learned within a team.

[Johnson et al. 1985], [Rich et al. 1994], [Muirhead et al. 1999], [Shirley et al. 1999] (p.148), [McCurdy 2001], [Hiltzik 1999], [Kidder 1981], [Ehlen 1994], [Hyman 1993]

3.3.3.2 Commitment

Team members are committed to the task, but especially committed to one another. Mutual help and influence is encouraged. [Labich 1996] goes as far as naming “humility” of team members towards the team as a whole the key ingredient of a broad spectrum of observed high-performance teams. This creates trust, respect and an atmosphere where team members are actively supporting each other. It also includes a sense of mutual dependency, mutual concern, and shared leadership.

[Ehlen 1994], [Labich 1996], [Katzenbach et al. 1993], [Westrum 1999], [Spear 1998]

Issue: Can lead to burned out team members at the end of project, which threatens sustainability of effort [Kidder 1981].

Can lead to conditions of burn-out and overworking in the course of the project which lead to fatal errors [JPL 2000]

3.3.3.3 Flat Management Structure and Participatory Leadership

The management structure is kept as flat as possible. Team members are empowered and encouraged to make decisions and work self dependent, in order to speed up decision making processes, utilize the knowledge of the team members, and increase their motivation.

[Paté-Cornell et al. 2001], [Shirley et al. 1999], [Pearce 2004], [Gustafson et al. 1994], [Ehlen 1994]

3.3.3.4 Generation of innovative ideas

A key characteristic of High Performance teams are their innovative (i.e. cost and time effective) solutions, allowing them to outperform other teams under similar constraints.

[Kur 1996], [Castka et al. 2001], [Katzenbach et al. 1993], [Shirley et al. 1999], [McCurdy 2001], [Johnson et al. 1985], [Rich et al. 1994], [Kidder 1981]

3.3.3.5 High quality communication

Communication is regularly pointed out as being of the highest importance in the working of high performance teams. This includes communication among team members, and communication of the team with the environment.

[Gustafson et al. 1994], [Castka et al. 2001], [Katzenbach et al. 1993], [Shirley et al. 1999], [McCurdy 2001], [Johnson et al. 1985], [Rich et al. 1994], [Kidder 1981]

3.3.3.6 Mutual accountability

The team holds itself accountable for its results. Team members commit to being held responsible for the outcomes of tasks they participate in, creating commitment and trust among the members. They do not feel that an "outside force" holds them accountable, but they themselves.

[Castka et al. 2001], [Katzenbach et al. 1993], [Gustafson et al. 1994], [Shirley 1999], [Kidder 1981]

3.3.3.7 Mutual trust of team members

Mutual trust of team members is often described as a basic enabler for high performance teams. It describes a relationship between the team members that exceeds professional collaboration.

[Hyman 1993], [Castka et al. 2001], [Gustafson et al. 1994], [Labich 1996], [Johnson et al. 1985], [Rich et al. 1994]

3.3.4 Team to Environment relation level

3.3.4.1 Challenging requirements

The requirements definition process results in challenging requirements. The requirements must reflect the level of complexity of the task, the size of the team and the resources allocated. A design-to-cost approach is employed. The team members feel slightly (but are not actually) over-challenged in order to maximize their motivation ("stretch goals").

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Shirley et al. 1999], [Kidder 1981], [Spear 1998], [Paté-Cornell et al. 2001]

3.3.4.2 Complexity of task matches requirements and resources

The team must be challenged by requirements and scarce resources, but the task must still be sensible and achievable under the given constraints.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994] [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Spear et al. 2000], [Shirley et al. 1999], [Kidder 1981]

3.3.4.3 Expandable Structure

The team structure is flexible to accommodate members with different levels of involvement with the team. This structure aims at balancing the need for a distinct core team with the need for intense and complex external interactions that call for constant change in the team setup. It allows for central coordination, while maintaining flexibility for decentralized execution of tasks.

[Ancona et al. 2002]

3.3.4.4 Extensive Ties

Extensive ties describe the network to persons outside the team in order to engage in external activities. These can consist of weak ties (supporting the identification of knowledge), or strong ties (supporting cooperation and / or transfer of complex knowledge)

[Ancona et al. 2002], [Castka et al. 2001]

3.3.4.5 External Activity

Internal activities are reinforced by external activities, by this boosting team performance [Ancona 2002]. External activities focus on the management across external boundaries and can be categorized into three types of external activities by the team: ambassadorial (i.e. managing upwards), scouting (i.e. identifying expertise and knowledge), and task coordination.

[Ancona et al. 1992], [Ancona et al. 2002]

3.3.4.6 High quality of results

The fundamental definition of a high performance team is that they constantly satisfy and exceed the expectations of their stakeholders. This can be summarized in the results of the team effort being on time, on cost, and of high quality.

[Kur 1996], [Castka et al. 2001], [Katzenbach et al. 1993]

3.3.4.7 Integration of Suppliers

Close communication and strong (personal) relationships with suppliers are established. Team members must assume responsibility for selecting suppliers and have inspection responsibility (Kelly's rules 7 and 8). This enables a quick response to inquiries or changes and helps utilizing the supplier's knowledge and expertise in problem solving.

[Johnson et al. 1985], [Rich et al. 1994], [Rich 1994], [Muirhead et al. 1999], [McCurdy 2001]

3.3.4.8 Management of Scope

The scope of the project is actively monitored and managed to avoid a creeping increase. This assures the maintenance of a proper balance between requirements and resources.

[Marcopulous 1998], [Rich 1994], [Spear 1998], [Shirley et al. 1999], [McCurdy 2001]

3.3.4.9 Mutual trust of team and environment

Kelly Johnson summarized this point as “There must be absolute mutual trust between the [external] organization and the [team] with very close liaison on a day-to-day basis. This cuts down misunderstanding and correspondence to an absolute minimum.”

[Johnson et al. 1985], [Rich 1994], [Shirley et al. 1999]

3.3.4.10 No micromanagement by environment

Micromanagement describes the process by which persons on a high position in the hierarchy directly and in detail manage processes on the working level. This often leads to suboptimal results, because decisions are made with a relatively low degree of expert knowledge. It also has a negative effect on the motivation of the team.

[Quinn 1985], [Pearce 2004], [Ehlen 1994], [Peters 2004]

3.3.4.11 Results on cost

See “High quality of results”

3.3.4.12 Stable and timely resource allocation

The resource allocation must be stable and the resources (especially financial) must be readily available when needed and under the control of the project manager.

[Johnson et al. 1985], [Rich et al. 1994], [Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Goldin 2000], [Griner et al. 2000], [Spear et al. 2000], [Hiltzik 1999], [Rhodes 1986], [Kidder 1981], [Marcopulos 1998], [Paté-Cornell et al. 2001]

3.3.4.13 Stable Requirements

Requirements must be kept stable for the duration of the project in order to avoid large-scale rework and replanning. Literature suggests that this is a prerequisite and all projects analyzed would have failed if the requirements had changed significantly (though Skunk Works might be an exception)

[Muirhead et al. 1999], [McCurdy 2001], [Young et al. 2000], [Griner et al. 2000], [Spear et al. 2000], [Rhodes 1986], [Kidder 1981], [Spear 1998]

3.3.4.14 Timely results

See “High quality of results”

3.4 Characterization of Factors via the Influence Diagram (according to Vester)

Following the description of the Influence Diagram given above, the factors discussed were analyzed.

The matrix containing the results can be found in the appendix, section 10.2. Before the Influence Diagram was plotted, the factors causing "-9" entries, i.e. effectively disabling other factors, were removed (see general discussion in method section 3.1 and specific discussion in the following section 3.5.1).

Plotting the results in the Influence Diagram yields the results displayed in Figure 3-4. A legend to the numbers follows the figure.

According to the categories defined in the discussion of the method (see section 3.1.3), the solid lines denote the clusters that are assigned to the corresponding categories. The dotted line represents the extension of the clusters into the "grey" area, where the factors could not be unambiguously assigned to any cluster.

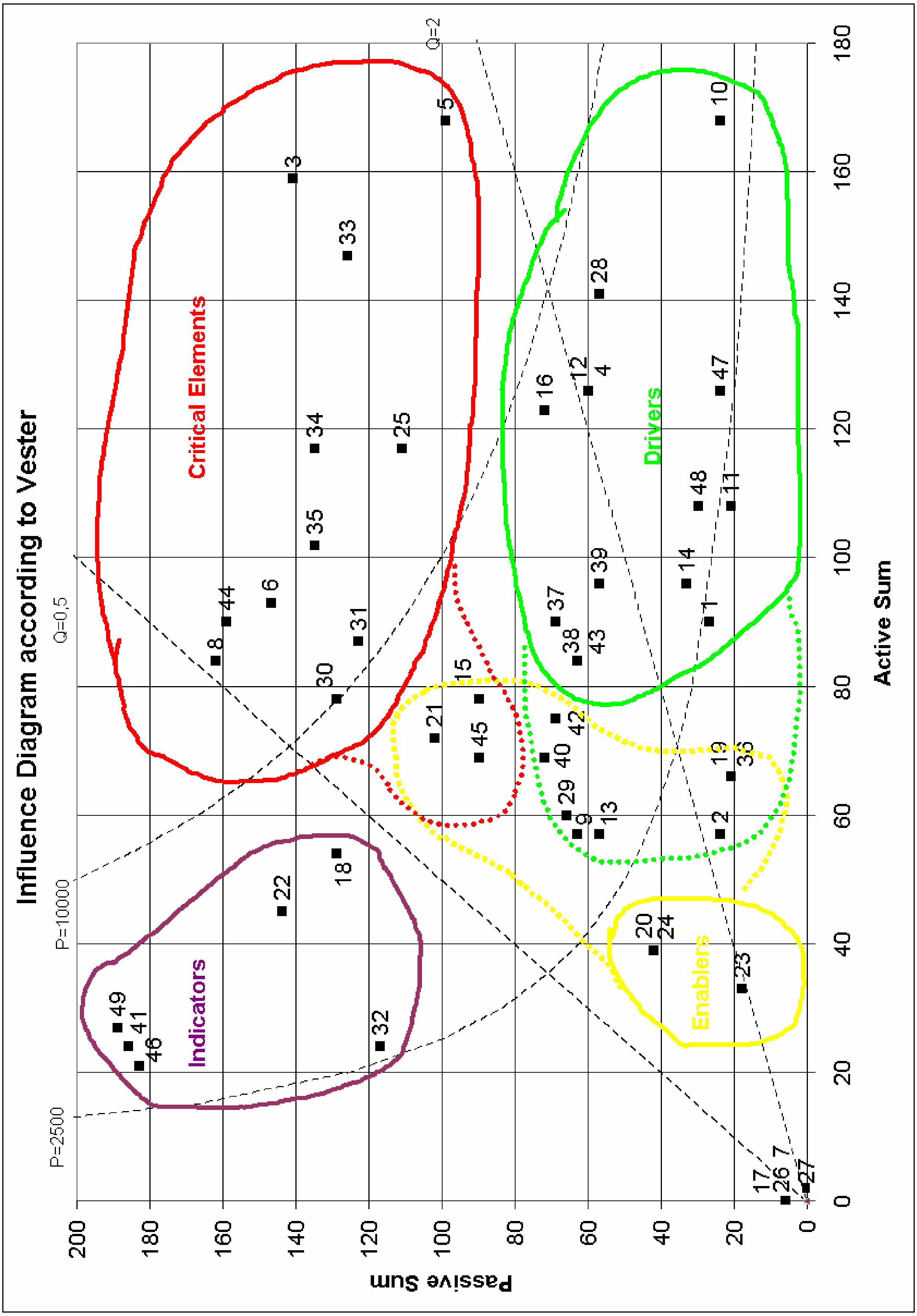

Figure 3-4: Characterization of Factors defining High Performance Teams

The following table can be used as a legend to the Influence Diagram and also gives an overview over the characterization of the factors on different system levels.

Nr.	Factor	Driver	Critical Element	Indicator	Enabler	Driver (extended)	Critical E. (extended)	Indicator (extended)	Enabler (extended)	Outside System
	Individual Team Member Level									
1	Hand-picked members	X								
2	Hands-on work on product					X			X	
3	High degree of motivation		X							
4	High degree of qualification	X								
5	Identification of members with team goals		X							
6	Proactive solving of problems		X							
7	Seamless employment / Sequential Multitasking									X
	Team Level									
8	Alignment of responsibility and Freedom		X							
9	Capturing of Lessons Learned					X			X	
10	Clearly defined goals, short and long term	X								
11	Collocation	X								
12	Common Approach	X								
13	Employment of best-practices model as overall process model					X			X	
14	Explicit Risk Management approach	X								
15	Flexible Membership						X		X	
16	Internal Mechanisms for execution	X								
17	Isolation									X
18	Minimum Process, Maximum resource constraints			X						
19	Mixture of high potential young and experienced senior engineers					X			X	
20	Performance-based incentives				X					

Nr.	Factor	Driver	Critical Element	Indicator	Enabler	Driver (extended)	Critical E. (extended)	Indicator (extended)	Enabler (extended)	Outside System
21	Positive but strict schedule, cost and performance reviews / monitoring						X		X	
22	Quick and reliable error correction			X						
23	Replication of Team structure in sub-teams				X					
24	Reuse of existing technology				X					
25	Small team size		X							
26	Strong Project Manager									X
27	Utilization of specific IT Tools									X
28	Well-balanced skills	X								
	Team Member to Member relation L.									
29	Coaching of young through experienced team members					X			X	
30	Commitment		X							
31	Flat Management Structure and Participatory Leadership		X							
32	Generation of innovative ideas			X						
33	High quality of communication		X							
34	Mutual Accountability		X							
35	Mutual trust of team members		X							
	Team to Environment Level									
36	Challenging requirements					X			X	
37	Complexity of task matches requirements and resources	X								
38	Expandable Structure	X								
39	Extensive Ties	X								
40	External activity					X			X	
41	High quality of results			X						
42	Integration of Suppliers					X			X	

Nr.	Factor	Driver	Critical Element	Indicator	Enabler	Driver (extended)	Critical E. (extended)	Indicator (extended)	Enabler (extended)	Outside System
43	Management of Scope	X								
44	Mutual Trust of team and environment		X							
45	No micromanagement by environment						X		X	
46	Results on cost			X						
47	Stable and timely resource allocation	X								
48	Stable requirements	X								
49	Timely results			X						

Table 3-5: Legend to Influence Diagram

3.5 Discussion of results

3.5.1 General assessment of overall system

The overall system of factors and their mutual influences only showed 16 “-9” influences, or contradictions, in its initial state. Taking into account that 2352 mutual influences were analyzed in total, this is a relatively small number (0,7%). These contradictions result from the diversity of sources taken into account to generate the list of factors.

Nevertheless, these contradictions indicate inconsistencies in the overall system model. This is not surprising, since the factors were compiled from a large range of literature. In fact, it illustrates a high degree of compatibility (100% - 0,7% = 99,3%) of the concepts discussed in the literature describing high performance teams in product development.

To derive a comprehensive model for this analysis, the inconsistencies represented by the “-9” influences, had to be eliminated. An analysis of the system showed that the minimum number of factors had to be eliminated, if the following factors were selected:

- Seamless Employment / Sequential Multitasking (7)
- Isolation (17)
- Strong Project Manager (26)

Seamless employment is very focused on keeping the same team members in the team at all times. The majority of the literature favored an approach where the team size is dynamically adjusted to reflect its needs. Thus, seamless employment was eliminated from the analysis. Isolation focused mainly on separating the team from its surrounding environment. But the majority of the literature argued in favor of close ties of the team with its environment. Accordingly, the factor of isolation was eliminated. The factor of a strong project manager was in contrast to the more participatory approach that was favored in the literature, and thus had to be eliminated. This does not imply that a team does not need good leadership or strong supporters in the environment.

A sensitivity analysis showed that the elimination of these factors had an effect on the system, but it did not cause any factor to change from one cluster into another. Also, the effect was relatively evenly distributed. Since the influences from these factors were dropped, they now appear at the origin of the matrix.

3.5.2 General assessment of system levels

The four different levels of the system (Individual Team Member, Team, Team Member to Member relation, Team to Environment) show distinct differences in the distribution of the character of the factors that were identified on these levels:

	Total Factors		**Drivers**		**Critical Elements**		**Indicators**		**Enablers**		**Others**	
System Level	**Absolute (level)**	***Relative (Total System)***	**Absolute (level)**	***Relative (level)***	**Absolute (level)**	***Relative (Level)***	**Absolute (level)**	***Relative (Level***	**Absolute (level)**	***Relative (Level***	**Absolute (level)**	***Relative (Level)***
Total System	49	*100 %*	14	*29 %*	11	*22 %*	6	*12 %*	3	*6%*	15	*31 %*
Individual Team Member Level	7	*14 %*	2	*29 %*	3	*42 %*					2	*29 %*
Team Level	21	*43 %*	6	*28 %*	2	*10 %*	2	*10 %*	3	*14 %*	8	*38 %*
Team Member to Member Relation Level	7	*14 %*			5	*72 %*	1	*14 %*			1	*14 %*
Team to Environment Relation Level	14	*29 %*	6	*43 %*	1	*7%*	3	*21 %*			4	*29 %*

Table 3-6: General assessment of system levels in High Performance Teams

The system levels can be characterized as follows:

- **Total System Level:** The focus of the elements is on drivers, critical elements and, with some distance, indicators, as would have been expected. The relatively large number of other elements (31%) can be explained by the different focus of the sources due to their variety.
- **Individual Team Member Level:** This level shows a balance between drivers and critical elements, which offer a multitude of possibilities to influence high performance teams, but does not contain many factors in total.
- **Team Level:** The team level shows the highest total amount of factors. The focus lies on drivers, which suggests ideal opportunities on this level to control the system.
- **Team Member to Member Level:** This level shows dominating Critical Elements, suggesting that it is responsible for a high degree of the dynamics of the system.
- **Team to Environment Relation Level:** The team to environment level is characterized by a relatively high degree of drivers, illustrating the dependence of a high performance team of a supportive environment.

3.5.3 Discussion of factors along clusters in the Influence Diagram

In the following, the factors which could be clearly assigned to one of the four clusters will be discussed briefly.

3.5.3.1 Drivers on individual Team Member Level

The drivers on individual team member level are

- Hand-picked team members (1) and
- High degree of qualification (4)

The result of the analysis is understandable, as both factors can be controlled when teams are created and are not directly subjected to any strong feedback. However, this might change if a long-term perspective is taken, where a team exists for many years. In particular, the degree of qualification of team members can be expected to experience stronger feedback, thus developing in the direction of a critical element over time.

3.5.3.2 Critical Elements on Team Member Level

The Critical Elements on the level of individual team members are

- High degree of motivation (3)
- Identification of members with team goals (5) and
- Proactive solving of problems (6)

Motivation is clearly a factor that is strongly influenced by the overall performance of the team, but also itself has a strong influence on many aspects of a team. The same seems true for the identification with team goals, as a strong identification supports the working of a team, but on the other hand a positive team experience also has an effect on the identification with the team's goals. Similarly, a team strongly benefits from a proactive solving of problems, but the factor itself also depends on a multitude of other factors.

3.5.3.3 Drivers on Team Level

The following factors are the Drivers on the Team Level:

- Clearly defined short and long term goals (10)
- Collocation (11)
- Common Approach (12)
- Explicit Risk Management Approach (14)
- Internal Mechanisms for execution (16) and
- Well-balanced skills (28)

Long-term goals are usually defined to a large extent before a team becomes fully operational, and thus are not strongly influenced by the team itself. Short term goals are derived from these long term goals, and are therefore also relatively independent of the team (although their concrete formulation of course strongly depends on the team). On the other hand, they play a central role in allowing the team to direct its efforts. Collocation also is a factor that is largely determined by outside forces, but has been shown to have a large influence on the working of the team, e.g. regarding communication and the formation of professional relationships. The relation of risk management and high performance teams will be discussed in detail in chapter 5. The factor of well-balanced skills is also largely resistant to team dynamics once installed, because it mostly depends on the actual team members. However, if team dynamics should have an effect on the membership of team members, this factor would drift towards the critical elements.

3.5.3.4 Critical Elements on Team Level

The Critical Elements on the team level are as follows:

- Alignment of responsibility and freedom (8)
- Small Team size (25)

The alignment of the responsibilities of the team with the according freedom to take action has been found to have a large influence on the performance of the team, e.g. by allowing quick and efficiently action to be taken once problems have been identified, instead of lengthy processes involving external elements. On the other hand, this alignment is very sensitive towards other factors, e.g. the qualification of the team members. The team size is one of the most often discussed elements. This analysis showed that it has a strong influence on the team, e.g. by supporting communication, mutual trust or mutual accountability, but is also strongly dependent on other factors, e.g. well-balanced skills within the team.

3.5.3.5 Indicators on Team Level

On the level of the team, the indicators are:

- Minimal Process, Maximum resource constraints (18)
- Quick and reliable error correction (22)

Indicators represent factors that can be understood as emergent properties of the system. Minimal process, maximum resource constraints represents a state in the team-system, where the team has the highest degree of freedom in regard to its internal working, only limited by the resources at its disposal. This is for example based on a high level of trust between the team and environment. Similarly, quick and reliable error correction heavily relies on other factors and is a result thereof, e.g. a high degree of qualification and a high quality of communication.

3.5.3.6 Enablers on Team Level

The three enablers identified in the system analysis are all located on the team level, they are:

- Performance-based incentives (20)
- Replication of Team structure in sub-teams (23)
- Reuse of existing technologies (24)

Performance-based incentives were not often explicitly described in the literature and thus are not represented with very strong relations to other factors. This might have resulted from an implicit assumption that performance based incentives were in place as a “basic” measure that was not explicitly discussed. In that case, it would move towards the Drivers area. Both the replication of the team structure in sub-teams and the reuse of existing technologies were described in the literature, and both factors were considered important. The analysis, however, did not show frequent and strong relations to other factors. This does not mean that these factors are “unimportant”, but merely states that they do not play a large role in the team dynamics of a high performance team, but can very well make perfect technical sense. This is particularly true for the reuse of exiting technology to limit the technical complexity of a given task.

3.5.3.7 Critical Elements on Team Member to Member relation Level

The member to member level shows a high count of Critical Elements. These are:

- Commitment (30)
- Flat Management Structure and Participatory Leadership (31)
- High quality of communication (33)

- Mutual Accountability (34)
- Mutual trust of team members (35)

At first, the concentration of Critical Elements on the team member to team member level seems surprising. But on a second look, the reasons become clearer: The dynamics of a high performance team depend strongly on the relationship of the team members towards each other. At the same time, the relations of the team members are always sensitive concerning a multitude of influences, reflecting the complex network of human interaction. Mutual trust is especially striking, being a basic enabler for any form of collaboration, but itself being very sensitive towards the actions of others.

3.5.3.8 Indicators on Team Member to Member relation Level

Maybe one of the most surprising findings was the one indicator on the member to member level:

- Generation of innovative ideas (32)

The generation of innovative ideas was clearly marked as an indicator through the system analysis, i.e. an emergent property of high performance teams. This contradicts the belief that was sometimes encountered in the literature identifying “innovation” as a driver of high performance teams.

3.5.3.9 Drivers on Team to Environment Level

A large number of drivers was identified on the team to environment level, they are:

- Complexity of task matches requirements and resources (37)
- Expandable Structure (38)
- Extensive Ties (39)
- Management of Scope (43)
- Stable and timely resource allocation (47)
- Stable requirements (48)

A high performance team is always an open system, and as such it is subject to influences from the environment. The analysis showed that these environmental influences play a large role in the operations of the team, and are fundamental to its success (or failure). In particular, the factors of stable and timely resource allocation and stable requirements are very frequently being pointed out as being absolutely essential for the success of any team. On the other hand, it is not very surprising that from a team perspective, all these factors appear as drivers, as the team has only limited influence on its environment.

3.5.3.10 Critical Elements on Team to Environment Level

The only critical element identified on the team to environment level is:

- Mutual trust of team and environment (44)

As has been said in describing the drivers on the team to environment level, the environment has a strong influence on the team. The factor of mutual trust is also characterized by the large influence the team itself has, thereby becoming a critical factor.

3.5.3.11 Indicators on Team to Environment Level

As a high performance team is mostly defined by its ability to satisfy its stakeholders, it is not surprising that the three main indicators on this level are:

- High quality of results (41)
- Results on cost (46)
- Timely results (49)

These represent the three categories of possible stakeholder satisfaction, which are closely linked with the definition of high performance teams. The analysis showed that these three factors emerge as the most prominent indicators, as would have been expected.

3.5.3.12 Elements outside the system

There are four elements that are displayed in the origin of the matrix, implying that they have no relation to the system whatsoever:

- Seamless Employment / Sequential Multitasking (7)
- Isolation (17)
- Strong Project Manager (26)
- Utilization of specific IT Tools (27)

The factors Seamless Employment, Isolation, and Strong Project manager have been eliminated from the analysis for reasons of system's integrity, discussed in section 3.5.1. The factor Utilization of specific IT Tools was included in the analysis on a hypothetical basis, to specifically investigate if certain types of IT applications seem to have an effect on the team performance. It was found that this is not the case. high performance teams do not seem to focus on specific IT tools, but on the contrary seem to avoid special software and focus on utilizing standard applications for their work (these standard applications include industry-specific applications like CAD or CAE tools which are commonly used in the team environment).

3.6 Summary on High Performance Teams

High performance teams support, by definition, crisis prevention. This chapter has given an overview of the literature that has been identified dealing with high performance teams in product development. From the literature, 49 factors describing high performance teams have been extracted. These factors were characterized with the help of a system analysis method, the Influence Diagram according to Vester. From the 49 factors, 14 were classified as drivers, 11 as critical elements, 6 as indicators, and 3 as enablers, and 15 could not clearly be assigned to one category (suggestions were made). The classification of the factors was discussed along these four categories.

4 Risk Management Methodology for Lean Product Development

As has been discussed in section 2.1.2, risk management is an important approach to crisis prevention. This chapter discusses risk management in product development in more detail. Section 4.1 outlines the research methodology employed, section 4.2 presents the literature base of the following discussions, section 4.3 briefly introduces a general process framework for risk management, and section 4.4 describes in detail a large selection of methods for risk management, along the process framework defined in the previous sections.

The focus of this chapter is on methods for risk management. The process framework is only developed to the extent necessary to serve as a general guidance and structure for the discussion of the methods.

The goal of this chapter is to give a concise and well structured overview over a risk management framework and methods. The aim is to provide the reader with a “construction kit” that can serve as the basis for designing a customized risk management.

4.1 Research Methodology

4.1.1 Literature Review

The process framework and method collection presented in this chapter are largely based on a review of the literature.

The main sources for the review were:

- MIT Libraries (both engineering and business libraries)
- WorldCat Search Engine: Search engines which includes all university and public libraries in the United States. Books not available on campus could be borrowed with this service.
- EngineeringVillage 2 database: Literature database which includes the majority of English language publications in the area of engineering
- Proquest (ABI/INFORM Global): Literature database which includes the majority of English language publications in the area of business

The searches were conducted based on keywords and forward / backward searches through the literature based on citations. The areas of risk management addressed are the areas which have been identified in section 2.4.4.

Although a large number of papers were identified, they were only included in the following discussion if they offered new insights which could not be found in published books. An outline of the literature base can be found in section 4.2.

For both the process framework and the methods collection, the literature was first prioritized according to the addressed topics, the reputation of the authors, and a personal quality judgment regarding the content. The literature is marked accordingly in the discussion (section 4.2)

4.1.2 Selection of methods

The methods presented in this thesis were selected according to the following criteria:

- Applicability of source literature to product development
- Prevalence of method in literature
- Reputation of author
- Total number of methods in process element
- Personal quality judgment of source literature

4.1.3 Field Study

A field study (see chapter 6) was conducted to

- Obtain an industry perspective on the theoretical risk management work and
- Offer an overview over the literature and concepts therein to the industry partner

For a detailed description of the research methodology applied, please refer to section 6.1.

4.1.4 Limitations

Although every reasonable effort has been made to base this literature review on a thorough basis, the literature base cannot be considered complete. Also, not all sources could be analyzed with the same thoroughness. Especially the area of financial risk management could not be treated in the length that it would deserve due to its long history and large literature body (also see the discussion of this point in section 2.4.4.3). Personal quality judgment played a role, in the prioritization of the literature as well as the selection of the method. Both processes could be improved to increase the objectivity of the results.

4.2 Literature base of discussion

As discussed above, areas of risk management addressed are the areas which have been identified in section 2.4.4. The area of financial risk management offers a huge body of literature. It could not be considered in detail in this thesis.

The following table (Table 4-1) gives an overview over the literature that has been included in the discussion of risk management methods. It also states the level to which each literature source could be taken into account. The areas of risk management the different sources belong to correspond to the areas of risk management identified as important for risk management in product development in chapter 2.4.4.

	RM Process			**RM Methods**			
Literature	**Analyzed in detail**	**checked for additional insights**	**Briefly checked for inconsistencies**	**Analyzed in detail**	**checked for additional insights**	**Briefly checked for inconsistencies**	**Recommended reading**
PD Risk Management							
[Smith et al. 2002]	X			X			X
[Hall 1998]	X			X			X
[Dorofee et al. 1996]	X			X			
Project Risk Management							
[PMI 2004]	X			X			X
[Cooper et al. 2005]		X			X		X
[Kendrick 2003]		X			X		X
[Wideman 1992]		X			X		
[Schuyler 2001]			X			X	
[Chapman et al. 2002]			X			X	
[Chapman et al. 2003]		X			X		X

Literature	RM Process			RM Methods			Recommended reading
	Analyzed in detail	checked for additional insights	Briefly checked for inconsistencies	Analyzed in detail	checked for additional insights	Briefly checked for inconsistencies	
Strategic Risk Management							
[Lessing et al. 2005]	X			X			X
[Frame 2003]		X			X		
[Heil 2000]	X			X			
[Sadgrove 1998]		X			X		
Reliability Risk Management							
[Birolini 2004]	X			X			X
[Stamatelatos 2002]	X			X			X
[Andrews et al. 2002]			X			X	
[Ayyub 2003]			X			X	
[Modarres et al. 1999]			X			X	
[Blischke et al. 2000]			X			X	
[Evans et al. 2000]			X			X	
Technical Risk Management							
[Thornton 2004]	X			X			
[Browning et al. 2002a], [Browning et al. 2002b]	X			X			X
[Browning 1999a], [Browning 1999b], [Browning et al. Working paper]		X			X		
Systems Risk Management							
[Hastings et al. 2004a]		X			X		
[Hastings et al. 2004b]		X			X		
[Haimes 2004]			X			X	X

Literature	RM Process: Analyzed in detail	RM Process: checked for additional insights	RM Process: Briefly checked for inconsistencies	RM Methods: Analyzed in detail	RM Methods: checked for additional insights	RM Methods: Briefly checked for inconsistencies	Recommended reading
Financial Risk Management							
[Doherty 2000]			X			X	X
[Crouhy et al. 2001]			X			X	X

Table 4-1: Overview over Risk Management literature

4.3 Process Framework for Risk Management

This section will give a brief outline of a possible framework for a risk management process. The design of the process is a complex task itself. In this thesis, it will only be discussed to the extent necessary for it to serve as a basis for understanding and structuring the different methods identified in the literature. The elements of the process framework are deliberately only discussed in general terms, with the goal to retain a high degree of freedom regarding specific implementations while providing enough guidance to support a general understanding and categorizing of the methods.

The risk management process framework presented in the following cannot deal with the (very interesting) question of the integration of risk management into an overall process and / or project management. But this topic has already been well covered in literature. See e.g. [Smith et al. 2002] (pp.178-182), [Hall 1998] (Parts II and III) or [PMI 2004] (chapter 11).

[Smith et al. 2002] define 5 steps in the risk management process for Product Development processes: Identify Risk, Analyze Risk, Prioritize and Map Risk, Resolve Risk and Monitor Risk. [Hall 1998] discerns the 5 process steps Identify Risk, Analyze Risk, Plan Risk, Track Risk, and Resolve Risk. [PMI 2004] defines as overall risk management processes risk management Planning, Risk Identification, Qualitative Risk Analysis, Quantitative Risk Analysis, Risk Response Planning, Risk Monitoring and Control (p. 237). The NASA NPG-7120.5 (cited in [Stamatelatos 2001] (p.9)), defines NASA's continuous risk management activities as follows: Identify, Analyze, Plan, Track, Control, and Communicate and Document.

The following model has been developed to unify the risk management process models:

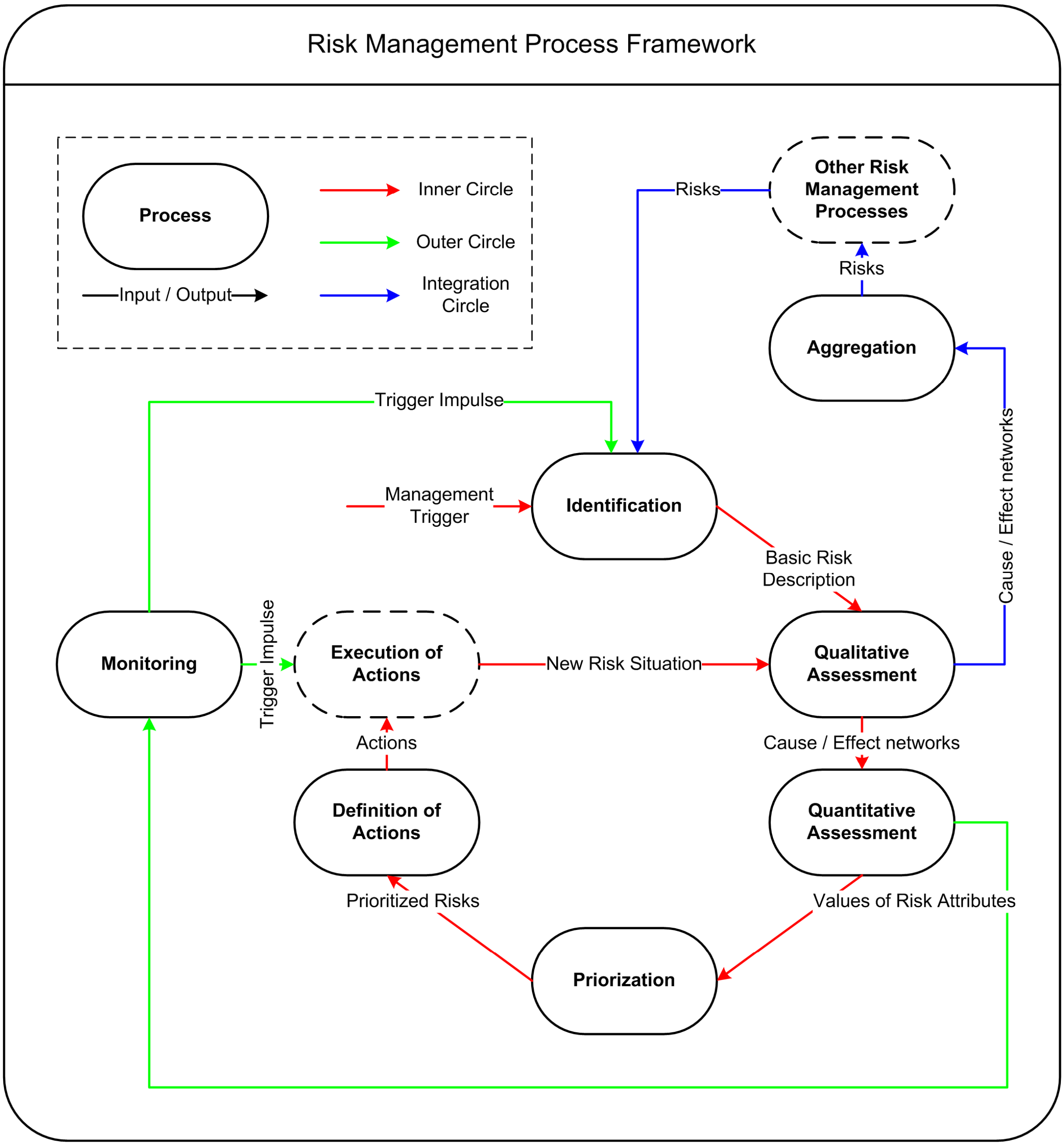

Figure 4-1: Overview over the Risk Management Process Framework

The "inner circle" or basic risk management activities consist of

- Identify risk,
- Qualitative risk assessment,
- Quantitative risk assessment,

- Prioritization of risks,
- Definition of actions and
- Execution of actions.

The “outer circle” adds a more advanced risk management processes element, which runs in parallel to the inner circle, adding

- Monitoring of risks

An “integration circle” links the overall risk management process to other peer risk management processes or to an overall enterprise risk management processes, adding

- Aggregation of risks

The risk management process is presented as an ongoing, iterative process, in accordance with the literature. The processes are presented in their logic sequence. However, the execution of the process itself can include multiple internal iterations, especially regarding the prioritization of risks at different stages of the process.

Some literature sources suggest including a planning step in the process framework. The planning associated with risk management is important, but in the context of this thesis regarded as a project planning meta-task (see the discussion of the relation / integration of the risk management process into an overall project or program management approach above). It has therefore been excluded from the discussion.

4.3.1 Risk Identification

In the Risk Identification process, potential risks are detected. This can be achieved in a multitude of ways. It collects the preliminary information available for every potential risk, including the rationale for the identification as potential risk.

Input: Regarding the start of the process: Management trigger to start identification process, trigger by monitoring process due to detection of significant changes, or trigger from other risk management processes to include certain risks; Regarding general information: Scope of information source defined by integration into overall project or program management.

Output: Brief description of potential risks

4.3.2 Qualitative Risk Analysis

In this framework, Qualitative Risk Analysis is defined as a step that further deepens the understanding of a potential risk, without assigning any numerical judgment. Any methods involving a numerical judgment are classified as Quantitative Risk Analysis. This differs from the perception in some of the literature, especially [PMI 2004]. There, the phase of deeper understanding a risk is part of the Risk Identification. Qualitative Risk Analysis does already involve rough numerical estimations of probability and impact as means of a preliminary prioritization, whereas Quantitative Analysis represents refined methods for Risk Assessment, involving expert interviews and judgments, and probability distributions.

Input: Brief description of potential risk

Output: Detailed description of potential risk, including the network of causal events and factors, as well as the network of events and factors describing the impact of the potential risk.

4.3.3 Quantitative Risk Analysis

In the Quantitative Risk Analysis, numerical values are assigned to a risk's probability of occurrence, magnitude of impact, and its timeframe. The quantification is not limited to mathematically exact models, but includes any type of quantification, for example the assignment to a certain (numerically specified) category based on team discussions. The Quantitative Risk Analysis should reflect the views of different stakeholders (e.g. top management) regarding the quantification.

Input: Detailed qualitative description of potential risk

Output: Quantified description of risk, including probability of occurrence.

4.3.4 Risk Prioritization

In Risk Prioritization, the quantitatively described risks are prioritized according to their descriptions. The prioritization process can be conducted along a multitude of different measurement or priority systems, taking one or more of the quantified risk attributes into account.

Input: Quantified description of risk

Output: Prioritized risks

4.3.5 Definition of Actions

Based on the prioritized risks, actions are defined to minimize the losses. The description of the action should include, besides the basic description, the expected impact on the risks, as well as timeframes for realization and responsible persons. For a discussion of the generic types of actions and more details on the elements of the description, see section 4.4.7.

Input: Prioritized risks

Output: Actions associated with risks

4.3.6 Execution of Actions

In this step, the actions defined earlier are executed. It is arguable as to whether this step should be considered to be "owned" by the risk management process. The execution of the actions will often be the responsibility of persons not directly associated with the risk management efforts, as the actions can possibly be in any area of the company. It has to be assured by the overall integration of the risk management process into the project or program management that the risk management process retains an appropriate level of authority and control over the execution process.

Input: Actions

Output: Impact on risk

4.3.7 Monitoring of Risks

The monitoring of risks can be aimed at monitoring the risks themselves, or monitoring the performance of the risk management process. Both cases are addressed in the methods section. The function of monitoring is to provide a transparent and current description of the current risk situation and to issue trigger impulses to inform decision makers of significant changes.

Input: Qualitative and quantitative risk descriptions

Output: Trigger impulses to inform management of changes in risk situation or initiate actions due to changes in risk situation.

4.3.8 Aggregation of Risks

In the Aggregation step, single risks are aggregated to the next higher level. This step is of central importance if an enterprise-wide integral risk management system is to be established over more than one hierarchical level or above a basic operational level (not discussed in this thesis). The aggregation process has to provide the capability of aggregating risks in a sensible manner along a multitude of possible lines, e.g. common causes, common effects, area of responsibility, product categories etc.

Input: Qualitative and quantitative risk descriptions, risk prioritization

Output: Qualitative risk description on higher level

4.4 Methods of Risk Management

4.4.1 Overview of the methods

After the general process framework has been described in the previous section, this section will present a selection of the methods identified in the literature (see section 4.2).

The following table (Table 4-2) gives a brief summary and overview of the methods later discussed in detail. The table contains the methods name, the categorization by process element in the risk management process framework, as well as a categorization by the possible risks they address along the three axiomatic risk attributes, i.e. the causal structure, the failure modes, and the timeframe.

Legend to Table 4-2:

●: Explicitly supported or addressed by method,

○: Not explicitly supported or addressed by method, but method still suitable for application,

blank: method not suitable without modifications

Methods		Process								Risk												
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
General Methods																						
1	Fault Modes, Effects and Criticality Analysis	●	●	●	●	●				●						●				○	○	○
	- FMECA 2-4	●								●						●				○	○	○
	- FMECA 5-6		●							●						●				○	○	○
	- FMECA 7,8,11					●				●						●				○	○	○
	- FMECA 9, 10			●	●					●						●				○	○	○
2	Risk Value Method			●	●			●		●						●				○	○	○
	- RVM 1			●						●						●				○	○	○
	- RVM 2			●						●						●				○	○	○

Methods		Process								Risk												
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
	- RVM 3			●	●					●						●				○	○	○
	- RVM 4							●		●						●				○	○	○
	- RVM 5							●		●						●				○	○	○
Methods for Identification																						
3	Identification by Failure Modes	●								○	○	○	○	●	●	●	●	●	●	○	○	○
4	Cause Structure – Failure Mode Matrix	●								●	●	●	●	●	●	●	●	●	●	○	○	○
5	Identification by Checklist	●								○	○	○	○	○	○	○	○	○	○	○	○	○
6	Interviews	●								○	○	○	○	○	○	○	○	○	○	○	○	○
7	Review of Documentation	●								●	●	○	○	○	○	○	○	○	○	○	○	○
8	Identification by Brainstorming	●								○	○	○	○	○	○	○	○	○	○	○	○	○
9	Identification by SWOT	●								○	○	○	○	○	○	○	○	○	○	○	○	○
10	Identification by Work Breakdown Structure	●								○	○	○	○	○	○	○	●	●	●	○	○	○
11	Requirements Analysis	●								●	●	○	○			●				○	○	○
12	Identification by Key Characteristics	●								●	○	○				●				○	○	○
13	Geometry-based Variation Simulation	●								●	●					●				○	○	○
14	Identification by Stress Factors	●								●						●				○	○	○
15	Identification by Project Schedule	●								○	○	○	○				●			○	○	○
16	Identification by Generic Development Process	●								○	○	○	○				●			○	○	○

Methods		Process								Risk															
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
Methods for Qualitative Risk Analysis																						
17	Qualitative Analysis with Risk Scenarios		●					○	○	●	●	●	●	●	●	●	●	●	●	●	●	●
18	Decision Tree Analysis		●	○		○				●	●	●	●	●	●	●	●	●	●	○	○	○
19	5 Whys		●							●	●	●	●	●	●	●	●	●	●	○	○	○
20	Ishikawa or Fishbone Diagram		●							●	●	●	●	●	●	●	●	●	●	○	○	○
21	Risk Categorization		●							●	●	●	●	●	●	●	●	●	●	○	○	○
22	Cause-oriented Event Sequence Diagrams		●							●	●	●	●	○	○	○	○	○	○	○	○	○
23	Fault Tree Analysis		●							●	○	○	○	○	○	●	○	○	○	○	○	○
24	Reliability Block Diagram		●							●			●			●				○	○	○
25	Part Count Method		●							●						●				○	○	○
26	Impact-oriented Event Sequence Diagram		●							○	○	○	○	●	●	●	●	●	●	○	○	○

Methods		Process								Risk												
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
Methods Quantitative Risk Analysis																						
27	General Classes of Impact, Likelihood, and Time Component			●						●	●	●	●	●	●	●	●	●	●	●	●	●
28	Risk Data Quality Assessment			●						●	●	●	●	●	●	●	●	●	●	○	○	○
29	Quantification by Group Consensus			●						●	●	●	●	●	●	●	●	●	●	○	○	○
30	Quantification by Assignment to Experts			●						●	●	●	●	●	●	●	●	●	●	○	○	○
31	Quantification by team-based Delphi			●						●	●	●	●	●	●	●	●	●	●	○	○	○
32	Failure Rate Tables			●												●				○	○	○
33	Statistical Quality Control			●												●				○	○	○
34	Statistical Reliability Test			●												●				○	○	○
35	Calculation-based quantification of likelihood			●						○	○	○	○	○	○	○	○	○	○	○	○	○
36	Risk Timeframe / Urgency Assessment			●						○	○	○	○	○	○	○	○	○	○	●	●	●
37	Calculation of Expected Loss			●						●	●	●	●	○	●	○	○	●	○	○	○	○
38	Risk Matrix for Likelihood and Impact			●						●	●	●	●	●	●	●	●	●	●	○	○	○
39	Expected Monetary Value Analysis			●						●	●	●	●	○	●	○	○	●	○	○	○	○
40	Probability Distribution of Impact			●						●	●	●	●	●	●	●	●	●	●	○	○	○
41	Monte Carlo Simulation			●						●	●	●	●	●	●	●	●	●	●	○	○	○
42	Risk Severity			●						●	●	●	●	●	●	●	●	●	●	●	●	●

Methods		Process								Risk												
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
Methods for Prioritization																						
43	Top 10 Risk Ranking				●					○	○	○	○	○	○	○	○	○	○	○	○	○
44	Pareto Analysis				●					○	○	○	○	○	○	○	○	○	○	○	○	○
45	Sensitivity Analysis				●					○	○	○	○	○	○	○	○	○	○	○	○	○
46	Utility Function				●	●				○	○	○	○	○	○	○	○	○	○	○	○	○
47	Nominal Group Technique				●					○	○	○	○	○	○	○	○	○	○	○	○	○
48	Weighted Multivoting				●					○	○	○	○	○	○	○	○	○	○	○	○	○
Methods for Definition of Actions																						
49	Classification of Actions					●				○	○	○	○	○	○	○	○	○	○	○	○	○
50	Action Plan					●				○	○	○	○	○	○	○	○	○	○	○	○	○
51	Application of Problem Solving Cycle					●				○	○	○	○	○	○	○	○	○	○	○	○	○
52	Risk Reduction Leverage					●				○	○	○	○	○	○	○	○	○	○	○	○	○

Methods		Process								Risk												
										Cause				Failure modes						Time-frame		
Nr	Name	Identification	Qualitative RA	Quantitative RA	Prioritization	Definition of A.	Execution of A.	Monitoring	Aggregation	Project	Company	Supply Chain	Environment	Lead Time	Lifecycle Cost	Performance	Schedule Adherence.	Budget	Quality	Short term	Medium term	Long term
Methods for Monitoring																						
53	Review of Actions initiated							●		○	○	○	○	○	○	○	○	○	○	○	○	○
54	Project Risk Management Panel							●		○	○	○	○	○	○	○	○	○	○	○	○	○
55	Monitoring of Expected Losses							●		○	○	○	○	●	●	●	●	●	●	○	○	○
56	Measuring Risks Prevented							●		○	○	○	○	○	○	○	○	○	○	○	○	○
57	Measuring Impact Mitigation							●		○	○	○	○	●	●	●	●	●	●	○	○	○
58	Counting New Risks Identified							●		○	○	○	○	○	○	○	○	○	○	○	○	○
59	Reserve Analysis							●		○	○	○	○	●	●	●	●	●	●	○	○	○
60	Unidentified but later occurred risks							●		○	○	○	○	○	○	○	○	○	○	○	○	○
61	Risk Management Index							●		○	○	○	○	●	●	●	●	●	●	○	○	○
62	Other Tactical Metrics							●		○	○	○	○	○	○	○	○	○	○	○	○	○
63	Risk Inventory							●		○	○	○	○	○	○	○	○	○	○	○	○	○
64	Monitoring of Risk Map							●		●	●	●	●	●	●	●	●	●	●	○	○	○
65	Scenario-based tracking							●		●	●	●	●	●	●	●	●	●	●	●	●	●
Methods for Aggregation																						
66	Total Risk Scenarios		○	○		○		○	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Table 4-2: Overview of risk management methods

The methods presented cover (for the first time) all areas of the risk management process framework, of the causal structure, and all failure modes. Very few methods explicitly addressed the timeframe-component of risk, although practically all methods implicitly supported it. Only one method has been identified that explicitly addresses the Aggregation process step to link a risk management process to an overall enterprise risk management. The fact that no methods were identified that cover the Execution of Actions process step is in line with the definition of this step as being the responsibility of the project or program organization.

4.4.2 General Methods

4.4.2.1 Fault Modes, Effects, and Criticality Analysis (FMECA)

The "classic" method to identify (and resolve) risks on a technical level is to conduct a FMECA. A FMECA is based on the Failure Mode and Effects Analysis (FMEA), but includes more risk management elements (steps 9 and 10 in the process model given below). The FMECA itself is not only a method for identifying risks, but in fact constitutes a basic technical risk management framework itself.

The basic procedure for conducting an FMECA is (according to IEC 69812, cited in [Birolini 2004])

1. Sequential numbering of the step that will be performed in the following.

2. Designation of the element or part under consideration, short description of its function, and reference to the reliability block diagram, part list, etc.

3. Assumption of a possible fault mode (all possible fault modes have to be considered).

4. Identification of possible causes for the fault mode assumed in step 3 (a cause for a fault can be a flaw in the design phase, production phase, transportation, installation or use)

5. Description of the symptoms which will characterize the fault mode assumed in step 3 and of its local effect (output / input relationships, possibilities for secondary failures or faults, etc.)

6. Identification of the consequences of the fault modes assumed in step 3 on the next higher integration levels (up to the system level) and on the mission to be performed.

7. Identification of fault detection provisions and of corrective actions which can mitigate the severity of the fault mode assumed in step 3, reduce to probability of occurrence, or initiate and alternate operational mode which allows continued operation when the fault occurs.

8. Identification of possibilities to avoid the fault mode assumed in step 3.

9. Evaluation of the severity of the fault mode assumed in step 3, e.g. I for minor, II for major, III for critical, IV for catastrophic.

10. Estimation of the probability of occurrence (or failure rate) of the fault mode assumed in step 3, with considerations of the cause of fault identified in step 4

11. Formulation of pertinent remarks which complete the information in the previous columns and also of recommendations for corrective actions, which will reduce the consequences of the fault mode assumed in step 3.

This model closely relates to the risk management framework introduced earlier. Step 2 identifies the element under consideration (Cause structure), step 3 defines the Failure Modes under consideration, step 4 represents a Risk Identification with the Cause Structure – Failure Mode matrix combined with a qualitative risk analysis, steps 5 and 6 are qualitative risk analysis, step 7 and 8 correspond to a preliminary definition of actions, steps 9 and 10 are a quantitative risk analysis, and step 11 finalizes the definition of actions.

The FMECA is performed bottom-up from a single component-level and is often mandatory in safety-related applications. It uses the methods of Risk Map in steps 9 and 10, and for the qualitative risk analysis in steps 4-6 it uses Failure Tree Analysis, Ishikawa Diagrams, Kepner-Tregoe Method, Pareto Diagrams, or a correlations diagram.

Other literature sources discuss FMEA / FMECA applications in specific contexts. For example, [Chao et al. 2003] focus explicitly on the product development process, and [Rhee et al. 2002] explicitly on the failure mode of increased lifecycle cost of the product.

Pro: Internationally recognized method, codified in international standards, very well compatible with general risk management approach

Contra: large effort required if it is to be performed for all elements on a low level

4.4.2.2 Risk Value Method

The risk value method is based on [Browning et al. 2002b] and aims at understanding and tracking the overall technical performance risk of a product and its components. It includes the concepts of technical performance measures (TPMs), Utility Functions and risk reduction profiles. In contrast to Earned Value Management Systems (EVMS), it does not measure progress by “counting” the amount of process completion, which tends to neglect the influence of superfluous activities, the differences of value of different parts of a process, missing process parts and rework.

1: Assessment of likelihood of TPM values with triangular Probability Density Functions

Technical Performance Measures are metrics to plan and track the level of technical performance attributes of the product during the PD process (also see [Thornton 2004] on Key Characteristics (pp. 34-42)). They are usually driven by customer requirements (e.g. range, payload, fuel consumption), but they can also include other attributes that help guide the design process (e.g. weight). The TPMs can be assessed with a triangular Probability Density Function, based on assessments of the minimum, maximum and most probable current value of the TPM, normalizing the area under the triangle to 1.

2: Assessment of impact of TPM values with Utility Functions

The basic concept of assessing the impact of certain TPM values is via Utility Functions. The utility is plotted on a scale from 0 to 1 as a curve over the range of TPM values under considerations. In simple cases, the utility can be expressed with quadratic or linear functions (as for example used by Taguchi loss functions [Taguchi 1992]), but general utility curves provide the highest flexibility (e.g. to incorporate step functions to represent the absolute thresholds of the requirements). The impact is defined as the differences in utility between the target level of performance and the actual performance, multiplied by a normalization constant (e.g. to convert units of utility into more intuitive measures like expected units sold, or scale the utility of different TPMs relative to each other).

Three basic types of utility functions can be considered: Smaller is better (SIB), larger is better (LIB) and nominal is best (NIB).

3: Calculation of Performance Risk

The performance risk for every TPM is calculated as the sum of the products of probability and impact for each unacceptable outcome. Three different cases have to be considered: In “larger is better”, the integral of the product for all TPM values up to the target value (or, in general, a utility threshold) is calculated, in the “smaller is better” case, the integral is calculated for all TPM values above the threshold, and in the “nominal is best” case, the integral is calculated for all TPM values outside an interval surrounding the optimum.

The total Product Performance Risk is calculated as the sum of the weighted performance risks of all TPMs. Advanced approaches try to calculate the overall performance risk based on multiattribute utility theory

4: Monitoring Performance Risk: TPM tracking charts and risk reduction profile

The TPM tracking chart shows the development of the probability density function of a TPM over time. In the case of a triangular PDF, for certain points in time the most likely value of a TPM, along with its upper and lower limits are shown (high-low or uncertainty bars). The different values for the TPM, as they develop over time are then plotted over a time-axis. The TPM tracking chart is, in a strict sense, not a method for risk monitoring, as it only tracks the probability density of the TPM value. The TPM tracking chart can also be used for planning purposes, by specifying an area on the chart that the TPM should follow over time.

5: The Risk Reduction Profile

The Risk Reduction Profile shows the level of risk associated with a TPM over time. In most cases, it will be a series of step-functions, as the risk of each TPM will not be continually assessed, but only at certain points in time. The Risk Reduction Profile can also be used for planning purposes by specifying a target paths at the beginning of the project.

Pro: Detailed and quantitative risk management for performance-related risks.

Contra: Needs detailed technical knowledge, might not be applicable in the early development phases.

4.4.3 Methods for Risk Identification

The methods for Risk Identification which were identified in the literature will be discussed in the following. In order to structure the presentation of the methods, the methods will be categorized along the main failure modes they address. For a full categorization of the methods along all categories, please see Table 4-2.

[Smith et al. 2002] repeatedly illustrate how important a diverse team is for an effective and sensible risk identification (p. 45). Also, it is stressed that a creative and open-minded approach is very important (p. 47).This strongly supports the team organization structures presented in this thesis.

[Smith et al. 2002] indicate that it might be useful to confine the Risk Identification approach to a single method to keep the process easy. They propose "Identification by Schedule" as the most promising approach. In case that different approaches are used, they advise to keeping track of which risks where identified by which approaches and check the top-ranking risks after the completion of the risk assessment to see which approach was the most useful one (p. 49).

4.4.3.1 General Methods for Identification

The methods in this section address risks from more than one failure mode.

Identification by Failure Modes

The team is presented with the failure modes of the project or process identified earlier, as well as with a list of the main goals and success criteria defined for the project (which should be reflected by the failure modes). These factors are then discussed by asking questions like "What could go wrong that would keep us from achieving this success criteria?" or "What could happen that would lead us to this failure mode?" ([Smith et al. 2002] p. 52)

Pro: Relatively easy to execute

Contra: Only supports risk identification on a high level and rough understanding and categorization along failure modes.

Cause Structure – Failure Mode Matrix

The method "Identification by Failure Mode" (discussed above) can be enhanced by taking another axiomatic risk attribute into account, the cause structure. By building a matrix from failure modes and cause structure, both aspects of "causes of risks" and "impact of risks" can be taken into account simultaneously. The matrix can also be used to build basic networks of risks to show their mutual influence and dependency.

Pro: Relatively easy to execute, because the method can be executed with a generic matrix.

Contra: If the entire scope of failure modes and causal structure is addressed, the scope of the Identification process might become to large for a single group to handle.

Checklist

Checklists can be used as reminders of possible risks or risks that have been identified in the past. Checklist can provide very detailed structured lists of risk specific sources and impacts, as opposed to the general causal risk structure and failure modes, which serves as a basic structure for categorizing risks. ([Hall 1998] (pp. 73, 75-78), a specific example can be found on p. 76). [PMI 2004] (p. 244) propose a Risk Breakdown Structure to ensure "a comprehensive process of systematically identifying risk to a consistent level of detail". It also basically is a checklist based on a causal structure. Also, checklists can be created on the basis of concrete risks identified or encountered in past projects. [PMI 2004] (p. 248)

A prompt list has been proposed as a special form of checklist that can be used to generate "provocative questions", which point the team members towards critical points where risks usually originate These lists should be generated in advance, taking the specific situation of the company into account. ([Smith et al. 2002] (p. 53-55))

Prompt List for question generation
Product Definition
• Conflicts with current or planned products • Clear, stable product definition • Understanding of market need, customer use • …
Development Team
• Project leadership • Availability of people • Specific skills needed • …
Quality and Legal aspects
• Quality and reliability issues • Safety and product liability issues • Patent infringement / protection • …
Technical
• Technology availability • Product verification and field testing • Hardware-software conflicts • …

Table 4-3: Example of Prompt List (according to [Smith et al. 2002])

The example table from [Smith et al. 2002] shows that a mixture of factors from the areas of failure modes and the causal structure are addressed simultaneously, i.e. risk causes and effects are not clearly differentiated.

Pro: Very easy to apply once the list exists, good way to capture knowledge

Contra: A “bad” checklist might lead to “white spots” during the risk analysis; up front time investment necessary to generate good checklist; needs historical information

Interviews

Risks can be identified by interviewing peer groups or subject experts to collect their experiences. The results can be collected in the form of a Checklist. [Hall 1998] (pp. 79-80), [PMI 2004] (p. 246), on interviews in general: [Haberfellner et al. 2002] (p. 483)

Pro: Use and conservation of internal and expert knowledge

Contra: Time consuming process

Review of Documentation

By a structured review of the available project documentation (including the before mentioned project plan and work breakdown structure, but also requirements definition, key assumptions and documentation of similar prior projects), risks can be identified by the team. [PMI 2004] (p.245, 248)

Pro: Structured process to assure that existing documented knowledge is used to identify potential risks.

Contra: Only addresses a certain subset of possible risk causes and effects.

Brainstorming

The brainstorming can be performed by an interdisciplinary team with the support of outside experts. A facilitator guides the group through an idea-generation phase. After the creative phase, the risks can be categorized, for example along the causal structure or failure modes. [PMI 2004] (p.245)

Pro: Stimulates generation of new ideas, especially suitable for identifying new risks

Contra: Does not provide the “completeness” of structured reviews, results strongly depended on participants.

SWOT (Strength, Weaknesses, Opportunities, Threats) Analysis

In general, a SWOT analysis is a tool for strategic planning, which identifies the strengths, weaknesses, opportunities and threats in a project or program. Risks can be identified on the basis of a SWOT analysis, focusing on the identified weaknesses (factors internal to the organization) and threats (factors external to the organization). The utilization of a generic strategic tool supports integral risk identification. [PMI 2004] (p. 248), for basics on SWOT analysis see e.g. [Grant 2004].

Pro: Well known method in industry, relatively high number of people trained

Contra: Not focused specifically on risk identification, very broad scope

Identification by Work Breakdown Structure

The work breakdown structure of a project can be used to guide the risk identification process. [Hall 1998] (pp. 77-78) This approach can be considered a special case of a general identification of risks along the causal structure.

Pro: Easily available, detailed

Contra: Can neglect the causal and timely relation between different work packages (which are captured in the project schedule).

4.4.3.2 Product Performance related methods for Identification

The methods in this section address risks associated with the failure mode of product performance.

Identification by Requirements Analysis

The customer and / or internal requirements can be analyzed in detail to understand the goals of the customer or other stakeholders. These goals or requirements can be hierarchically decomposed until they reflect the level of analysis (e.g. voice of the customer, specifications, system requirements, and part requirements). This analysis serves as basis to understand possible product-related failure modes and define Key Characteristics or Technical Performance Measures. [Thornton 2004] (pp. 42-51)

Pro: Yields very detailed understanding of possible failure modes and associated risks.

Contra: Needs clearly defined requirements

Identification by Key Characteristics / Technical Performance Measures

In order to identify the technical performance risks, the technical Key Characteristics [Thornton 2004] or Technical Performance Measures [Browning et al. 2002b] have to be identified first. The Key Characteristics of a product are driven by the customer requirements. They are the technical parameters that have a strong impact on the degree of fulfillment of the customer requirements by the product. [Thornton 2004] (pp. 35-36) lists as important characteristics of KCs: The target values and variations of KCs must be quantifiable, KCs can be identified on different hierarchical levels (e.g. product, system, assembly, part or process), the variation of a KC must have a strong impact on the fulfillment of customer requirements (or, as in this case, on the value of the product), and the variation of the KC must be likely to occur.

The relation of different KCs (on the same or different hierarchical level) has to be established and can be visualized with a Variation flowdown graph [Thornton 2004] (pp. 38-42, 52-64).

Pro: Very detailed definition of risks

Contra: Needs deep and detailed technical knowledge

Geometry-based Variation Simulation

An analysis or simulation based on an assembly model of the product, which includes geometry data and assembly rules. The analysis can predict overall variations in geometric properties based on tolerances of the single parts. Information can be derived if the overall assembly meets certain tolerance criteria, or which tolerances need to apply to single parts based on overall constraints. [Thornton 2004] (pp. 81-82, 89-91)

Pro: Very objective results

Contra. Needs detailed and CAD-based knowledge of product

Identification by Stress Factors

A stress factor is defined by the quotient of applied load to rated load. By systematically assessing environmental conditions (physical, chemical, electrical) and internal loads of components, the components experiencing the highest level of stress under the expected circumstances are identified. [Birolini 2004] (pp. 33-35)

Pro: Relatively objective method

Contra: Needs detailed understanding of product and environmental influences

4.4.3.3 Process Schedule related methods for Identification

The methods in this section address risks associated with the failure mode of process schedule adherence.

Identification by Project Schedule

It is strongly proposed by [Smith et al. 2002] (p. 50) to use the project schedule as the guiding element in the risk identification process. The project schedule is presented, and the different elements are discussed in regard to the possible risks that might originate or occur there. It can be combined with a brainstorming-like process, where team members first pin sticky notes to the schedule with their ideas, which are later analyzed and discussed.

Pro: Intuitively very accessible method

Contra: Does not necessarily consider unforeseen events

Identification by Generic Development Process

This method is very similar to the "Identification by Project Schedule", only that the project schedule is replaced by a generic description of the development process. This approach is especially useful when generic checklists for the risk identification process are generated ([Smith et al. 2002] p. 51). This method can also be combined with a brainstorming-like approach (see above)

Pro: Intuitively very accessible method

Contra: Does not necessarily consider unforeseen events

4.4.4 Methods for Qualitative Risk Analysis

The methods for Qualitative Risk Analysis (as well as the methods for Quantitative Risk Analysis in the following section) will be categorized according to the characteristic of the risk they analyze, i.e. regarding probability, impact or timeframe.

4.4.4.1 Methods for general risk analysis

The methods discussed in this section apply to the analysis of more than one risk characteristic.

Qualitative Analysis with Risk Scenario

Scenarios can be used to subject risks to a qualitative analysis, regarding probability, impact as well as its timeframe. Two types of scenarios need to be discerned: The first type are state-based scenarios. They model the development of the values of certain key factors that describe the system. The possible developments of the values of the key factors are projected into the future, and compatible projections of different key factors clustered into possible future scenarios. This scenario analysis focuses on the state of the system over time [Gausemeier et al. 1996]. This type of scenario is especially suited for defining early warning indicators and threshold values or the impact of a risk.

The second type of scenarios are the event-based scenarios. They focus on a possible chain of events that lead to or from a central event under investigation (e.g. a certain type of failure) Examples of these scenarios are event or failure trees. [Stamatelatos 2002] (pp. 74-95). This type of scenario is especially well suited for developing causal networks to quantify the probability of an event.

The state of a system and certain events are closely linked: any state change is always triggered by an event and the change itself can be understood as an event. On the other hand, every event-based scenario always leads to a certain (system) state (e.g. good or failed). Whereas event-based scenarios show a development over time, state-based scenarios always represent a time-slice at a certain point in time. Event and state based scenarios can thus be understood as being perpendicular to each other, with a state based scenario being associated with every possible event.

This scenario approaches can be generalized into developing a network of factors or events which influence the magnitude of the impact the risk event has, before, during and after the risk event, or analogous regarding its probability. The events and factors associated with the impact are not necessarily different from the events or factors associated with the probability. This network of events and factors is the basis to holistically analyze and understand a risk.

Pro: Yields very detailed understanding of risk and the causal network it is embedded in

Contra: First time generation of scenarios can be very time consuming

Decision tree analysis

A decision tree analysis helps to structure and visualize a chain of possible decisions. It can be used as a basis to generate causal and impact factor's networks, as well as serve as a basis for likelihood and impact quantification (in conjunction with the concept of Expected Monetary Value (EMV; see below)), or as a tool in developing actions. Decision tree analysis usually utilizes a decision tree diagram, consisting of the decision definition, one or more decision nodes describing the possible alternatives in the decision, and chance nodes describing developments in the environment. Cost can be assigned to the decision nodes, probabilities to the different outcomes of chance nodes, and values to different decision / chance node combinations. With this information, the EMV for the decision under consideration can be calculated. [PMI 2004], (p. 257-258)

Pro: Detailed understanding of risk situation and possible developments

Contra: Potentially very time consuming

5 Whys / Root cause analysis

The "5 Whys" method can be used to trace the root causes of a risk. It helps to sharpen the definition of a risk and provides the basis for an assessment of the risks probability and the definition of effective actions. [Hall 1998] (p. 91), [PMI 2004] (p. 248)

Pro: Easy to perform, established method in industry

Contra: Might support a singular cause-and-effect view

Ishikawa or Fishbone Diagrams

Ishikawa diagrams can graphically represent causal relationships over multiple hierarchy levels. It is a widely accepted representation, e.g. in Quality Management [PMI 2004] (p. 248), [Birolini 2004] (p. 78)

Pro: Established method in industry, understood by many people due to application in Quality Management

Contra: Can display hierarchical decompositions, but the network relation between different factors only to a limited extent.

Risk Categorization

To get a better understanding about the nature of the overall risk exposure, a risk categorization can be performed. This can be done along the categories defined in the risk taxonomy (section 2.4.6.5). All the risks identified are assigned to specific categories. Additionally to counting the number of risks, as part of a more quantitative analysis, other data like total expected loss per category can be aggregated (see e.g. the methods for quantitative risk analysis and monitoring). [PMI 2004] (p. 253)

Pro: Easy to do if categories have been established

Contra: Historical data is needed to correctly interpret the distribution of risks among the different categories.

4.4.4.2 Cause- or probability-related methods for risk analysis

The methods presented in this section address the causes and probability of a risk.

Cause-oriented Event Sequence Diagrams (ESD)

Cause-oriented Event Sequence Diagrams are a special case of the scenario method discussed above. [Smith et al. 2002] (p. 66), [Hall 1998] (pp. 90-91, 95) propose to develop the "risk event drivers". This approach can be generalized by identifying the events and circumstances leading to a final state by modeling them as event sequence diagrams [Stamatelatos 2002] (pp. 30-34). The ESD is a flowchart, with different paths leading through a number of events to a final state (e.g. the loss of value being analyzed). An ESD can be transformed to a Fault Tree for quantitative analysis.

Pro: More simple to use than scenario method

Contra: Traditionally, event sequence diagrams follow multiple single string cause-and-effect relation, and do not focus on relations in between these strings.

Fault Tree Analysis (FTA)

A FTA is a systematic top-down investigation of the causes underlying a top event or final state. It can be easily derived from an ESD in order to calculate the probabilities of the possible final states. The top event is the result of AND, OR and NOT combinations of the causes at lower levels. The result of a FTA can be graphically represented by a Fault Tree [Stamatelatos 2002] (pp. 30-34), [Birolini 2004] (pp. 76-78) and references cited therein.

Pro: Well documented and widely accepted approach

Contra: Calculation relies on accurate modeling and data

Reliability Block Diagram

The reliability block diagram (RBD) is a technical event diagram. It answers the questions which elements of the item under consideration are necessary for the item to perform its function, and which elements can fail without affecting the function. Elements are represented by rectangles. The dependencies to other elements are symbolized by connecting lines. Elements can basically be connected in series, or in parallel (redundancy). RBDs differ from functional block diagrams. An RBD can only show two states (good or failed), and only addresses one (technical) failure mode for each element. Different failure modes must be treated in different RBDs. Also, any given element can appear in a RBD more than once. The method has five steps: 1. Definition of the item and of its associated requirements, 2. Derivation of the corresponding reliability block diagram, 3. Determination of the reliability of each element in the RBD, 4. Calculation of the overall item reliability, 5. Elimination of reliability weaknesses and return to step 1 or 2. [Birolini 2004] (pp. 28-32, 67-71)

Pro: Well established method

Contra: Detailed knowledge of product structure necessary to perform method

Part Count Method

The reliability of a system is assessed on the basis of the number of parts. The components are counted and classified into functional categories. For every functional category, estimates are made regarding the reliability of the components therein, based on field data or considerations of technology, environmental and / or quality factors. It is generally assumed that there is no redundancy in the system. [Birolini 2004] (p. 51)

Pro: Very simple to perform

Contra: Usefulness limited to specific applications

4.4.4.3 Effect- or impact-related methods for risk analysis

Impact-oriented Event Sequence Diagrams (ESD)

Impact-oriented Event Sequence Diagrams are again a special case of the scenario method discussed above. Analogues to the ESD developed to determine the likelihood of occurrence of an event, ESDs can be used to model events that have a significant influence on the impact, or events that could cause an additional impact after the first risk scenario occurred. [Smith et al. 2002] (pp. 67-68), [Hall 1998] (pp. 90-91) propose to develop "impact drivers" for the Impact, which they consider to be different from the risk event itself. Technically speaking, an Impact-oriented ESD is identical with a Cause-oriented ESD. The main difference is in the perception of the events modeled: In cause-oriented diagrams, the attention is directed towards elements that influence the likelihood of an event associated with a loss of value, in impact-oriented diagrams, the attention is directed towards events that themselves are associated with a loss of value, or which directly or indirectly influence the magnitude of a loss of value of another event.

Pro: More simple to use than scenario method

Contra: Traditionally, event sequence diagrams follow multiple single string cause-and-effect relation, and do not focus on relations in between these strings.

4.4.5 Methods for Quantitative Risk Analysis

4.4.5.1 General Methods and Definitions

Definition of general scales for impact, likelihood and time component of risk

For the impact, likelihood and timeframe of risk, a generic scale can be established for each. This assures that risks from different domains, which might be assessed along different dimensions, can be compared to each other.

After the general scales have been defined, the impact, likelihood and time component of risks can be described and / or quantified for each of the classes for different dimensions of assessment. This gives for example top management an option to set the standards for risk assessment and ensure that their views are represented (see in the literature e.g. [Smith et al. 2002] (p. 77) on "qualitative scales", [Hall 1998] (pp. 100-101), and [PMI 2004] (p. 245) on Impact Scales).

With this approach, it is possible to make risks from different domains (causes and / or impacts) comparable to each other. For example, the loss of 1 workweek on the executive level could constitute a major impact, whereas the loss of 1 workweek on a lower operational level could be a minor impact. Similarly, a probability of failure of 1% would be an extremely high likelihood when assessing overall reliability of a technical system (e.g. a nuclear power plant, an airplane or an airbag inflation mechanism), but could be an extremely low probability when assessing the scrap rate of a complex manufacturing process.

Also, this definition of general classes can facilitate the Risk Analysis process by providing the team members with guidance on necessary accuracy for their assessments.

The following table presents a proposal regarding a general scale for the probability of occurrence. It includes a general probability scale, a general verbalization of the scale, and specific descriptions of every scale level, oriented on the causal structure.

Probability of Occurrence (Example)				
Probability Scale	1	2	3	4
General Verbalization	Remotely Possible	Possible	Probable	Highly Probable
Specific description				
Project Level				
Risks related to development process	So far has not ever occurred in company or at competitors	Has occurred once or a few times in the past in company or at competitor	Has occurred several times in past projects in company, and might occur once	Has frequently occurred in the past and might occur more than once in the current project
…				
Company Level				
Risks related to other processes in our company	So far no occurrence within the company is known	Risk has occurred in the past, but not in relation to the process analyzed	Risk has occurred in the past in the process under investigation	Risk has frequently occurred in relation to the analyzed process
…				
Supply Chain / B2B Level				
Risks caused by partner companies in supply chain	So far an occurrence has never been reported anywhere in our supply chain	An occurrence has been reported, but was not related to us	Has occurred in the past, also in relation to our company	Has occurred frequently in the past in relation to us
…				
Environmental Level				
Risks caused by natural hazards	Unlikely to occur anywhere in the world and so far never happened	Unlikely to occur in our product / project during lifetime, but possible in industry	May occur once during lifetime of product / project	Several occurrences during lifetime of product / project
…				

Table 4-4: General scale for Probability of Occurrence (example)

The following table presents a proposal regarding a general scale for the severity of impact of a risk. It includes a general impact scale, a general verbalization of the impact scale, and specific descriptions of every scale level, oriented on the failure modes.

Severity of Impact (Example)				
Impact Scale	I	II	III	IV
General Verbalization	Slight	Considerable	Major	Catastrophic
Specific description				
Increase of Lead Time				
Time to market	+ 1% overall development time / 1 week late	+ 5% overall development time / 5 weeks late	+ 15% overall development time / 15 weeks late	+ 35% overall development time / 35 weeks late
Production Time of single units	…	…	…	…
…				
Increase of Lifecycle Cost				
Unit production cost	+ 2% planned cost / 2000 EUR	+ 5% planned cost / 5000 EUR	+ 10% planned cost / 10000 EUR	+ 15% planned cost / 15000 EUR
Unit operation cost	…	…	…	…
…				
Reduction of performance				
Exciter & delighter attributes	- 5% decrease from requirements	- 15 % decrease from requirements	- 30% decrease from requirements	- 50% decrease from requirements
Performance / linear attributes	…	…	…	…
…				
Schedule Overrun				
Element on critical path	+ 1% planned time	+ 5% planned time	+ 15% planned time	+ 35% planned time
Element of critical path	…	…	…	…
…				
Budget Overrun				
Tasks with large budget (> 1 Mio EUR)	+ 2% planned cost or 20000 EUR	+ 5% planned cost or 50000 EUR	+ 10% planned cost or 100000 EUR	+ 15% planned cost or 150000 EUR
Tasks with medium budget (500k – 1 Mio	…	…	…	…

Severity of Impact (Example)				
Impact Scale	I	II	III	IV
General Verbalization	Slight	Considerable	Major	Catastrophic
Specific description				
EUR)				
…				
Non-Conformity to standards				
In relation to development and documentation of safety-critical elements	Very slight process deviations, no potential legal implications	Small process deviations, minor potential legal implications	Noticeable process deviations, potential monetary fines	Significant process deviations, potential large fines and imprisonment
In relation to general quality management documentation	…	…	…	…
...				

Table 4-5: General scale for Severity of Impact (example)

The following table presents a proposal regarding a general scale for the timeframe of a risk. It includes a general timeframe scale, a general verbalization, and specific descriptions of every scale level.

Timeframe (Example)				
Timeframe Scale	A	B	C	D
General Verbalization	Long term	Medium term	Short term	Immediate
Specific description				
Product-oriented				
Main impact of risk	Late in lifecycle of product	Early in lifecycle of product	During development process	During currently active tasks
Occurrence of first risk-related events	…	…	…	…
Timeframe for countermeasures	…	…	…	…
…				
Process-level				
Main impact of risk	Late in development process	Within next phase of development process	Within current phase of development process	During currently active tasks
Occurrence of first risk-related events	…	…	…	…
Timeframe for countermeasures	…	…	…	…
…				

Table 4-6: General scale for Timeframe (example)

Pro: Risks from different areas can be assessed and compared to each other.

Contra: The assessments presented above only define one point on the probability-impact-timeframe continuum for one risk, it does not assess risks by probability distributions.

Risk Data Quality / Confidence Assessment

In addition to the assessment of the risk itself, the quality (including the concepts of accuracy, reliability and integrity) of the assessment itself can be judged. This would generate additional information in regard to the understanding of the risk situation and would represent an intermediate stage between the "point assessments" discussed above and the risk assessment in the form of probability distributions.

Pro: Higher quality of results than simple “point based” assessments

Contra: Additional effort

Quantification by Group consensus

Guided by the general classes of likelihood, impact and timeframes, and their specific descriptions and quantifications, group members assign values to each risk’s likelihood, impact and / or timeframe. These are discussed until there is consensus among the team members. [Smith et al. 2002] (p. 73), [PMI 2004] (p. 251)

Pro: High level of acceptance of results

Contra: Inexperienced teams might need relatively long time

Quantification by assignment to experts

The risks are split up into different categories, and each category is assigned to the team member, or small group of team members, most familiar with these risks. The experts then assign values to each risk’s likelihood, impact and / or timeframe. [Smith et al. 2002] (p. 73), [PMI 2004] (p. 251)

Pro: Relatively fast perform

Contra: Potentially low quality due to lack of discussions and potentially low acceptance of results

Quantification by team-based Delphi method

Each team member anonymously votes for her or his estimate regarding the values to each risk’s likelihood, impact and / or timeframe. The estimates are then visibly recorded on a flipchart or whiteboard. The voting is repeated until consensus in the group is reached.

Pro: Relative high level of quality regarding results and general acceptance of results

Contra: Time consuming method

4.4.5.2 Methods for the Quantification of Impact (Total Loss)

The impact or total loss of a risk is the magnitude of the loss value accrued when a risk event occurs. In general, the impact can fall into any (one or multiple) categories of the failure modes defined earlier, which are directly linked to the categories of value under consideration. The impact is assessed for every identified risk, based on the understanding generated during the qualitative analysis. No methods besides the methods suited for a general quantification were discussed in the literature.

4.4.5.3 Methods for the Quantification of Likelihood

In the area of quantification of the likelihood of a risk, several methods are discussed in the literature with a focus on the product’s performance, especially reliability. The basic mathematical principles of probability and reliability are discussed in section 2.4.8.

Failure rate tables

For many components, especially electronic components, typical failure rates have been derived and tabulated. These can serve as a basis to calculate an overall reliability or probability of failure, for example as part of a failure tree analysis. Failure rate tables can also be developed for specific components as part of the risk management process. [Birolini 2004] (pp. 35-38)

Pro: Relatively accurate quantification possible

Contra: Extensive historical data necessary

Statistical Quality Control

The fraction of defective elements can be quantified with methods from the area of statistical quality control. These are based on a limited number of samples, from which an overall failure rate can be calculated. The methods can be used to estimate or demonstrate the defective probability of an element using sampling tests. The methods for statistical quality control include one-sided sampling plans, simple two-sided sampling plans, and sequential tests. [Birolini 2004], (pp. 259-269)

Pro: Mathematically stringent methods to derive failure rates

Contra: Requires sampling of actual products, and might require a large number of samples for a high level of confidence. A prediction of values is thus limited by historical data and the similarity of the historic process or element to the one currently under investigation.

Statistical Reliability Test

Reliability tests are similar to the tests performed in statistical quality control. The goal is different, namely to evaluate the achieved reliability of an element as early as possible to allow for cost-effective correction. The method allows for estimation and / or demonstration of a reliability value and constant failure rate lambda. [Birolini 2004] (pp. 270-281)

Pro: Mathematically stringent methods to derive failure rates

Contra: Requires sampling of actual products, and might require a large number of samples for a high level of confidence.

Calculation based quantification of likelihood

Based on a detailed network of causal factors, the likelihood can be calculated according to the logic relations of the probability values assigned to every element (see e.g. Failure Tree Analysis). For a discussion of the basic mathematical principles of probability theory, please see section 2.4.8.

Pro: Mathematical stringent deduction of overall probability

Contra: One basic problem with this approach is that the likelihood of an event has a tendency to decrease with the size of the network taken into considerations, because every additional element taken into account lowers the overall likelihood of the final event.

4.4.5.4 Methods for the Quantification of time-related elements

Risk Timeframe / Urgency Assessment

A preliminary assessment of the time-related component of a risk can be made on the basis of the time until the risk might first occur, the time until a risk response would take effect, the status of the relevant early warning indicators, and the overall risk rating. [PMI 2004], (p. 253)

Pro: Generation of additional information on risk central to effective deployment of countermeasures

Contra: Different types of “timeframes” in relation to risk must be kept clearly separate in order to avoid confusion

4.4.5.5 Methods for Multi-dimensional Quantifications: Likelihood and Impact

Calculation of Expected Loss

[Smith et al. 2002] propose to calculate the expected loss as a measure of risk by multiplying the likelihoods of the events leading to the loss with the total loss, if the risk occurs.

$$L_e = P_R \cdot L_T$$

With L_e: expected loss, P_R: probability of risk, L_T: total loss (impact). [Hall 1998] defines this value as Risk Exposure (pp. 92-93)

Pro: This quantification represents the most common understanding of risk, i.e. that risk is probability * impact.

Contra: Does not take time-related effects into account.

Risk Matrix for Likelihood and Impact

A risk matrix is a graph that shows likelihood on one axis and impact on the other. Risks can be placed in the graph according to their values of likelihood and total loss[2]. Lines of constant expected losses (which would show as hyperbolae) can be drawn to divide the map into different fields of priority. [Smith et al. 2002] (p. 35-36, 89-93), [PMI 2004] (p. 251-252).

The example below shows the classes of probability and impact as defined in this thesis. Additionally, a threshold is shown below which risks have been defined as “low”.

---

[2] Please note that in a Risk Map, the likelihood should always be mapped against the total loss, not against the expected loss or the severity. The likelihood of the risk has already been taken into account for the latter two. If the timeframe of the risk is to be taken into account, the risk severity method should be adapted to be based on the total loss, not the expected loss. The Risk Map can then be developed based on this time-related (but not likelihood-related) risk severity.

Pro: Classical risk management tool; additionally, the risk map offers an important tool to integrate management guidance by the possibility to assign different prioritization levels to the different quadrants of the matrix.

Contra: Does not take time related risk attributes into account.

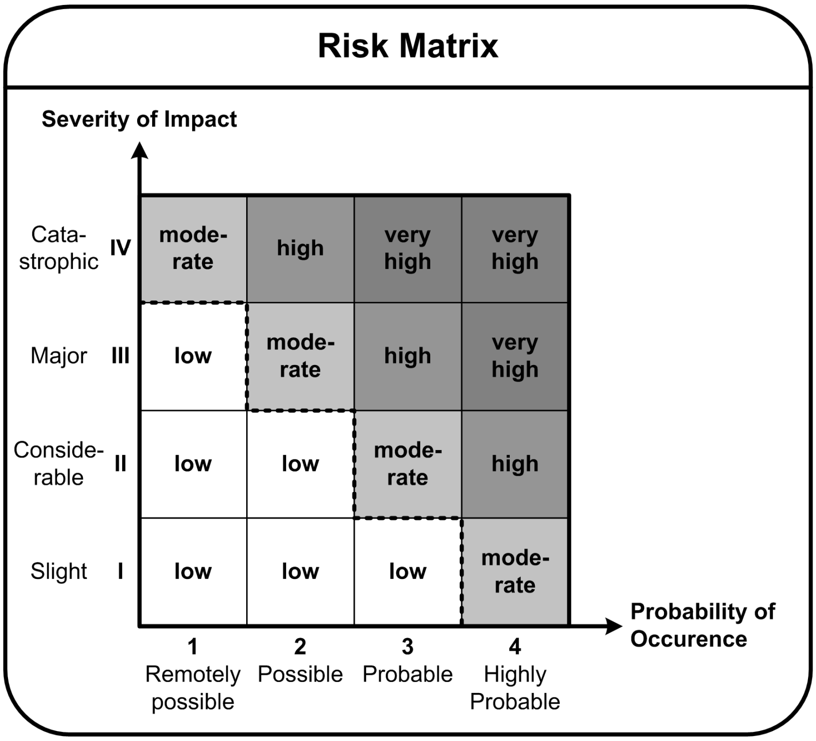

Figure 4-2: Risk map with expected losses and threshold

Expected Monetary Value analysis

The Expected Monetary Value (EMV) is a statistical concept that can be used to calculate average outcomes under uncertainty. The EMV of risks will usually be expressed as negative values. The basic method is to multiply the value of each possible outcome with the probability of its occurrence[3], and add these up. The EMV analysis is often used in conjunction with a decision tree analysis. The use of computer models and simulations are suggested to yield objective data. [PMI 2004] (p. 257)

Pro: Quantified aggregation of a multitude of outcomes

Contra: Prone to misuse, if not based on objective computer models and simulations

[3] Also see „Calculation of Expected Loss“

Probability Distribution of Impact

Discrete distributions, i.e. one impact associated with one likelihood, are well suited to represent uncertain events. In the case of uncertain values on a continuous range, continuous probability distributions are better suited to describe the uncertainty.

Especially well suited is the representation with Triangular Distribution. A triangular distribution can be easily generated from a three point estimate of the impact under consideration (e.g. cost or schedule). The three points are the minimum (or low), most likely, and maximum (or high) case. These are then plotted as the triangular probability distribution, with the value range of the impact on the x-axis, and the relative probability on the y-axis. Other commonly used distributions are the beta, uniform, normal and lognormal distributions. [PMI 2004] (p. 256)

Pro: Mathematical more accurate representation of situation

Contra: Not as easily understandable and interpretable as simple "point-based" assessments

Monte Carlo Simulation

A simulation can be used to translate the uncertainty associated with single elements on a detail level, into uncertainty and potential impact on a higher, project or program, level.

Based on the probability distribution functions of the elements on the detail level, the corresponding probability distribution function on the program or project level (e.g. total cost) are computed. This is done by iteratively calculating the overall value on the basis of random samples of the basic values (according to their probability distribution). A cost simulation can for example be based on the cost distributions of the elements in the work breakdown structure, a schedule simulation can be based on a precedence diagram. [PMI 2004] (p. 258-259)

Pro: Objective, quantitative results

Contra: Dependent on accurate simulation model

4.4.5.6 Methods for Multi-dimensional Quantifications: Likelihood, Impact and Time-relation

Risk Severity

Risk Severity is based on the Expected Loss of a risk, but also takes the time-component of a risk into account. The general rule is that the severity of a risk increases with the expected loss as well as the impact. [Hall 1998] (p. 93) propose the following matrix to quantify the risk severity, based on expected loss and the timeframe of a risk, with 10 being the highest severity and 1 the lowest severity:

		Expected Loss		
		Low	Medium	High
Timeframe	Immediate	7	9	10
	Short term	5	8	9
	Medium term	3	6	7
	Long term	1	2	4

Table 4-7: Risk Severity from Timeframe and Expected Loss (adapted from [Hall 1998])

Pro: Explicit acknowledgement of time-component of risk

Contra: Has to be integrated with a classical probability-and-impact centric prioritization approach.

4.4.6 Methods for Risk Prioritization

Top 10 Risk Ranking

[Smith et al. 2002] propose a simple ranking of the risks by the expected loss calculated. (pp. 34-35, 86-88), [Hall 1998] (pp 93-94) proposes a ranking by risk severity. A risk ranking can be used to give an overview over the most critical or important risks. It should contain at least a statement of the risk, the current priority, and the actions taken, their status and the respective owners of the risk and actions. Additionally, detailed information on the risk assessment and other characteristics of the risk can be added.

Pro: Clear hierarchy of risks

Contra: Information on likelihood and impact is lost, different types of loss are difficult to compare

Pareto Analysis

A Pareto analysis is based on the assumptions that a relatively small fractions of the risks cause a relatively big fraction of the expected losses, or that a big fraction of all risks are caused by a relatively small number of causal elements, represented by the Pareto rule that 80% of the possible problems are generated by 20% of the possible causes. Generally speaking, it is a graphical presentation of the frequency and cumulative distribution of elements.

Thus, there are several possible approaches to the Pareto analysis: One is to rank all risks by their expected losses, and then the cumulative expected losses are calculated for the risks in the order derived earlier. A second possibility is to count the risks per causal element (e.g. along the causal structure defined earlier), rank the causal elements according to their risk count, and then calculate the cumulative number of risks. Another Pareto analysis would be to look at the cumulative expected losses along causal elements. [Hall 1998] (pp. 96-97), [Birolini 2004] (p. 78)

Pro: supports objective prioritization, relatively small effort

Contra: Dependent on quality of risk analysis

Sensitivity Analysis

If a quantitative computational model of the risks with causal and impact factors has been derived, a sensitivity analysis can be performed by changing each variable to its extreme points and holding all other variables on their default value. Through this analysis, the variables with the biggest impact on the overall system can be derived. It can be used to analyze the extent to which the uncertainty of one element affects the overall objectives [Hall 1998] (p. 99), [PMI 2004] (p. 257)

Pro: Quantitative results

Contra: Needs detailed model

Utility Function Models

An approach that is more refined than the sensitivity analysis is the Utility Function models. Not only are the risk networks taken into account, but also the stakeholders and managers preferences and attitudes toward risk. This way, critical thresholds can be assessed at which decisions regarding risks would change. [Hall 1998] (p. 99)

Pro: Explicitly takes stakeholders into account

Contra: Needs detailed model

Nominal Group Technique

Based on the information generated in the assessment process, every team member ranks the risks from 1 (most important) to n (least important). The rankings of all team members are summed up, and the risks ranked from the lowest score to the highest score. [Hall 1998] (p. 102)

Pro: Very quick and easy to perform

Contra: No feedback and discussion amongst team members to enrich each others mental models of the problem and reach a consensus by agreement

Weighted Mulitvoting

Every team members rates the risks by assigning a certain number of points from a pool of available points (e.g. 10) to each risk. The points assigned to each risk are then summed up, and the risks prioritized from the highest to the lowest score. [Hall 1998] (p. 102)

Pro: Quick and easy to do

Contra: Does not facilitate discussion amongst team members

4.4.7 Methods for Definition of Actions

Classification of Actions

In order to facilitate the definition of actions, they can be classified into different categories.

Examples from the literature are [Smith et al. 2002] (pp. 106-115), who propose the general categories of Avoidance of Risk, Transfer of Risk to third party, Redundancy, Mitigation of Risk (Prevention Plan and Contingency Plan), and Reserves; [Hall 1998] (p. 111-114) proposing acceptance, avoidance, protection, reduction, research, reserves, and transfer; and [PMI 2004] (p. 261-262) proposing the categories of Avoid (eliminate threat, isolate objectives from risk impact, relax objects under risk), transfer ownership of risk, Mitigate risk (lower probability and / or impact)

The following table presents a proposal to unify these categorizations:

		Scope of Action		
		Probability	**Impact**	**Integral**
Type of Action	**Avoid**	Eliminate causes of risk (e.g. eliminate threat)	Eliminate impact of risk (e.g. isolate objectives from risk)	Drop risk-afflicted element
	Reduce	Reduce probability (e.g. redundancy)	Reduce impact (e.g. reserves, contingency planning, relax objectives under risk)	Simultaneously reduce probability and impact (e.g. hedging)
	Transfer	Transfer responsibility for occurrence to third party (e.g. outsourcing)	Transfer responsibility for impact to third party (e.g. insurance)	Transfer entire risk to third party (e.g. sell risk afflicted element)
	Accept	Accept probability of risk	Accept impact of risk	Accept total risk

Table 4-8: Possible general classification of actions

Pro: Classification of actions might help in the definition of actions or a general strategy

Contra: The risk attribute “timeframe” is not acknowledged

Action Plan

Action Plans are used to keep track of the actions defined and initiated to assure that all risks are properly addressed. The action plan should contain the risk addressed, the objective, means of measurement of completion, completion date, responsible individual, and the resources allocated for the task [Smith et al. 2002] (pp. 36-38, 104-105). Others propose to include Action, Objectives, Alternatives, Approach, Approval Authority, Owner, Resources required, start date, Activities, Due date, actions taken, results achieved.

Pro: Easy way to keep track of actions

Contra: Might get “overloaded”, appropriate IT support might be necessary

Application of Problem Solving Cycle to Definition of Measures

A general problem solving cycle (see e.g. [Lindemann 2002]) can be applied to the definition of actions ([Hall 1998], pp. 110-111). In the first step, the problem is defined by selecting the risks for which actions are to be developed according to the assessment done. If necessary, high priority risks can be assessed in more detail by the methods described this section. At this stage, scenario analysis can be very helpful in understanding the dependencies of the risks under investigation. In a next step, alternative actions to treat a risk are developed, e.g. in accordance with the different categories of actions defined above. After possible actions have been defined, the desired actions are selected. This selection can be based on an integrative approach that tries to resolve as many risks with as few actions as possible. The Risk Reduction Leverage (see below) also yields valuable input for judging an action.

Pro: Professional way to define actions

Contra: Might be time-consuming for untrained teams

Risk reduction leverage for Cost-Benefit analysis

The risk reduction leverage is a simple cost / benefit analysis for assessing actions associated with risk management. It is the quotient of the decrease in expected loss due to the action and the cost of action. [Smith et al. 2002] (pp. 115-117), [Hall 1998] (pp. 115-116)

$$RRL = \frac{L_{e,b} - L_{e,a}}{\sum_i C_{a,i}}$$

With $L_{e,b}$: Expected loss before actions, $L_{e,a}$: expected loss after actions, and $C_{a,i}$: the cost of an action associated with a risk.

Pro: Allows for a first cost / benefit analysis regarding the actions

Contra: Reduction of expected loss, i.e. the reduction of the probability or impact, due to the actions might be difficult to assess.

4.4.8 Methods for Execution

As has been discussed in section 4.3, the execution of the actions is considered part of day-to-day management. Therefore, standard management techniques apply. No specific methods were found in the literature.

4.4.9 Methods for Monitoring

The methods described in the following are mostly focused on specific metrics. The selection of the methods for employment as part of a risk management process strongly depends on the specific goals, therefore the methods in this section will not be assessed.

4.4.9.1 Monitoring the Risk Management Activities

Review of Actions initiated

[Smith et al. 2002] propose to regularly review the state of the actions that have been initiated to mitigate the risks identified earlier (p. 39)

Project Risk Management Panel

Several metrics can be displayed on a Risk Management Panel or Risk Management Overview Chart. The metrics selected are based on the needs of the management [Hall 1998] (pp. 126-129).

Monitoring of expected losses

[Smith et al. 2002] propose to monitor the expected losses of the risks identified. If the actions initiated against the risks, the expected losses should be declining, because the actions either reduce the likelihood of the risk or its total loss (p.39)

Measuring risks prevented

It is proposed to track the number of risks having been successfully prevented, by counting the number of risks for which the latest possible time of occurrence has passed. This can be used as method to assess the effectiveness of the preventive actions taken ([Smith et al. 2002], p.39, 135).

Measuring impact mitigation

[Smith et al. 2002] propose to track the extent by which the impacts of risks that have actually occurred have been mitigated by action plans defined. This can be used as a method to assess the effectiveness of the contingency actions defined (p. 39).

Counting new risks identified

[Smith et al. 2002] (pp. 129-130) propose to track the number of new risks identified in the course of the project as a measure for the ability of the risk management system to stay in touch with the evolving project.

Reserve Analysis

Reserve Analysis compares the amount of contingency reserves remaining in the project or program to the current risks. The goal is to determine if the current reserves are adequate. [PMI 2004] (p. 266)

Tracking of unidentified and later occurred risks

As a measure for the quality of the risk management system, the risks which slipped through the identification system can be tracked to serve as input for the next project. [Smith et al. 2002] (pp. 135-136)

Risk Management Index

The risk management index is the relation of the expected loss of all risks identified relative to the according value of the project in percent, e.g. project budget divided by expected financial loss

Other Tactical Metrics

- Risk Status Trend: [Smith et al. 2002] (pp. 137-138) A graph showing the number of active and closed risks, as well as issues identified over time (e.g. every month), for the top ten risks identified. This chart can be used to track risk management goals, e.g. a small number of issues and steadily declining active risks.
- Active Risk Loss Summation: Trend charts for Total Loss, Expected Loss and Actual Loss for the top ten risks. This can be used as an indicator for the effectiveness of the active actions plans. [Smith et al. 2002] (pp. 138-139)
- Number of Risks: Number of Risks currently identified and managed [Hall 1998] (p. 129)
- Number of Risks per Category: Number of Risks currently identified and managed per category (see Risk Taxonomy above). [Hall 1998] (p. 129)
- Risk Exposure: Cumulative current risk exposure [Hall 1998] (p. 129)
- Risk Severity: Cumulative current risk severity [Hall 1998] (p. 129)
- Risk leverage: Cumulative current risk leverage of active actions, or distribution of risk leverage among actions
- Early Warning Indicators: The value of certain selected Early Warning Indicators can be displayed [Hall 1998] (p. 129)
- Return on Investment: The Return on Investment for the risk management actions is the summation of all savings through actions divided by the total cost of actions. $L_{e,b,i}$ being the expected loss before, $L_{e,a,i}$ the expected loss after actions taken for risk i, n being the total number of risks, C_j being the cost for action j, m being the total number of actions. After [Hall 1998] (p. 129)

$$\frac{\sum_{i=1}^{n}(L_{e,b,i} - L_{e,a,i})}{\sum_{j=1}^{m} C_j}$$

4.4.9.2 Monitoring the Risks

Risk Inventory / Risk Tracking Spreadsheet

[Smith et al. 2002] propose a Risk Tracking Spreadsheet that will contain all information of the risks being investigated and which will be continually completed in the course of the risk management process (p. 45). According to the risk model presented in this thesis, the spreadsheet should contain the following information: a consecutive number, name of risk event, brief description of risk event, owner of risk, precursor events, follow-on events, position in cause-structure, likelihood of event, failure mode addressed, description and magnitude of impact, priority, timeframe of risk, associated actions, owners of associated actions and timeframe of actions. [Hall 1998] (pp. 82-83) proposes a similar, IT-based approach that also contains information on early warning indicators, thresholds, and a detailed mapping of the risk to different models (e.g. project schedule, work breakdown structure, resources involved, etc.)

Monitoring of changing risks on Risk Map

The movement of risks is tracked on the Risk Map to make trends in certain risks transparent.

Scenario-based tracking of risks

High-severity risks can be monitored by a scenario-based approach. Also see the “Total Risk Scenario” method in section 4.4.10.

Establishment of Early Warning Indicators

Some actions defined during the early Control phases might not have initiated directly, because a risk was under a certain threshold at that time. To make sure that a timely reaction to a changing risk situation is possible, Early Warning Indicators can be defined based on the networks defined during the risk scenario analysis. These Early Warning Indicators are linked to specific thresholds, risks and reserved actions. [Lessing et al. 2005], [Hall 1998] (pp. 111-112).

Early Warning Indicators can for example be based on Technical performance measures (TPMs) [Hall 1998] (p. 125), [Browning et al. 2002b]

Monitoring of Risk Scenarios

The risk scenarios are continuously monitored and updated to assure that their structure represents the current state of knowledge. [Lessing et al. 2005], [Hall 1998] (p. 124)

Monitoring of Value of Early Warning Indicators

The value of the Early Warning Indicators are monitored and compared to the threshold values. Every Early Warning Indicator is associated with one or more risks and the according (reserved) actions. [Lessing et al. 2005], [Hall 1998] (pp. 124-125)

4.4.10 Methods for Aggregation

In the literature review, only one approach could be identified that explicitly addresses the aggregation of risk over multiple levels of management.

Total Risk Scenarios

The method itself is part of a larger risk management architecture, including organizational structure and process elements, which cannot be discussed in detail here, but which are compatible to the approaches presented in this thesis.

Similar to the scenario analysis performed for single risks, total risk scenarios can be developed to describe the risk situation a project, department or company is facing. The scenarios are constructed from the risks which have been identified in order to analyze and understand their complex relationships. Since the Total Risk Scenarios have a much greater scope than the scenarios discussed before, which addressed only one risk, they become much more complex. This leads to higher requirements regarding the quality of the execution of this method. It also requires the organizational capacity to manage Integral risk management processes, i.e. to deal with risks scenarios which might practically involve an entire company and need to take a multitude of stakeholders into account.

Analogous to the scenarios for single risks, Early Warning Indicators can also be defined for Total Risk Scenarios in order to maintain transparency over the risk situation on an aggregated level. This is part of larger Early Warning System to support higher level management.

To reduce the level of complexity, generic Total Risk Scenarios can be defined which represent the interests of top level stakeholders. These can then be customized to represent the actual risk situation. [Lessing et al. 2005]

Pro: Treatment of complex risk situations and enterprise-wide integration of risk management activities possible.

Contra: Development of initial Total Risk Scenarios can be very time consuming.

4.5 Summary of Risk Management Methodology

Risk management had been identified as a key action to crisis prevention in the last phase of the Munich Procedural Model.

This chapter offered an overview of the important literature discussing risk management in product development, including the areas of product development centric risk management approaches, project risk management, strategic or enterprise risk management, reliability-oriented risk management, technical risk management, and systems risk management.

A risk management process framework was presented that unifies and is compatible with the approaches identified in the literature. It consists of an inner process circle describing the basic risk management process, an outer circle incorporating a more advanced monitoring process, and an integrative circle linking several risk management processes to an overall enterprise risk management.

An extensive collection of methods in the area of risk management in product development has been presented, including the characterization and discussion of 66 methods.

The basic concepts to describe the axiomatic risk attributes introduced in section 2.4.6 were used and proved very helpful in categorizing and describing the methods.

The methods presented cover (for the first time) all areas of the risk management process framework, of the causal structure, and all failure modes. Very few methods explicitly addressed the timeframe-component of risk, although practically all methods implicitly supported it. Only one method has been identified that explicitly addresses the Aggregation process step to link a risk management process to an overall enterprise risk management.

5 Interim Summary: Relation of High Performance Teams and Risk Management

In the two previous chapters, high performance teams and risk management have been discussed as approaches to crisis prevention. This chapter briefly discusses the relation of the two in the light of crisis prevention.

Risk management has been explicitly cited by some high performance teams as a key enabler for there success (see especially [Greenfield 2001], [Cornford et al. 2001], [Griner et al. 2000] (p. 40), [Spear et al. 2000]).

The analysis of high performance teams suggests that explicit risk management approaches can be considered a driver for high performance teams (see sections 3.3.2.7 and 3.5.3.3).

The goals of risk management in product development are directly aligned with the goals of high performance teams, as risk management aims at supporting superior development processes and products.

Also, the following elements are explicitly stated as risk management goals:

- cross-functional integration
- proactive solving of problems
- Capturing of Lessons learned

All elements are important aspects of high performance teams. It could be said that high performance teams, by adopting those and other elements, also implicitly perform risk management.

Also, the good integration and communication of high performance teams, both internally and externally, are key elements to support successful risk management activities

As risk management is a process that will be executed by a team, it is trivial that it would benefit from being executed by high performance teams. The topic is nevertheless explicitly addressed in the literature, for example by [Hall 1998] (p. 166).

These results strongly suggest that high performance teams profit from using risk management as part of their product development project, and risk management strongly benefits from important factors of high performance teams.

6 Field Study on Product Level

In the following, a field study will be discussed that has been conducted at a large internationally active North American corporation from the automotive sector. It will discuss the results of the literature-based chapters 3 - 5 in the context of application in industry. Section 6.1 outlines the research method employed, section 6.2 describes the situation at the industry partner, and section 6.3 presents the results of the field study, in relation to risk management, high performance teams, and the relation of risk management and high performance teams.

The goal of the field study was twofold:

- Obtain an industry perspective on the theoretical work of this thesis
- Offer an overview over the literature and concepts therein to the industry partner

6.1 Research method

6.1.1 Description of method

The research at the industry partner was done in three phases,

- Allow for a general understanding and analysis of the situation,
- Primarily investigate the current and planned team structures in the area under investigation,
- Primarily investigate the process itself in detail.

A total of 13 experts were interviewed several times in the course 4 visits and a total of 16 days.

The visits were prepared by conducting literature reviews in the according areas (high performance teams and risk management methodology, see chapters 3 and 4. The research on site consisted of introductory discussions and semi-structured interviews [Haberfellner et al. 2002]. The interviews and discussions were followed up with document reviews off site and open questions were discussed via telephone and / or email as necessary.

6.1.2 Limitations of approach

Although all reasonable efforts have been made to include a wide variety of dialogue partners in the research, to cover a broad spectrum of the organizational structures and processes described later, not all areas could be covered in the same depth. Therefore, the situation can only be represented with a certain degree of accuracy. The lack of certain views or elements in the following presentation of discussions and interviews might very well be the result this limitation and must not be mistaken for an actual lack of these elements.

6.2 Description of situation

6.2.1 Context and process description

The field study focuses on team reorganization and process improvements surrounding the Virtual Prototyping Process (VPP). The goal of the VPP is to support a front-loading of a development program by conducting a series of CAD-geometry related assessments before a first physical prototype is build. The process is divided into five functional areas:

- Basic geometric compatibility: Issues related to the clearance of parts, static and dynamic displacements, movement, and heat clearances are addressed, as well as questions of basic CAD data maturity and quality.
- Craftsmanship and Appearance: This element deals with issues related to the quality perception of the car from a customers point of view.
- Service: This functional area focuses on issues related to the Servicing of the vehicle throughout its lifetime, including for example issues of cost of ownership, warranty, export conditions and special diagnostic computer tools.
- Manufacturing and Assembly: This process element deals with the geometry-related assessment of parts (including manufacturing-specific elements like, for example welds), the manufacturing process and all resources needed for the execution of the process.
- Ergonomics. Issues related to the ergonomics of the vehicle operation, for example ingress and egress, reach, vision and accessibility are addressed by this part of the VPP process.

Parallel to the process improvements through the VPP, the structure and responsibilities of the teams executing this process are addressed as well. Interdisciplinary and interdepartmental Area Teams are formed. They are made up of representatives of the different functional areas that need to be involved in the VPP process. The vehicle is split into several geometric areas, and each Area Team is assigned to one of these areas with the responsibility to execute the VPP.

6.2.2 Problem description

The VPP and Area Teams are being developed to address a set of root causes associated with severe schedule slippages and high additional costs in late phases of the product development process.

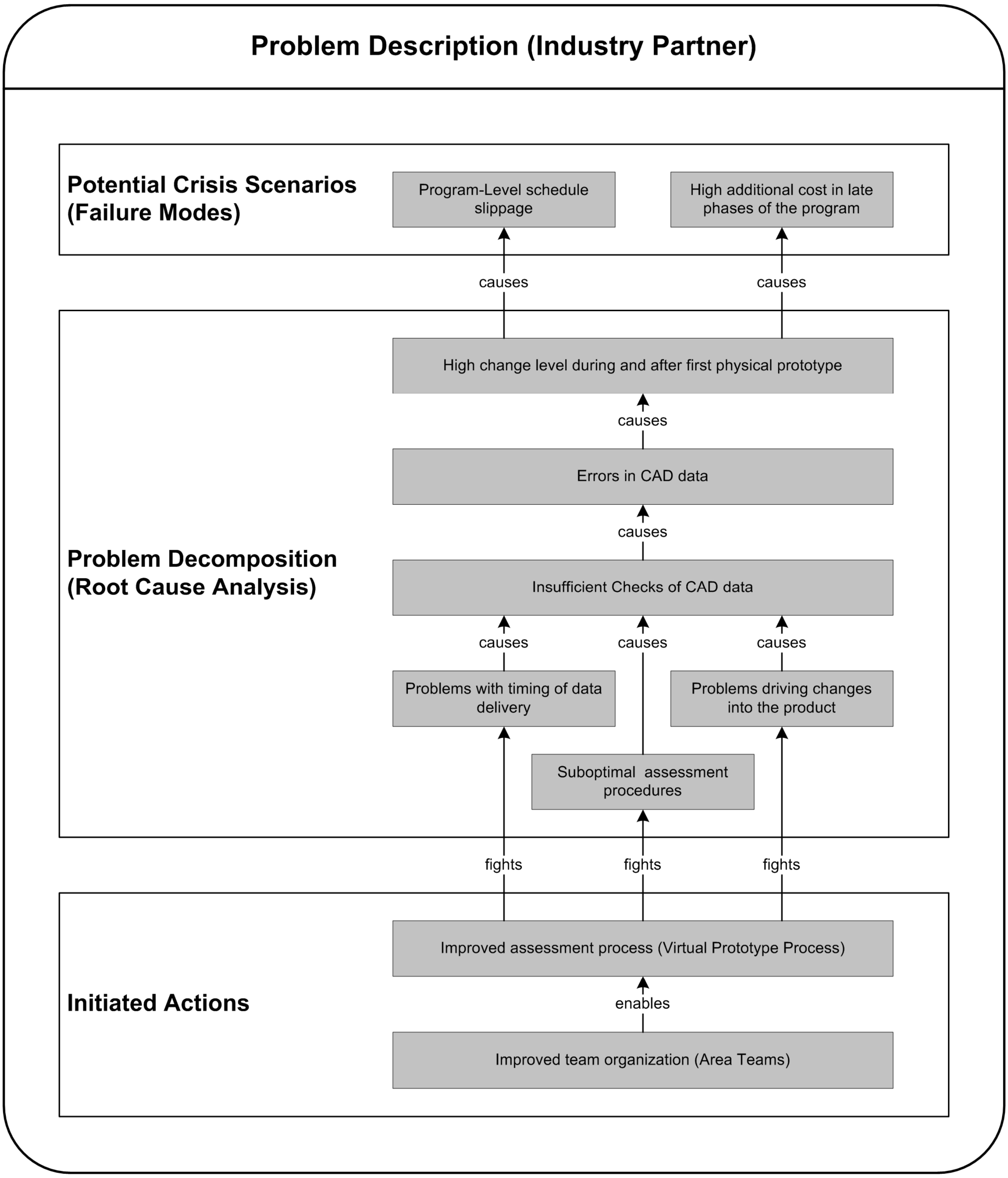

Figure 6-1: Description of Problem Situation at Industry Partner

High change levels during and after the physical build of prototypes led to potentially severe schedule slippages and additional costs. The reason for the high change levels were traced to errors in the CAD data, for example component interference, insufficient clearances, fastener misalignments, insufficient clearance of components to assembly fixtures or other assembly components or dissatisfying assembly ergonomics. These errors could remain in the CAD data due to insufficient checks and assessments of the CAD data. The root causes for this was identified as lack of data integrity (e.g. incorrect version- or variant-markings of parts), suboptimal timing of CAD data delivery, suboptimal assessment processes for the CAD data, and a suboptimal driving of changes into the product data. These root causes are addressed by the VPP process (see above), which is enabled through the Area Teams.

6.3 Results

6.3.1 Applicability of Risk Management model in Field Study

It is reasonable to consider the VPP process as a risk management process, aimed at crisis prevention, because the objectives of the VPP process are closely aligned with the general risk management goals, and because the VPP explicitly addresses the issues that have been identified as potential Product Development crises.

6.3.1.1 Alignment of VPP and Risk Management Goals

Similarly to a risk management process, the VPP aims at managing and reducing the uncertainties associated with the product and development focus. It shares the following goals with risk management (see section 2.4.4.2):

- Avoiding "surprise problems" in late development phases
- Achieve cross-functional integration
- Retain and apply best practice solutions
- Avoid reoccurrence of same problem
- Support proactive tackling of problems

The VPP does however not share the goal of identifying the root causes of the problems encountered. This can be explained with the fact that the VPP is already addressing what has been identified as root causes before.

The VPP does also not address the full breadth of risk management in product development, but focuses on the operational technical level. It mostly addresses the product performance and, to a lesser degree, product lifecycle cost and schedule adherence. The other areas are only addressed indirectly or to a much lower degree.

6.3.1.2 Crisis Prevention through the Virtual Prototyping Process

In the description of the problems which led to the VPP, as well as the description of the VPP itself (see above), it is apparent that the VPP addresses the root causes of potentially severe schedule slippages and high additional costs through late changes in the product development process. These two situations have been identified as potential crises in product development (section 2.5.3). The VPP can therefore be reasonably be considered a process aimed at crisis prevention.

6.3.2 Discussion of results regarding team structures

6.3.2.1 Discussion of the applied method (Influence Diagram)

The method chosen for the analysis of the factors determining high performance teams, the influence diagram according to Vester, was presented and discussed. The method found wide acceptance and credibility. A limitation is the fact that no negative influences have been addressed in the systems analysis, which was illustrated during one discussion. This fact is part of the discussion of the limitations of the method in section 3.1.6.

Single elements of the matrix were randomly selected and discussed. There was general agreement to the quantifications in the matrix.

6.3.2.2 Discussion of results from literature review from industry perspective

The factors determining high performance teams, which have been identified in the literature review, were sufficient to discuss the topic. No additional factors needed to be introduced into the discussion. This suggests that the factors presented in this thesis exhaustively characterize high performance teams.

No factor discussed has been deemed unimportant. All factors discussed were regarded as comprehensive and important in the context of high performance teams.

The grouping of the factors into the four categories (Enablers, Drivers, Critical Elements and Indicators) was discussed. The discussions showed a general agreement to the grouping of the factors. For example, with the help of the Indicators, a dialog partner could directly describe the scenarios encountered in different past programs. Especially interesting in this context was the notion that the Indicator "Minimum process, maximum resource constraints" was strongly dependent on the successes (or, more general, results) that a team or team leader has achieved in the past, as opposed to the other Indicators being linked to the current performance of the team.

6.3.2.3 Discussion of industry initiatives from literature perspective

The discussion showed that most of the factors identified in the literature for high performance teams, and regarded as problematic in the current organizational setup, are addressed by the Area Team reorganization.

For the category of Drivers, these are:

- Clearly defined goals: The clear definition of the area of responsibility (geometric area of a vehicle), along with the process improvements, address this element
- Hand picked team members: On the level of Area Teams, team leaders will have greater influence in the selection of team members.

- Explicit risk management activities: see discussion of results regarding process improvements below
- Well defined basic processes: The explicit setup as Area Teams along with generic rules and the improved VPP process address this factor.

One factor that has been identified as potentially problematic and which is not being addressed through the Area Team organization is:

- Stable and timely resource allocation: The factor is outside the scope of the Area Team organization. Nevertheless, it is very important to be addressed in order to support the team's performance.

In this category, the following factors have been reported as already well under control:

- Qualification
- Stability of Requirements
- Collocation
- Complexity Match
- Balanced Skills
- Extensive ties
- Expandable structure

For the category of Critical Elements, the factor regarded as currently problematic, but addressed by the Area Team organization is:

- Small Team Size: The organization into Area Teams gives great leverage to keep the team size to a minimum throughout its lifecycle.

The following elements have been identified as already well under control:

- Identification with Team Goals
- Motivation

However, in the category of Critical Elements there are several factors that might still be problematic with the new Area Team organization:

- High quality of communication: The communication will be improved horizontally within the team, but the vertical communication is not addressed in the same depth.
- Mutual accountability, mutual trust (inside the team and regarding the environment): These factors might be difficult to address due to two factors: First, a competitive overall atmosphere and secondly, it is most sensitive towards problems resulting from the potential misalignment or different prioritization of goals among different functions. The Area Team organization might support the resolution of these difficulties by making potential conflicts transparent and helping to resolve them.

- Flat Management Structure and Participatory Leadership: An issue with the three factors mentioned before might cause issues with this factor. Another area of concern is the integration of two different management chains within the Area Team, which only intersect on a high level.

In the category of Indicators, a strong dependence of their values on the specific project or program has been reported. This confirms and supports the classification of these factors as Indicators.

6.3.3 Discussion of results regarding process improvement

6.3.3.1 Methods and Processes at Industry Partner

The following matrix gives an overview over the methods identified during discussions and interviews, aimed at managing and reducing uncertainty and risk in the product and process. As mentioned earlier in the discussion of the limitations of the research approach (section 6.1.2), not all areas of the VPP could be covered in the same level of depth. The following collection of methods and approaches is focused on three areas, Basic geometric compatibility, Service, and Ergonomics.

Risk Management Framework	Product			Process		
	Lead Time	Lifecycle Cost	Perfor-mance	Schedule adherence	Budget	Quality
Risk Identification			Requirements Analysis Knowledge-based checks / Lessons Learned Automated Part Vicinity Check	Data readiness schedule		
Qualitative Risk Analysis						
Quantitative Risk Analysis		Cost Metrics	Performance Metrics Execution of CAD-based checks			
Risk Prioritization		Metrics-based prioritization				
Definition of Actions						
Execution of Actions						

Risk Management Framework	Product			Process		
	Lead Time	Lifecycle Cost	Perfor-mance	Schedule adherence	Budget	Quality
Monitoring			Single Part Requirements Verification Table Part Pairing Requirements Verification Table Metrics Panel Chart	Track Chart for percentage of parts complete Number of Issues Development Path Number of requirements checked and compliant Throughput		Age of parts before Check
Aggregation						

Table 6-1: Risk management methods identified in field study (product level)

Check catalogue based on Requirements Analysis

Requirements Analysis is a process whereby the requirements for the vehicle are defined in more detail to a level where the characteristic of a part or group of parts can be quantitatively assessed regarding this requirement. It also includes that requirements defined by different sources (e.g. internal norms, benchmarking processes etc.) are aggregated in a matter that makes transparent which group of requirements applies to which part or group of parts in a vehicle. This overall process produces a check catalogue of requirements, which are the basis to identify the possible risks of performance-related failures. Theoretically, this process should yield a complete list of all possible performance-related risks for every part, but this list becomes extremely large if applied to all vehicle components, and tends to exceed practical limitations.

Knowledge-based checks / Lessons Learned

Known issues from past programs are collected and are used as a checklist against which new programs are assessed. These might for example include past issues with climate control components in vehicles which were exported to countries with extreme temperature conditions. This produces a list of limited length which includes important past risks, but is limited to the identification of risks that occurred in the past, offers no value in the assessment of yet unknown risks.

Rule-based Part Identification

To compensate for the limitations of the Knowledge-based checks on the one hand, and to reduce the workload which would result from a test of all parts against all requirements, a Rule-based Part Identification is conducted to identify and prioritize the parts that need to be checked in detail against the extensive checklist from the Requirements Analysis, to identify possible performance risks associated with these parts. This rule-based identification can be conducted along three categories, the degree of newness of a part, the cost and lead time of parts, and the complexity of the surrounding area of a part.

In the analysis regarding the newness of parts, the parts are prioritized for checking against the requirements checklist along three categories: In the first category (top priority to be checked against requirements checklist), completely new parts and parts containing new technology are collected. In the second category (medium priority), modified parts are collected, and carry over parts build the third category (low priority).

The analysis based on cost and lead time of parts prioritizes parts according to rules based on cost and lead time objectives. In the top priority, parts with high change costs and long lead times are collected (e.g. parts associated with the powertrain or dash panel), the lowest priority is made up of parts with low change costs and short lead times.

The complexity of the surrounding area is assessed according to the judgment of geometric and interface complexity, and parts are prioritized accordingly on different levels. The top priority is assigned to parts in highly complex areas (e.g. the engine compartment), second priority is assigned to parts in medium complex areas (e.g. instrument panel), and the third priority is assigned to parts in areas of low complexity.

This reduces the number of checks in relation to the check catalogue, to a manageable level along clearly defined rules, thus enabling a structured process, but potentially excludes certain checks (but does so in a structured fashion, as opposed to a random exclusion when time runs out due to an exceeding number of required checks).

Automated Part Vicinity Check

Certain checks are based on requirements relating to the relative geometric position of two parts. In order to limit the number of parts that need to be checked in relation to a specific part being analyzed, Automated Part Vicinity Checks generate a list of parts in a volume around the specified part. These CAE tools can also measure certain values of the relative geometric position of two parts, and thus automatically execute certain checks.

Data readiness schedule

The data readiness schedule is a main tool to track the uncertainty and potential risks related to unfinished CAD data. Based on a generic product structure defined at the beginning of the program, the CAD data delivery times for all parts along different maturity levels are defined in advance. In addition to allowing for different functions to plan their checks accordingly, it also allows them to assess the general level of risk associated with the definition of the product.

Performance and Cost Metrics

Based on the geometry-related requirements and their degree of fulfillment, performance and cost metrics are defined to assess the magnitude of impact of the geometric values. This can include for example assessments of the repair time based on ergonomic analysis, or warranty cost based on damageability assessments.

Execution of CAD-based checks

After the parts and the according requirements have been identified, the assessments are executed with CAE tools. Regarding the probability, most checks are binary in nature, discerning only between 0% (risk will not occur, or requirement fulfilled) and 100% (risk will occur, requirement not fulfilled). Parts of the assessments can be automated (see for example the Automated Part Vicinity Check), some assessments are based on expert judgment supported by the visualization through CAE tools.

There are two tools employed to track the status of the requirement verification (or assessment of performance risk):

Single Part Requirements Verification Table

This chart tracks the status of single parts. The parts are listed along with all requirements that apply to the part. The status of the assessment of the fulfillment of the requirements is noted, along with countermeasures that were defined, in case requirements were not fulfilled satisfactorily.

Part Pairing Requirements Verification Matrix

Similarly to the Single Part Requirements Verification Table, this matrix tracks the status of the assessment of all part pairings. Parts are listed in columns and rows, and the status of the interface checks is noted at the intersection.

Metrics Panel Chart

The development of the metrics discussed earlier is tracked on a Metrics Panel Chart. It displays the current value, as well as target values and other reference values.

Track Chart for Percentage of CAD parts complete

The percentage of CAD-data complete is tracked against requirements defined in the Data readiness schedule. This provides fundamental information for overall program tracking and control, as well as an estimation of the degree of certainty or risk elimination in the process.

Number of Issues Development Path

The number of issues / risks identified and not resolved are tracked over time on a chart. A target development corridor is predefined on the chart that sets the overall goals for the number of identified and unresolved issues. The corridor sets a high and rising number of issues / risks at the beginning of the program, and then develops into a steady decline until the program's end. By requiring a large number of unresolved issues / risks at the program beginning, an incentive is given to actually identify issues and risks, and not to hide them. To define a sensible target development corridor, historical data and expertise from comparable programs are needed.

The following methods are used to track the identification process.

Number of Requirements Checked and Compliant

The number of requirements that were checked and found compliant is tracked as a measure of the progress of the identification process. This gives orientation about the status of the identification process, but might not reflect actual amount of work done or open, as different requirements might require a different amount of work to check.

Age of Parts before Checks

The age of parts, before they are checked for possible issues or risks, is tracked. The target values are specified according to the stage of the development process. In the early phases, parts are allowed to have an age in the order of weeks, in later phases parts must not be older than a certain number of days before they are checked.

Throughput of Parts

As a performance measure for the identification process, the number of parts checked per time unit is tracked.

6.3.3.2 Discussion of results from literature review from industry perspective

A possible issue with the risk management activities was highlighted in one discussion. The process tends to assume a strong “control” focus with a high degree of needed discipline to be executed properly. It might not appeal to the same individuals who are attracted to more “creative” processes within Product Development.

The following methods directly correspond to methods identified in the literature review: Requirements Analysis directly corresponds to the method “Requirements Analysis”, Knowledge-based checks is very similar to the methods “Identification by Checklist” and “Review of Documentation”, although these methods are discussed in the literature for a broader application range. Performance- and Cost metrics directly correspond to the method “Identification by Key Characteristics”, as does in part the metrics-based prioritization. The Metrics Panel Chart corresponds to the method “Project Risk Management Panel”, although the focus of the metrics themselves is different. The Track Chart for percentage of parts complete corresponds to the method “Measuring Risks Prevented” and the Number of Issues Development Path to method “Counting New Risks Identified” (although the Development Path method is more advanced by setting a certain number of issues / risks identified as a target value).

The following methods identified in the industry had not been identified in the literature. This might be in part due to the specialized and focused nature of the VPP process: The Data

Readiness Schedule can be seen as a specialization of the method “Identification by Project Schedule”. The Automated Part Vicinity check and the Execution of CAD-based checks are similar to the method “Geomety-based Variation Simulation”, since they use CAE tools, but both have a very specific focus and scope. Both the Single Part Requirements Verification Table and Part Pairing Verification Matrix are not discussed in this form in the literature and present an interesting addition on the technical level. The Number of Issues Development Path has already been mentioned above as being similar but more advanced than the method “Counting New Risks Identified”. The Number of Requirements Checked is a metric that has not been discussed in the literature, as well as the metrics of the Age of Parts, before they are checked, and the Throughput of parts.

6.3.3.3 Discussion of industry initiatives from literature perspective

Obviously, the VPP process focuses on certain aspects of an overall risk management system, in accordance with its goals. From a failure mode point of view, the distribution of the methods shows a concentration on product performance. From a risk management process framework point of view, there is a concentration on Identification, Quantitative Analysis and Monitoring. Both limitations are in line with the goals of the VPP process (see section 6.2).

In the following, the VPP process will briefly be discussed along the generic risk management Process Framework.

- Regarding Identification, the VPP is very strong, within the limitations of its scope discussed above.
- Regarding Qualitative Assessment, the analysis suggests that the VPP process does not include qualitative assessments. These usually aim at root cause analyses of the risks / issues identified. This can be explained taking into account that the VPP implementation itself is a measure aimed at addressing root causes. The risks / issues identified are thus treated as root causes.
- Regarding the Quantitative Assessment, a more fundamental limitation, which might even question applicability of discussing the VPP as a risk management process, is the focus on issues rather than risks. Issues can be understood as risks with a 100% probability of occurrence.
- Regarding the Prioritization, not many explicit methods have been found. The interviews suggest that all risks / issues identified are treated relatively equally. Although issues might be grouped into different level of priorities, the requirements are that they all need to be resolved. This implicitly supports an equal treatment of all issues and thus undermines any prioritization.
- The definition and execution of actions are implicit part of the Verification Tracking Table and Matrix. The lack of methods in this area might be attributed to a limitation of the research process. If not, it must be ensured that the VPP process has the according interfaces to drive the changes related to the issues identified into the product.

- The aggregation of issues / risks in the sense defined in the risk management framework does not occur
- The monitoring process element shows strong tools, limited to the scope of the VPP process. From a scope of content point of view, the limitations are on product performance aspects, which can be verified with CAE tools. It also shows some elements addressing process schedule adherence. Aspects associated with product lead time, product lifecycle cost, process budget and process quality, are addressed to a much lower degree (as the VPP is a process improvement initiative, it will also implicitly address process quality by supporting stronger process discipline). These areas need to be covered by other processes, and the according interfaces integrated into the VPP process.

The possible applications of methods from the literature review in the VPP depends on the goals that are followed and can be discussed as

- Increasing the scope of the process by stronger focusing on other failure modes than on product performance,
- Increasing the breadth of the process by placing more emphasis on qualitative analysis, definition and execution of actions, and aggregation,
- Increasing the depth of the process while maintaining scope and breadth.

The first two options would assume that the goal would be to increase the scope or breadth of the process. For both cases, the literature review offers a wide variety of methods that might be applied. But assuming that the goals that lead to the establishment of scope and breadth of the VPP process are still current, a discussion of the increase of the depth of the process might be interesting. The literature review offers the Risk Value Method (method number 2). It also focuses on the technical product performance, as well as on the process side on quantitative assessment, prioritization and monitoring. As the VPP is already very strong in the identification part, the distribution of elements in the RVM might be fitting.

The Risk Value Method could be used to enhance the VPP capabilities to include assessments of probabilities, as well as support the handling of more complex requirements above basic CAD data properties. The RVM does not replace the VPP, but might add capabilities, either as a new process, or as an upgrade to the existing VPP process.

The Risk Value Method offers a way to describe the current probability distribution of a performance metric in an easy way, as well as capture the utility associated with different levels of performance. Additionally, the performance metric is characterized according to its type (e.g. “more is better”, “less is better”). This allows for the calculating of the risks that every performance aspect of a product is exposed to. The RVM also includes methods to monitor the development of the performance metrics. For a description of the RVM, see section 4.4.2.2.

6.3.4 Discussion of the relation of team structures and processes

6.3.4.1 Discussion of results from literature review from industry perspective

The research showed that the risk management oriented process optimization was accompanied by improvements in team structure as well, which are strongly related to each other. This strongly supports the hypothesis that high performance teams and risk management activities are mutually beneficial.

6.3.4.2 Discussion of industry initiatives from literature perspective

The improvement initiatives in the industry, both address process improvements and improvements regarding the organizational structure these processes will be executed in. Both improvements are designed to mutually benefit from each other. The literature strongly supports this approach (see chapter 5).

6.4 Summary

This chapter described a field study done at a large North American company in the automotive area. The situation at the company has been described. Process improvements and changes in team organization that were initiated to prevent crisis situations (schedule and budget overrun) in the product development process were analyzed.

It was shown that the discussion of high performance teams in this thesis is suitable to discuss high performance teams in industry. The factors identified could be verified.

Additionally, the process improvements were analyzed in regard to risk management content. It could be shown that large parts of the risk management activities were covered in the risk management method discussion of this thesis; other methods identified in the field study seemed to be specializations from these. The process focuses on performance risks, which is in line with its targets.

It could be argued that the process encountered at the industry partner could not yet be called a risk management process, as it only rudimentarily addressed the probability of occurrence of the risks discussed. Nevertheless, the risk management framework proved suitable to describe the industry process, and clearly showed the directions by which the process could be developed to a more advanced state from a risk management point of view. It could be argued that the process encountered in this field study represents a risk management process on a very basic level.

7 Conclusions

This chapter will briefly discuss the results of the thesis in the light of the goals and hypothesis defined at the beginning.

Regarding goal (1) "Present the basic definitions and overview over the fields necessary to discuss Crisis Prevention in Lean Product Development from a High Performance Team and Risk Management point of view":

The thesis has addressed the question of crisis prevention in lean product development. Following the Munich Procedural Model, the focus of this thesis were high performance teams and risk management as important elements in crisis prevention (section 2.1.2).

A concept was developed that linked crises and crisis prevention to lean product development via the categories of value in product development and the directly associated types of crises (sections 2.2.3 and 2.5).

A comprehensive concept for describing risk and the axiomatic risk attributes was developed. Similar to the crisis, it was linked to lean product development with the concept of the failure modes, which are based on the categories of values (sections 2.4.5 and 2.4.6).

Definitions of high performance teams were discussed. They implicitly state their crisis prevention capabilities (section 2.3).

Regarding goal (2) "Investigate in a literature review the factors defining High Performance Teams":

Based on an literature review regarding high performance teams, 49 factors describing high performance teams have been extracted and described in detail (section 3.3). These factors were characterized and clustered into four groups (drivers, critical elements, indicators, and enablers) with the help of systems analysis methods, and the classification discussed. 14 factors were classified as drivers, 11 as critical elements, 6 as indicators, and 3 as enablers, and 15 could not clearly be assigned to one category, but suggestions regarding possible characterizations were made (sections 3.4 and 3.5).

Regarding goal (3) "Research a general framework and a collection of methods applicable to Risk Management in Product Development, with a focus on the methods":

An overview of the important literature discussing risk management in product development was given (including the areas of product development centric risk management approaches, project risk management, strategic or enterprise risk management, reliability-oriented risk management, technical risk management, and systems risk management) (section 2.4.4.3).

A risk management process framework was presented that unifies and is compatible to the approaches identified in the literature. It consists of an inner process circle describing the basic risk management process, an outer circle incorporating a more advanced monitoring process, and an integrative circle linking several risk management processes to an overall enterprise risk management (section 4.3).

An extensive collection of methods in the area of risk management in product development has been presented, including the characterization and discussion of 66 methods. The basic concepts for describing the axiomatic attributes of risk proved very helpful in the presentation and discussion of the methods. The methods presented cover (for the first time) all areas of the risk management process framework, of the causal structure, and all failure modes. Very few methods explicitly addressed the timeframe-component of risk, although practically all methods implicitly supported it. Only one method has been identified that explicitly addresses the Aggregation process step to link a risk management process to an overall enterprise risk management (section 4.4).

This suggests that hypothesis (III) is true ("The literature on Risk Management will offer a collection of methods on Risk Management, which are applicable to Product Development")

Regarding goal (4) "Discuss the relation of High Performance Teams and Risk Management":

Risk management has been explicitly cited by some high performance teams as a key enabler for there success. The analysis of high performance teams suggests that explicit risk management approaches can be considered a driver for high performance teams. The goals of risk management in product development are directly aligned with the goals of high performance teams. Some goals of risk management (cross-functional integration, proactive solving of problems, capturing of lessons learned) are important aspects of high performance teams. It could be said that high performance teams, by adopting those and other elements, also implicitly perform risk management. The good integration and communication of high performance teams, both internally and externally, are key elements to support successful risk management activities (chapter 5).

These findings suggest that the hypotheses (I) and (IV) are true ("As best practice examples, high performance teams in Product Development will show certain elements of Risk Management to prevent crises" and "The organizational structure of high performance teams and the processes of Risk Management are mutually beneficial")

Regarding goal (5) "Discuss the literature findings from these three areas in the light of a field study":

It was shown that the discussion of high performance teams in this thesis is suitable to discuss high performance teams in industry. The factors identified could be verified.

Additionally, the process improvements were analyzed in regard to risk management content. It could be shown that large parts of the risk management activities were covered in the risk management method discussion of this thesis; other methods identified in the field study seemed to be specializations from these. The process focuses on performance risks.

It might be argued that the process encountered at the industry partner could not yet be called a risk management process, as it only rudimentarily addressed the probability of occurrence of the risks discussed. Nevertheless, the risk management framework proved suitable to describe the industry process, and clearly showed the directions by which the process could be developed to a more advanced state from a risk management point of view. It could be argued that the process encountered in this field study represents a risk management process on a very basic level (chapter 6).

This suggests that the hypotheses (II) and (V) are true ("Risk Management in Product Development is an effective tool for Crisis Prevention" and "The field study will support and further illustrate the findings from the literature review").

8 Outlook and Future Research

This chapter briefly gives an overview of the possible future research in the area of this thesis.

The results of the research documented in this thesis suggest possible future research questions in several different dimensions.

Regarding Risk Management and High Performance Teams

This thesis only addresses the first phase of a product's lifecycle, the development phase. It would be very interesting to develop an overall approach for crisis prevention, risk management, and high performance teams, that took the entire product lifecycle into account, i.e. also addresses production, assembly, operation, service, and the recycling of the product.

Regarding High Performance Teams

The model used to describe and characterize high performance teams in this thesis is basically a static model that also does not include any negative influences. The next step would be to transfer this basic model into a dynamic simulation environment. This could yield more insights into the dynamic development of high performance teams, and address questions like how to create and how to sustain high performance teams.

Also, high performance teams have not been discussed from a corporate perspective. This view taken in this thesis always aims at an optimization of a single project or program. Questions arising at a company level, e.g. is it better to concentrate all high-performing and highly qualified individuals in a few selected teams, or better spread them out over different teams so they can act as "nuclei" for the formation of high performance teams, have not been addressed in this thesis, but would be very interesting to investigate further.

Regarding Risk Management

It has been shown that risk management supports high performance teams. Also, risk management is regarded by the Munich Procedural Model as suitable for crisis prevention. However, no hard quantitative data has been encountered in the literature supporting this assumption. It would be very interesting to develop a model to assess the value of risk management processes in product development environments. This would also allow for the benchmarking of different risk management implementations.

In the area of risk management, the review of the methods showed a shortcoming in the area of the overall aggregation of risks and integration of different risk management processes into an overall enterprise risk management. It would be interesting to follow this line of thought and develop and overall product- or even enterprise-centric approach which would link the risk management activities of different departments in different phases of the lifecycle.

Also, the risk management method review showed the unresolved question of "point based" risk assessments, where one pair of probability and impact is defined, facing "continuous" risk assessments, where probability distribution functions are used. Both approaches seem to make sense in specific applications, but the question does not seem to be explicitly discussed in the literature so far.

This thesis addressed the question of the roll-out and integration of risk management processes in a program or project environment only very superficially. It would be very interesting to investigate the introduction of a high performance team / risk management process element into a (probably already running) project or program.

The field study also poses the question of a phase model for the introduction of risk management processes. If the example presented in the field study shows a very basic scenario for the establishment of a risk management process environment, it would be very interesting to investigate the possible future options to further enhance the risk management part step by step.

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10 Appendix

10.1 Glossary

Area Team

Area team is an expression from the field study. Parallel to the VPP (see below), the teams executing this process are addressed as well. Interdisciplinary and interdepartmental Area Teams are formed. They are made up of representatives of the different functional areas that need to be involved in the VPP process. The vehicle is split into several geometric areas, and each Area Team is assigned to one of these areas with the responsibility to execute the VPP.

Crisis

In this thesis, the term crisis refers to crises in Product Development. They are typically characterized by

- Unexpected and / or unwanted event
- Occurrence late in development process
- High degree of necessary changes
- Very high time pressure and pressure for results

Expected Loss

The expected loss can be used as a measure of risk. It is derived by multiplying the likelihoods of the events leading to the loss with the total loss, if the risk occurs. The expected loss is identical with the "classical" understanding that risk equals probability times impact.

High Performance Team

This thesis follows the definition of high performance teams from the literature. They have been defined as teams that "consistently satisfy the needs of customers, employees, investors and others in its area of influence" with the result that "these teams frequently outperform other teams that produce similar products and services under similar conditions and constraints". High performance teams are also described as "a team of people who have unleashed their potential toward their stakeholder shared purpose".

Risk

In this thesis, risk is defined as

- an uncertain,
- time-related

- loss of value,
- being part of and influenced by complex dynamic networks of factors and/or events.

The first element captures the concept of uncertainty and probability of the risk definitions, the second element explicitly notes the time-related nature of risk, the third element integrates the definition of risk with the Lean school of thought (see section 2.2.3 for a discussion of the concept of value in lean product development), and the fourth and final element addresses the complex nature of risks as being part of causal networks rather than simple single cause-and-effect relations.

Risk Attributes (probability, impact, timeframe, scenario)

Based on the definition of risk, four basic attributes are derived to describe any given risk. These are

- The probability of occurrence, based on a (more or less complex) causal structure,
- The timeframe of the risks development,
- The type and magnitude of the risks impact, and
- Causal networks describing the causes and effects of the risk (e.g. scenarios).

Risk Management

In this thesis, risk management is defined as a system consisting of the elements

- Risk Definition with the axiomatic attributes,
- Risk Management Process Framework,
- Risk Management Methods, and
- Organizational Structure associated with Risk Management.

Total Loss

The total loss is the aggregated impact of a risk.

VPP / Virtual Prototyping Process

VPP is an expression from the field study conducted as part of this thesis. The goal of the VPP is to support a front-loading of a development program by conducting a series of CAD-geometry related assessments before a first physical prototype is build. The process is divided into five functional areas:

- Basic geometric compatibility
- Craftsmanship and Appearance
- Service

- Manufacturing and Assembly
- Ergonomics

10.2 Influence Matrix of Influence Diagram

Table page 2 right

To (below) / From (right)	Hand-picked members	Hands-on work on product	High degree of motivation	High degree of qualification	Identification with team goals	Proactive solving of problems	Seamless Employment / Sequential Multitasking	Alignment of Responsibility and Freedom of Execution	Capturing of Lessons Learned	Clearly defined goals, short and long term	Collocation	Common Approach	Employment of best-practices model as overall process model	Explicit Risk Management approach	Flexible Membership	Internal mechanisms for execution	Isolation	Minimal Process, Maximum resource constraints on Team	Mixture of high pot. young and experienced sen. eng.	Performance-based incentives	Positive but strict schedule, cost and performance reviews	Quick and reliable error correction	Replication of Team structure in sub-teams	Reuse of existing technology	Small size	Strong Project Manager	Utilization of specific IT Tools	Well-balanced skills
Individual Team Member Level																												
Hand-picked members		0	0	0	0	0	0	0	0	3	0	0	0	0	3	0	0	0	0	0	0	0	0	0	9	3	0	9
Hands-on work on product	0		0	0	0	0	3	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	3	3	0	0	3
High degree of motivation	3	0		3	9	3	3	9	0	3	3	0	0	0	3	0	3	3	3	3	0	3	0	0	3	0	0	3
High degree of qualification	9	3	0		0	0	3	3	3	0	0	3	3	3	3	0	0	0	3	0	0	0	0	0	0	0	0	3
Identification with team goals	3	0	3	0		3	3	3	0	9	3	3	3	0	0	0	3	3	3	3	0	0	0	0	3	0	0	3
Proactive solving of problems	3	3	9	3	9		3	9	9	3	3	0	3	3	0	3	0	3	0	3	3	3	0	3	3	0	0	3
Seamless Employment / Sequential Multitasking	0	3	0	0	0	0		0	0	0	0	0	0	0	-9	0	0	0	0	0	0	0	0	0	0	0	0	0
Team Level																												
Alignment of Responsibility and Freedom of Execution	9	3	9	9	9	3	0		3	3	0	3	3	3	0	3	0	9	3	3	3	0	3	0	9	-9	0	3
Capturing of Lessons Learned	0	3	3	0	3	3	3	0		0	3	3	3	3	-3	3	0	-3	3	0	0	3	0	3	0	3	0	0
Clearly defined goals, short and long term	0	0	0	0	0	0	0	0	0		0	3	0	3	0	3	0	0	0	0	0	0	0	0	0	3	0	0
Collocation	0	0	0	0	0	0	0	0	0	0		3	0	0	0	3	3	0	0	0	0	0	0	0	3	0	0	0
Common Approach	0	3	0	0	3	0	0	0	0	9	3		3	3	0	9	3	-3	0	0	0	0	9	0	3	3	0	3
Employment of best-practices model as overall process model	0	0	3	3	0	3	3	3	3	3	0	9		3	3	3	0	-3	0	3	3	0	0	0	0	0	0	0
Explicit Risk Management approach	0	0	0	0	0	3	0	0	3	3	0	3	3		3	3	0	0	0	0	3	0	0	0	0	0	0	0
Flexible Membership	0	0	3	3	3	0	0	0	0	3	0	-3	0	3		9	-9	0	0	3	0	0	0	0	0	0	0	3
Internal mechanisms for execution	3	3	3	3	0	3	0	3	0	3	3	3	3	3	0		0	0	0	3	3	0	3	0	3	3	0	9
Isolation	0	0	0	0	0	0	0	0	0	0	9	3	0	0	-9	0		0	0	0	0	0	0	0	3	3	0	0
Minimal Process, Maximum resource constraints on Team	3	0	3	9	3	3	0	9	3	3	0	3	0	0	0	3	0		0	0	0	3	0	0	9	-3	0	9
Mixture of high potential young and experienced senior engineers	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	3
Performance-based incentives	0	0	0	0	0	0	0	0	0	9	0	9	0	0	0	3	0	0	0		0	0	0	0	0	0	0	0
Positive but strict schedule, cost and performance reviews / monitoring	3	0	3	3	3	3	3	3	3	9	3	9	3	3	0	9	0	0	3	3		0	3	3	3	3	0	3
Quick and reliable error correction	3	3	9	9	9	9	3	3	3	3	9	9	3	3	3	3	3	0	3	3	3		3	3	3	0	0	3
Replication of Team structure in sub-teams	0	0	0	0	0	0	0	0	0	0	0	3	3	0	3	3	0	0	0	0	0	0		0	0	0	0	0
Reuse of existing technology	0	0	0	3	0	3	3	0	3	0	0	0	3	3	3	3	0	0	3	0	0	0	0		0	0	0	0
Small size	3	0	3	9	3	3	0	3	0	0	0	9	0	3	3	3	0	0	0	0	0	0	0	3		-3	0	9
Strong Project Manager	0	0	0	0	0	0	0	-9	0	0	9	0	0	0	-3	0	0	-3	0	0	0	0	0	0	-3		0	0
Utilization of specific IT Tools	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0		0
Well-balanced skills	9	0	0	3	0	0	0	0	0	9	0	0	0	3	3	3	0	0	3	0	0	0	0	0	0	0	0	
Team Member to Team Member relation Level																												

Table page 3 below

Figure 10-1: Influence Matrix, Page 1

Table page 1 left

To (below)	From (right)	Team Member to Team Member relation Level	Coaching of young through experienced team members	Commitment	Flat Management Structure and Participatory Leadership	Generation of innovative ideas	High quality communication	Mutual Accountability	Mutual trust (Inside Team)	Team to Environment relation Level	Challenging requirements	Complexity of task matches requirements and resources	Expandable Structure	Extensive Ties	External Activity	High quality of results	Integration of Suppliers	Management of Scope	Mutual Trust (Team-Environment)	No micromanagement by environment	Results on cost	Stable and timely resource allocation	Stable requirements	Timely results
Individual Team Member Level																								
Hand-picked members			0	0	0	0	0	0	0		0	0	3	0	0	0	0	0	0	0	0	0	0	0
Hands-on work on product			0	0	0	0	0	0	0		3	0	0	0	0	0	3	0	0	0	0	0	0	0
High degree of motivation			3	3	9	3	3	3	3		9	9	3	0	0	3	0	3	3	9	0	9	9	3
High degree of qualification			3	0	0	3	3	3	0		0	0	3	3	3	0	3	0	0	0	0	0	0	0
Identification with team goals			3	3	9	0	3	3	3		3	9	0	0	0	0	3	3	3	3	0	3	3	0
Proactive solving of problems			0	3	0	3	3	9	3		3	0	3	3	3	0	9	0	3	3	0	9	0	3
Seamless Employment / Sequential Multitasking			0	0	0	0	0	0	0		0	0	-9	0	0	0	0	0	0	0	0	0	0	0
Team Level																								
Alignment of Responsibility and Freedom of Execution			3	9	9	0	3	9	9		3	3	0	0	0	0	0	3	3	9	0	3	3	0
Capturing of Lessons Learned			9	3	0	0	0	3	0		0	0	0	0	3	0	3	0	0	0	0	0	0	0
Clearly defined goals, short and long term			0	0	0	0	3	0	0		0	0	0	0	0	0	0	3	0	0	0	0	9	0
Collocation			0	0	0	0	0	3	0		0	0	-3	0	-3	0	-3	0	0	0	0	0	0	0
Common Approach			0	3	0	0	3	0	0		0	0	0	0	0	0	0	0	0	0	0	0	3	0
Employment of best-practices model as overall process model			0	0	0	0	0	0	0		3	3	0	0	0	0	0	3	0	0	0	3	0	0
Explicit Risk Management approach			0	0	0	0	0	0	0		3	0	3	3	0	0	0	0	0	0	0	0	0	0
Flexible Membership			0	3	3	0	3	-3	9		0	0	9	3	3	0	3	0	9	0	0	9	0	0
Internal mechanisms for execution			3	3	0	0	3	3	3		0	0	0	0	0	0	0	0	0	0	0	3	0	0
Isolation			0	0	0	0	0	3	0		0	0	-9	-9	-3	0	-3	0	0	0	0	0	0	0
Minimal Process, Maximum resource constraints on Team			0	0	3	0	3	3	3		3	0	0	0	0	9	0	3	3	9	9	9	0	9
Mixture of high potential young and experienced senior engineers			0	0	0	0	0	3	0		3	0	3	3	3	0	0	0	0	0	0	0	0	0
Performance-based incentives			0	0	0	0	0	3	0		3	0	0	0	0	3	0	0	0	0	3	0	0	3
Positive but strict schedule, cost and performance reviews / monitoring			3	3	0	0	3	3	0		0	0	3	3	3	0	3	0	3	0	0	0	0	0
Quick and reliable error correction			3	3	0	3	9	3	3		0	0	3	3	3	0	3	0	3	0	0	3	0	0
Replication of Team structure in sub-teams			0	0	0	0	0	0	0		0	0	3	3	0	0	0	0	0	0	0	0	0	0
Reuse of existing technology			3	0	0	3	3	0	0		0	0	0	3	3	0	3	0	0	0	0	0	0	0
Small size			0	0	9	0	3	3	0		0	3	3	3	0	0	3	9	0	3	0	9	9	0
Strong Project Manager			0	0	-9	0	0	-3	0		0	0	-3	-3	-3	0	0	0	0	0	0	0	0	0
Utilization of specific IT Tools			0	0	0	0	0	0	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0
Well-balanced skills			0	0	0	0	0	3	0		0	3	3	3	3	0	0	0	0	0	0	0	9	0
Team Member to Team Member relation Level																								

Table page 1 left

Table page 4 below

Table page 4 below

Figure 10-2: Influence Matrix, Page 2

Table page 1 above

Table page 4 right

To (below) / From (right)	Individual Team Member Level	Hand-picked members	Hands-on work on product	High degree of motivation	High degree of qualification	Identification with team goals	Proactive solving of problems	Seamless Employment / Sequential Multitasking	Team Level	Alignment of Responsibility and Freedom of Execution	Capturing of Lessons Learned	Clearly defined goals, short and long term	Collocation	Common Approach	Employment of best-practices model	Explicit Risk Management approach	Flexible Membership	Internal mechanisms for execution	Isolation	Minimal Process, Maximum resource constraints on Team	Mixture of high pot. young and experienced sen. eng.	Performance-based incentives	Positive but strict schedule, cost and performance reviews	Quick and reliable error correction	Replication of Team structure in sub-teams	Reuse of existing technology	Small size	Strong Project Manager	Utilization of specific IT Tools	Well-balanced skills	Team Member to Team Member relation Level
Team Member to Team Member relation Level																															
Coaching of young through experienced team members		0	3	3	3	3	0	0		0	0	0	3	3	0	3	-3	3	0	0	9	0	3	0	0	0	0	0	0	3	
Commitment		3	3	9	3	9	3	3		3	0	3	9	3	0	0	0	3	3	3	3	0	3	3	0	0	9	0	0	3	
Flat Management Structure and Participatory Leadership		9	3	9	3	9	3	3		3	0	3	9	3	0	3	0	3	0	3	3	0	0	0	3	0	9	-9	0	9	
Generation of innovative ideas		3	3	9	3	9	3	3		3	3	3	3	3	0	3	3	3	0	3	9	3	3	0	0	0	0	0	0	3	
High quality communication		3	3	9	3	9	3	3		3	0	3	9	3	0	3	3	3	3	3	0	3	3	3	3	0	9	0	0	3	
Mutual Accountability		0	3	9	3	9	9	0		3	0	9	3	9	0	3	0	3	0	3	0	0	3	3	3	0	9	-9	0	3	
Mutual trust (Inside Team)		3	3	9	3	9	3	3		3	3	3	9	3	3	3	0	3	3	3	3	0	3	3	0	0	9	0	0	3	
Team to Environment relation Level																															
Challenging requirements		0	0	0	0	0	0	0		0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Complexity of task matches requirements and resources		3	3	0	0	0	0	0		3	3	9	0	0	0	3	3	0	0	0	0	0	3	0	0	3	0	3	0	0	
Expandable Structure		0	0	0	0	0	0	0		0	0	3	-3	-3	0	0	9	9	-9	0	0	0	0	0	0	0	0	0	0	3	
Extensive Ties		0	0	3	3	3	3	0		0	0	3	0	-3	0	3	3	3	-9	0	0	0	0	0	0	0	0	0	0	3	
External Activity		0	0	3	3	3	3	0		0	0	3	-3	-3	0	3	3	3	-9	0	0	0	0	0	0	0	0	0	0	3	
High quality of results		3	3	9	9	9	3	3		3	3	9	3	3	3	3	3	3	0	3	3	3	9	3	0	3	3	3	0	9	
Integration of Suppliers		0	0	3	3	3	3	3		0	0	3	0	0	3	3	3	0	-9	0	0	0	0	0	3	3	0	0	0	3	
Management of Scope		0	3	3	3	3	3	3		0	3	3	3	0	3	3	0	3	0	0	0	0	3	0	0	3	0	3	0	0	
Mutual Trust (Team-Environment)		3	3	3	3	9	3	3		3	3	3	0	0	3	3	3	3	-9	0	3	0	3	3	0	3	9	0	0	3	
No micromanagement by environment		0	3	9	3	9	3	3		3	0	0	0	0	0	0	3	0	9	0	0	0	0	3	0	0	0	9	0	3	
Results on cost		3	0	9	9	9	3	3		3	3	9	3	3	3	3	3	3	0	3	3	3	9	3	0	3	3	3	0	9	
Stable and timely resource allocation		0	0	0	0	0	0	0		0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	
Stable requirements		0	0	0	0	0	0	0		0	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	0	
Timely results		3	0	9	9	9	3	3		3	3	9	3	3	3	3	3	3	0	3	3	3	9	9	0	3	3	3	0	9	

Figure 10-3: Influence Matrix, Page 3

Table page 2 above

Table page 2 above

Table page 3 left

Table page 3 left

From (right)	**Team Member to Team Member relation Level**	Coaching of young through experienced team members	Commitment	Flat Management Structure and Participatory Leadership	Generation of innovative ideas	High quality communication	Mutual Accountability	Mutual trust (Inside Team)	**Team to Environment relation Level**	Challenging requirements	Complexity of task matches requirements and resources	Expandable Structure	Extensive Ties	External Activity	High quality of results	Integration of Suppliers	Management of Scope	Mutual Trust (Team-Environment)	No micromanagement by environment	Results on cost	Stable and timely resource allocation	Stable requirements	Timely results
To (below)																							
Team Member to Team Member relation Level																							
Coaching of young through experienced team members			3	0	0	3	3	3		0	0	3	3	3	0	0	0	3	0	0	0	0	0
Commitment		3		9	0	9	9	9		9	0	0	0	0	0	0	0	3	3	0	0	0	0
Flat Management Structure and Participatory Leadership		3	3		0	9	9	9		0	0	0	0	0	0	0	0	0	3	0	0	0	0
Generation of innovative ideas		3	3	3		9	3	3		3	0	3	3	3	0	3	0	3	0	0	0	0	0
High quality communication		3	3	9	0		3	9		3	0	0	3	3	0	0	0	3	3	0	0	0	0
Mutual Accountability		0	9	9	0	3		9		0	0	0	0	0	0	0	3	0	9	0	3	3	0
Mutual trust (Inside Team)		3	9	3	0	9	9			3	0	0	0	0	3	0	0	3	3	3	0	0	3
Team to Environment relation Level																							
Challenging requirements		0	0	0	0	0	0	0			3	0	0	0	0	0	0	0	0	0	0	0	0
Complexity of task matches requirements and resources		0	0	0	0	3	0	0		0		3	9	0	0	0	9	0	0	0	9	3	0
Expandable Structure		0	0	3	0	3	-3	3		0	0		3	3	0	3	0	9	0	0	3	0	0
Extensive Ties		0	0	0	0	3	-3	3		3	0	3		3	0	3	0	3	0	0	3	0	0
External Activity		0	0	0	0	3	0	0		3	3	3	9		0	9	0	3	0	0	3	3	0
High quality of results		3	3	3	3	9	3	3		0	9	3	3	3		3	9	3	3	0	9	9	0
Integration of Suppliers		0	0	0	0	3	3	0		3	0	9	3	9	0		0	3	0	0	0	3	0
Management of Scope		3	0	0	0	3	0	0		0	3	0	3	0	0	0		3	0	0	0	3	0
Mutual Trust (Team-Environment)		0	3	0	0	9	3	9		0	9	3	9	3	3	9	3		3	3	9	9	3
No micromanagement by environment		0	0	0	0	3	0	0		-3	3	3	3	3	3	0	3	9		3	9	3	3
Results on cost		3	3	3	3	9	3	3		0	9	3	3	3	0	3	9	3	3		9	9	0
Stable and timely resource allocation		0	0	0	0	0	0	0		0	3	0	3	0	0	0	3	3	0	0		9	0
Stable requirements		0	0	0	0	0	0	0		0	9	0	3	0	0	0	9	3	0	0	0		0
Timely results		3	3	3	3	9	3	3		0	9	3	3	3	0	3	9	3	3	0	9	9	

Figure 10-4: Influence Matrix, Page 4