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RISK MANAGEMENT IN PRODUCT DEVELOPMENT – CURRENT METHODS

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1. Introduction

1.1 Necessity of Risk Management in Product Development

Products and processes in product development are becoming increasingly complex. As a result, errors associated with product development increase, thus product and process failures become more and more frequent. This leads ultimately to an increase in the number of crises related to product development, both in number and severity. In the worst cases, these crises can lead to the closing of a company.

A solution to the challenge of increasing complexity and decreasing robustness of products and processes, are advanced procedural models for product development. They offer a structured approach to complex problems while maintaining efficiency and the necessary flexibility to adapt to changes. One of these models, the Munich Procedural Model (MPM) proposes risk management activities to ensure the achievement of the set goals in the product development process [Lindemann 2004].

Additionally, there is a strong pressure from the financial and controlling community to include explicit risk management practices in operational areas aswell (e.g. Basel-II, Sarbanes Oxley Act, or in Germany the KonTraG law).

1.2 Goals of this paper

The main interest of this paper is to review and discuss current methods employed in the area of risk management in product development. A very broad view is taken at the field, including process and product risks, as well as suggestions for methods from outside the realm of product development.

In order to be able to present the methods in a structured manner, a general risk management process model is introduced.

The aim is to unite both theory and practice by combining a detailed literature review with research into the industrial application of risk management.

In our context, risk is understood in a wide sense as a uncertain and time-related loss of value, which is part of, and influenced by complex dynamic networks of factors and/or events.

2. Research Approach

This paper is based on research into risk management, its potential for crisis prevention, and associated learnings from high performance teams. The research was academically embedded in the area of Lean Product Development, which was matched by an application study in product development in industry. Here, a subset of the results are presented which are directly related to the methods employed in risk management.

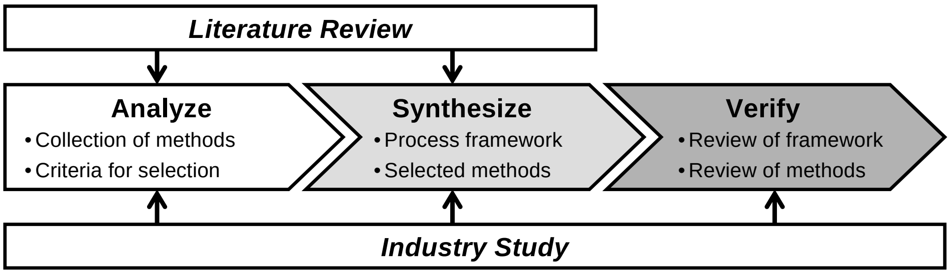

Figure 1. Overview research approach: Information sources and research process

2.1 Information Sources: Literature Review and Industry Study

Literature from several fields have been included in the review. In the best case, risk management in product development is explicitly addressed in literature. This is the case with [Smith et al. 2002] and [Hall 1998]. Product development processes are dependent on project management. Project risk management addresses in detail the process aspect and is therefore taken into account [PMI 2004]. Technical risk management focuses on the risks related to the performance of the product itself, [Browning et al. 2002b]. Reliability risk management can be seen as a subset of technical risk management, focusing explicitly on safety and reliability issues of products [Birolini 2004], [Stamatelatos 2002]. Strategic risk management deals with the question of integrating different risk management activities into an overall enterprise risk management approach and providing central monitoring and early warning capabilities [Lessing et al. 2005].

An industry study has been conducted at a large internationally active North American corporation from the automotive sector. The goal was to obtain an industry and application perspective regarding the literature findings on risk management methods in product development.

The study focused on risk management aspects on the execution level, analyzing the development of a new virtual prototyping process. The aim of the new virtual prototyping process was to address root causes of severe schedule slippages and high additional costs in the late phases of the overall development process, caused by high change levels. These seem to be typical examples of severe risks and potential crisis situations in product development.

2.2 Research Process: Analysis, Synthesis and Verification

In the analysis step, methods were collected from literature sources (see above) and industry application in a field study. Also, crisis prevention and lean product development principles were taken into account. Criteria for the selection of methods were established. Among them were the applicability of the source to product development, the prevalence of a method in the literature, the reputation of the author and a quality judgment of the source literature.

In the synthesis step, methods were selected and aggregated from different sources. A subset of 12 from the 66 methods identified is presented here. Also, a general process framework was derived from the literature to structure and support the identification of methods.

In the verification step, the literature findings regarding the process framework and the methods were subjected to a critical review in the light of industry application and the learnings from the industry study.

3. Results

3.1 Risk Management Process Outline

The following model has been developed to unify the process models discussed in the literature ([Smith et al. 2002], [Hall 1998], [PMI 2004], [Stamatelatos 2001], [Lessing et al. 2005]):

- Risk Identification: Potential risks are detected. It collects the preliminary information available for every potential risk, including the rationale for the identification.

- Qualitative Risk Analysis: A step that further deepens the understanding of a potential risk, without assigning any numerical judgment. This differs from the perception in some of the literature, especially [PMI 2004].
- Quantitative Risk Analysis: Numerical values are assigned to a risk's probability of occurrence, magnitude of impact, and its timeframe. It can include mathematically exact models, as well as other types of quantification, for example the assignment to a certain (numerically specified) category based on team discussions.
- Risk Prioritization: The quantitatively described risks are prioritized. 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.

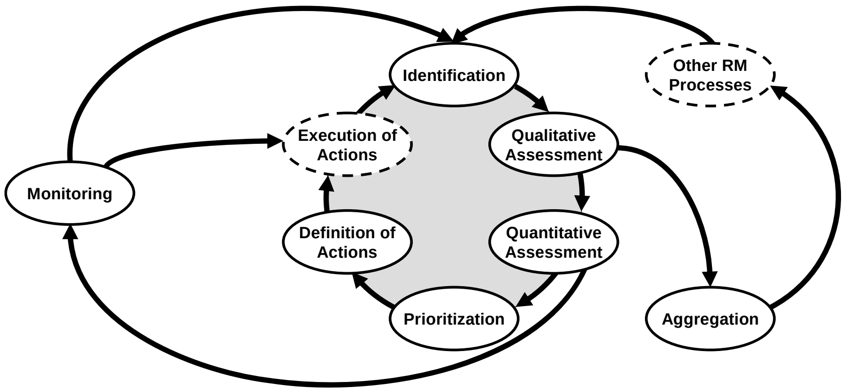

Figure 2. Risk Management Process Framework

- Definition of Actions: Based on the prioritized risks, actions are defined to minimize the risks. This step is not covered in the methods description below, as the other process steps proved to be more interesting from a methodological point of view.
- Execution of Actions: This step is not considered to be "owned" by the risk management process, but by the line organization responsible for the risk.
- Monitoring of Risks: It can be aimed at the risks themselves, or at the performance of the risk management process. The goal is to provide a transparent and current description of the risk situation and to issue trigger impulses to inform decision makers of significant changes.
- 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.

This model proved very helpful in providing a basic structure to collect and discuss different risk management methods from literature and industry. It also proved helpful in mapping different models in the literature and the state in industry, as well as helping in the communication of concepts.

3.3 Risk Management Methods

In the following, a selection of risk management methods is presented from the literature and the industry study. Methods were selected on the basis of the breadth of their potential application. Methods which cover a broad application field in product development were preferred over more focused methods. Also, an effort was made to evenly cover the risk management process.

3.3.1 Methods for Risk Identification

Identification by Failure Modes

In the first step, the possible process and/or product failure modes have to be identified.

The failure modes as well as a list of the main goals and success criteria, defined for the project (which should be reflected by the failure modes) are then used to identify possible risks 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)
The industry study showed that failure modes were derived from the main categories of requirements and functionality (both specific and generic). These were used as overall guidance to derive more specific failure modes on a technical level.

- Pro: Relatively easy to execute
- Contra: Only supports risk identification on a high level and rough understanding, and categorization along failure modes.

Checklists

Checklists can be used as reminders of possible risks or risks that have been identified in the past. Checklist can provide highly detailed and structured lists of risk specific sources and impacts, as opposed to the general failure modes ([Hall 1998] (pp. 73, 75-78)). [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 is also basically a checklist based on a causal structure. Additionally, 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)). A mixture of factors related to different failure modes can be addressed simultaneously.
Checklists were used extensively in industry. A multitude of sources were utilized. A requirements analysis provided input regarding most critical and complex requirements. Also, lessons learned and experience from problems in past projects was captured in the checklist.

- 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

3.3.2 Methods for Qualitative Risk Analysis

In the field study, no specific methods for qualitative risk analysis were identified. This can be attributed to the fact that the analyzed process, on a technical level, was focused on identifying and eliminating risks, not on understanding their origin or root causes in the PD process.

Qualitative Analysis with Risk Scenarios

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 [Lessing 2005].
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). [Smith et al. 2002] (p. 66) uses simple causal scenarios to analyze causal networks leading to a risk, and impact networks growing from the risks. This type of scenario is especially well suited for developing causal networks to quantify the probability and/or the (different) impacts of an event.
The 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 risks and its causal network
- Contra: First time generation of scenarios can be very time consuming

5 Whys

The "5 Whys" method can be seen as a strongly simplified scenario-approach regarding the causes of a risk. It 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, has only very limited application to analyze impact of a risk event

3.3.3 Methods for Quantitative Risk Analysis

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 work week 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. Additionally, 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 field study showed that this principle is partially employed in industry. For the most important types of risks, scales and metrics were established to assess the potential impact, i.e. product cost and performance.

- Pro: Makes risks from different sources and with different type of impact comparable.
- Contra: Sensible general scales can be very hard to define.

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 . 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).Additionally, a threshold can be defined, below which, risks are judged to be "low".

- 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.

3.3.4 Methods for Risk Prioritization

A general concept in risk prioritization is the "expected loss". It describes the product of probability and impact.

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

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

3.3.5 Methods for Monitoring of Risks

"Number of Risks" Development Path (Risk Management Process related Monitoring)

It is often proposed to install a software-based "risk management cockpit" that can display several important figures related to the risk management process itself. One of these figures is presented here.

[Smith et al. 2002] (pp. 129-130) proposes 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. The field study showed an interesting addition to that method in industry: The number of 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.

- Pro: Support proactive risk management, prevents hiding of risks
- Contra: Historical data needed for sensible corridor definition

Scenario-based tracking of risks (Risk related)

High-severity risks can be monitored by a scenario-based approach. Some actions defined during the early Control phases, might not have been 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]. 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). 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)

3.3.6 Methods for Aggregation of Risks

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.

3.3.7 Combined Methods

Brownings Performance Risk Management Method

This risk management 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.

Triangular probability density functions are used in conjunction with TPMs to capture the likelihood of a TPM reaching a certain value at the end of the PD process. Utility functions are then used to assign a utility to every TPM value, e.g. smaller is better, larger is better or nominal is best. Both are then normalized and multiplied to derive a measure for the performance risk, according to type of the utility functions. This is done for all TPMs of a product, which are then weighted and aggregated to an overall performance risk.

The development of the performance risk can then be monitored with tracking charts and risk reduction profiles, which visualize the development of the performance risk.

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

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

4. Conclusion

The necessity for risk management in product development has been discussed. Taking literature review and industry study into account, it could be shown that there is a clear and growing interest in the field. In addition, there exists a big pool of knowledge regarding risk management outside the product development domain. A general process framework was presented and a selection of risk management methods discussed. The industry study revealed that risk management methods are applied in industry, but the application is in large parts still in its infancy regarding scope and sophistication.

It became clear that risk management in product development includes at multitude of factors. These are usually not treated in one holistic approach, but focused in one area or the other, based on the legacy of the work. It therefore might be helpful for a structured discussion to develop a general framework. It might include a risk definition for product development, based thereon axiomatic descriptions for risks (such as the different failure modes addressed, e.g. in product or process, a general causal structure for risks to discuss sources of risk, a timeframe and network component), a generic risk management process outline (as briefly discussed above), a collection of methods (differentiating between different risks and process steps where necessary), and, most importantly, the organizational implementation of a risk management approach.

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