Chapter 4

A Model Based Approach to Support Risk Management in Innovation Projects

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New product development is notably affected by uncertainties that are a consequence of insufficient experience and missing knowledge. If uncertainties are not managed adequately, they will finally lead to risks. We therefore advocate an integrated agile development process, allowing for explicit modelling of uncertainties and reaction strategies as well as the evaluation of the resulting risk caused by the changes to the product in development or the development process. As changes can again lead to undesired change propagation, finally resulting in new uncertainties and in consequence new risks, uncertainty response strategies need to be developed, evaluated and conducted collaboratively. In this publication the Integrated System and Risk Managing Model is presented, enabling users to describe and analyze product and process based uncertainties as well as potential response options within one consistent system. This paper elaborates the underlying structure of the model and concentrates on the modelling process, also explaining the application using examples from a case study.

4.1 Introduction

Product innovation is the result of a renewal process that broadens knowledge or applies available knowledge in a new context (Ericson and Kastensson, 2011). Innovation projects are thus accompanied by the presence of uncertainties that in general are understood as a consequence of insufficient experience and missing knowledge (Ehrlenspiel, 2007). Uncertainties may occur at all stages of product development, potentially influencing the entire product lifecycle (Browning, 1998). It is obvious that uncertainties not handled adequately will seriously affect project success. Managing uncertainties is therefore essential in order to reduce risks in innovation projects.

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Traditional engineering approaches follow a sequential process assuming that the entire system is developed top-down. Verification and validation activities are primarily carried out at the end of the development process. In consequence, uncertainties are addressed behind time when expensive cost and schedule overruns are no longer avertable. Especially the rising complexity of products and the increasing pressure of shortening the feedback loops have stimulated the creation of incremental development approaches. These are based on the idea of subdividing the complex development project into smaller iteration cycles which then deliver fast feedback, for example by providing prototypes with growing level of maturity. Approved incremental models are e.g. the Spiral Model (Boehm, 1988) and the V-Model that both were initially developed for software engineering and later adapted to other industries (VDI, 2004). While these models already cater for a more dynamic proceeding, they still do not address uncertainties as a central problem of new product development explicitly.

In order to address uncertainties and resulting risks in a more thorough manner, specific risk management models were established. These models describe risk management on an operational level as an iterative procedure, usually comprising the stages of risk identification, risk analysis and risk response (Ferreira and Ogliari, 2005). However, risk management commonly coexist beside the superior models of product development.

Due to the particular significance of uncertainties in new product development we ask for an integrated product development and risk management model considering uncertainties explicitly in decision making. Moreover, we propose a highly agile development process for innovation projects enabling immediate reactions to upcoming uncertainties by conducting risk oriented changes to both, the product in development as well as the development process.

The procedure presented in this contribution is supported by an integrated modelling approach based on Multiple-Domain Matrices (Maurer, 2007), enabling the representation and analysis of product and process based uncertainties as well as potential response options. Several response strategies can be evaluated directly with regards to the caused benefit and effort, and thereby made comparable. This paper focuses on the modelling approach and its application in the risk management process. The theoretical background is presented in section two. Section three presents a real-life scenario detailing the challenges of new product development and motivating the proposed method. This is followed by a discussion of related work relevant in the presented context. Section five describes the modelling-approach as well as the underlying procedure, followed by an application to the example given within the case study. Finally, section six concludes the chapter giving an overview about ongoing research related to the presented approach and future work.

4.2 Theoretical Background

In order to understand the presented approach, a clear definition of the key concepts of *uncertainty* and *risk* has to be achieved.

In literature the term *uncertainty* is not universally defined. Several definitions are used, originating from different disciplines of research. *Uncertainty* as defined in decision theory relates to the information base relevant for decision making. A *decision made under uncertainty* can thus be understood as a *decision based on uncertain decision criteria*. These uncertain criteria comprise potential deviations of product or process properties caused by knowledge deficits at the point of decision making (Engelhardt *et al.*, 2011), discrepancies between the information currently available and the information necessary for conducting a task (Verworn, 2005) as well as statistical process results or information not yet collected ("things that are not known, or known only imprecisely" (Hastings and McManus, 2004)). Based on literature review we identified seven classes of uncertainties, namely uncertainties rooted in the market context and use context, in politics, law and society, technology, fabrication, procedure and applied methods as well as the utilized resources. These classes can be further subdivided into endogenous and exogenous types (Weck *et al.*, 2007).

In context of decision making, an additional interpretation referring to the result of the decision process is relevant to our method. A decision based on uncertain decision criteria may be seen as uncertain itself. In order to classify these we propose a categorization aligned to the three partial systems: the target system, the technical system and the execution system which constitute the generic reference frame for the decision process.

The term *risk* is also discussed controversially. Bitz e.g. defines risk simply as a danger of loss (Bitz, 2000). In a similar manner Smith and Merritt describe risk as the hazard of project disruptions triggered by an undesired event or the absence of a desired event (Smith and Merritt, 2002). The extraction of definitions already shows that a clear differentiation between the terms uncertainty and risk often does not exist. This fact can be traced back to the divergent understanding of the term risk, differentiating between a cause based and an effect based interpretation. Following the cause based interpretation risk refers to the unpredictability of the future and the occurrence of disruptions (Gleißner, 2011). The cause based understanding therefore is similar to some definitions of uncertainty. Instead we follow the effect based interpretation of risk (Hölscher, 1987) which puts the consequences of disruptions into focus and reflects to the hazards of not achieving project goals. According to that understanding risk describes an evaluation quantity providing information about the likelihood for damage as well as the expected impact of that incident (e.g. Conrow, 2003). Here damage must be interpreted as a loss caused by not achieving schedule, costs and quality objectives.

4.3 Scenario

In order to clarify the demand for a model based risk management approach, a scenario is presented reflecting the experience made within a German federal research and development project. The project aimed at providing innovative solutions for search and rescue robots operating in unstructured environments.

In the project the development of a snake-like robot was considered which offers a high degree of kinematic redundancy, enabling it to operate in collapsed buildings. The robot as well as its development process is complex with regard to the number and variety of system elements, development activities, involved disciplines and the strong interdependencies between those. An intense need for risk management was identified, as the project partners had to deal with uncertainties regarding imprecise target definitions, the technology in development and the design process itself. While in some cases uncertainties could be reduced by local changes of the technical solution or local modifications of the development process, the majority of cases called for macroscopic response, affecting interrelated project parts in a significant manner.

A representative example of uncertainty regarding the technical system is discussed in the following: The snake like motion concept of the robot was realized by four similar modules interconnected by joints, each offering five degrees of freedom. As part of the modular design approach, a special motor-unit was developed and implemented for each degree of freedom. When conducting a risk analysis we identified uncertainties regarding the performance characteristic of the actuator. No qualified decision could be made whether the torque provided by the joint would be sufficient to lift the robot's sensor head, as shown in Figure 4.1.

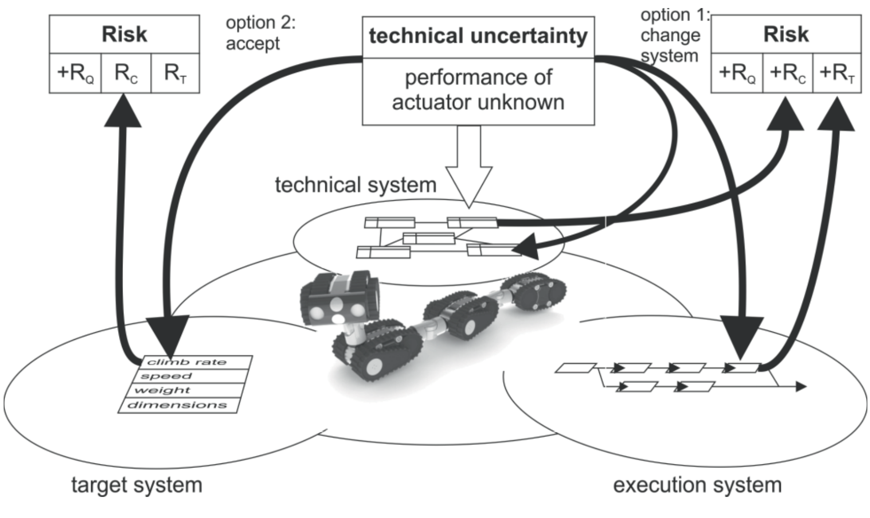

Figure 4.1. Heterogenic model of the system domains with uncertainty, response options and resulting risks

4.3.1 Treatment of Risks in the Presented Scenario

To deal with this uncertainty, several response options were considered that Gericke formally defines as *preventive*, *reactive* and *proactive* risk response (Gericke, 2011).

Preventive risk treatment
Preventive risk treatment aims on a reduction of risk by removing its causes. In the present example one could change the technical system by redesigning the motor-unit in order to allow for the integration of a more powerful motor. Changing the concerned part of the system will obviously reduce the uncertainty, but will also extend project duration (time risk R_T) and cost (cost risk R_C) due to the redesigning process. Moreover, the new motor-module will probably increase the system weight, consequently reducing the operating duration (quality risk R_Q). Finally, the changes to the technical system in turn will cause changes to other parts of the system, e. g. the chassis elements, resulting in additional quality, cost and time risks.

Reactive risk treatment
Reactive risk treatment addresses the impact of the risk and is applied not until the risk event has occurred. In the present example one could wait until tests with a physical prototype of the snake robot provide exact results. Changes at this time will probably result in broad schedule and budget overruns. One can also accept the risk of insufficient torque, conducting no changes at all. In that case the decision will result in a reduced quality of the product, but schedule and budget overruns can be avoided.

Proactive risk treatment
Proactive risk treatment also aims on a reduction of the effect of the risk, but risk treatment measures are selected before the risk occurs. In the example hardware-in-the-loop tests could be applied in order to acquire the necessary characteristics of the motor-module proactively. The engineering design of the test bench and conducting the tests will require additional project time and result in budget overruns but there is a chance that no negative impact on the quality occurs at all in case the original design proves valid.

4.3.2 Discussion of the Scenario

The presented example shows that a suitable modelling approach supporting the risk management in innovation projects has to integrate several domains, in particular the ones represented in the target system, the technical system and the engineering system and has to manage the dependencies in between. Moreover, the scenario demonstrates that an adequate modelling approach simultaneously assesses the effects of uncertainties and response strategies within all three dimensions of the *iron triangle*: *quality*, *costs* and *schedule*. In order to communicate uncertainties and risk management associated information between all stakeholders, the approach furthermore has to support the formalized description and assessment of uncertainties and potential response options.

4.4 Related Work

While, to the best of our knowledge, none of the approaches presented in literature complies with the outlined situation in product development satisfactorily, related work can be identified in the research areas of Quality and Change Management.

In the field of quality management primarily methods and models are provided to support the analysis of uncertainty effects in the dimension of quality. The well known Failure Modes and Effects Analysis (FMEA) e.g. aims at an early identification and formalized assessment of failures, taking into consideration the likelihood of occurrence (O), its significance (S) and probability of detection (D). Failures are prioritized by assigning the risk priority number, defined as the mathematical product of O, S and D. In comparison Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) allow for a more detailed diagnosis. The underlying risk model of FTA is based on the principle of causality, expressing that each fault can be traced back to at least one cause. A set of lower level causes is defined that are connected to each other using Boolean logic. ETA inverts the principle of FTA and studies the effect of an initiating event on the system.

While System FMEA, FTA and ETA put quality aspects of the technical system into focus, approaches in the field of change management are provided that mainly concern the effects of changes in the dimensions of costs and schedule. The Design Structure Matrix (DSM) is widely used in order to investigate change propagation quantitatively. Clarkson *et al.* introduce the Change Prediction Method (CPM), using DSMs for tracing potential change propagation paths among the interconnected components of a technical system (Clarkson *et al.*, 2004). Chua and Hossain analyse the propagation of changes considering the development process and its interrelated design activities (Chua and Hossain, 2012). Smith and Eppinger present a model based on DSMs to simulate activity durations and probabilities for iteration (Smith and Eppinger, 1997). Beside such domain specific approaches, focusing either on the product or process domain, attempts are made to expand the analysis of change propagation across multiple domains. Koh *et al.* investigate the dependencies between requirements and components (Koh *et al.*, 2012). Tang *et al.* present a method linking entities in the product domain to the process and organization domain (Tang *et al.*, 2008). Ahmad *et al.* introduce a cross-domain approach to identify change propagation including the information domains of requirements, functions, components and the detail design process (Ahmad *et al.*, 2013).

These approaches have in common that they either focus on the impact of an uncertainty to quality aspects, or the effects of a change to schedule or costs. None of these approaches offers an integrated view that encompasses all three presented dimensions of risk. Moreover, uncertainties and the resulting response strategies are only modelled indirectly as attributes of the system elements and are not explicitly expressed.

4.5 The Model Based Risk Management Approach

The Model Based Risk Management Approach presented here consists of two parts: The Integrated System and Risk Management Model on the one hand which serves as the informational backbone of the approach, allowing for an explicit description of risk related aspects from a product, process and requirements point of view. The modelling process on the other hand describes the application of the model within the risk management process. Both parts are described in the following sections.

4.5.1 Integrated System and Risk Management Model

The *Integrated System and Risk Management Model* (*ISRM-Model*) provides the basic structure representing the information and relationship between all elements of the model. It is composed of Domain-Structure and Domain-Mapping Matrices, creating one integrated Multiple-Domain Matrix. The model itself consists of two parts, the *Target System, Technical System and Engineering System Model* (*TTE-System Model*) and the *Risk Management Model*, which each are represented by Multiple-Domain Matrices. Figure 4.2 shows the topography of the model.

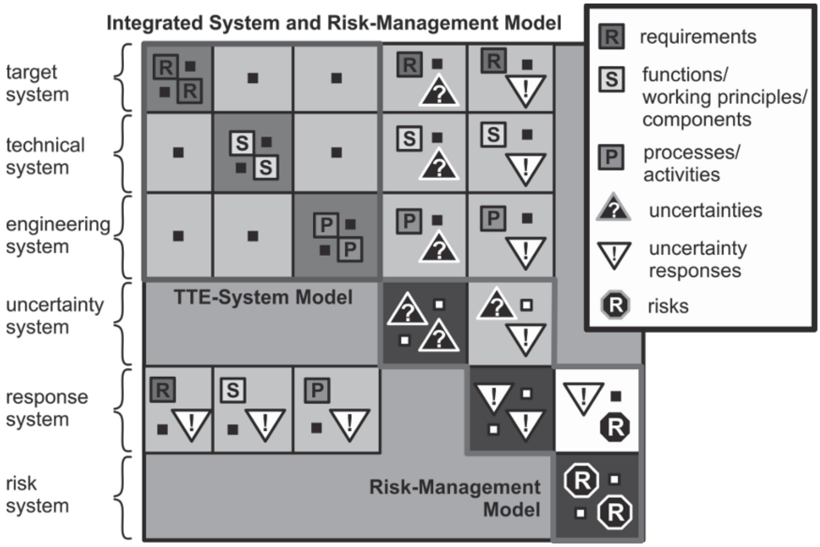

Figure 4.2. Structure of the Integrated System and Risk Management Model (ISRM-Model)

The *TTE-System Model* contains three domains, denoted as *target system*, *technical system* and *engineering system*. The *target system* is used to describe and structure all requirements while functions, working principles, components and their relationships are modelled in the *technical system*. The *engineering system* represents the development process and its activities, and details the information flow in between. Domain-Mapping Matrices are used to express cross-domain relations.

The *Risk Management Model* provides information about risk management associated aspects. The *uncertainty system* allows the formalized description of uncertainties and their assignment to related elements of the TTE-System Model. In the *response system* potential reactions to uncertainties are modelled. The modelling approach distinguishes different strategies for handling uncertainties which are discussed in the following section. For each response option associated elements are marked in the appropriate Domain-Mapping Matrices. Finally, the *risk system* holds information about the calculated risks that are caused by one or a group of response options.

4.5.2 Modelling Process

The modelling process describes the course of action when applying the ISRM-Model in the risk management process. The process we propose is a recursive procedure carried out in five stages. Figure 4.3 provides an overview of the procedure and the relevant model elements.

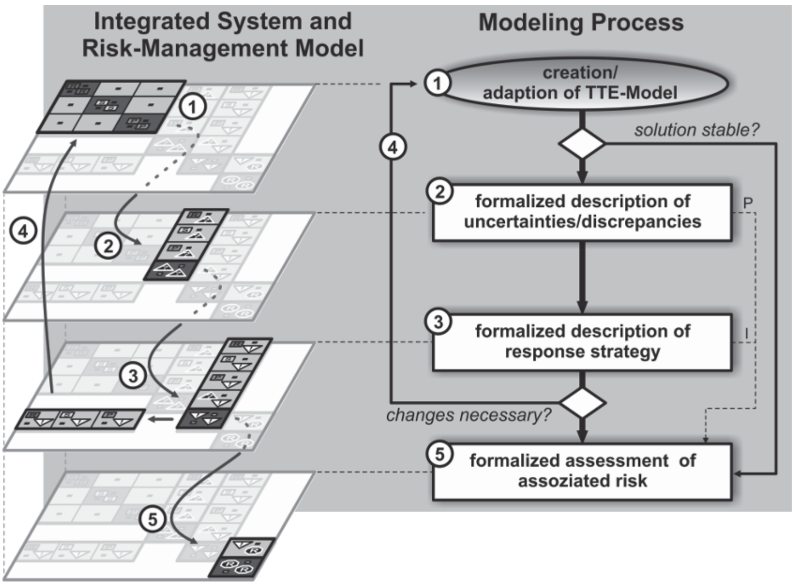

Figure 4.3. Modelling process

In the first stage the TTE-System Model is created or adopted to reflect the current status of the project. Uncertainties within the current situation are identified in stage two. These are described in the uncertainty system using standardized forms and linked to the affected sources. Thereafter a formalized description of potential response strategies is conducted in the response system. Uncertainties handled by the chosen response strategy are marked as well as the associated elements in the TTE-System. If changes are necessary, the process iteratively continues at stage one. When the solution is stable after the changes are carried out (i.e. there are no new uncertainties resulting from the changes) or there is no need for further changes, the process enters stage five where a formalized assessment of the risk associated to the response strategy is conducted. Risk is finally calculated as the product of likelihood and impact. Each risk is represented by a triplet of quality-risk, cost-risk and time-risk. This value is used to evaluate the response strategies developed to deal with a set of uncertainties.

The approach defines three basic types of response strategies: With “proactive action”, changes to the TTE-System are incorporated immediately, regardless of the chance that the uncertainty might not occur (this usually leads to an over engineered solution while meeting or exceeding all requirements). The second strategy, “no action”, represents the response option that the uncertainty is accepted and no response is carried out (this usually leads to quality risks). With the third strategy, “reactive action”, the changes necessary to respond to an uncertainty are planned, but will only be executed when it is certain (i.e. as a result of a test) that the uncertain event occurs.

4.5.3 Application

To clarify the presented results, the proposed approach is applied to the example introduced in chapter three (Figure 4.4). The application scenario addresses the actuator unit as a standardized key subsystem of the mobile robot. The correct dimensioning of the motor with regard to its performance characteristics is questioned as a consequence of unknown friction forces and complex load profiles arising especially in unstructured terrain. Two different response options are shown in Figure 4.4 and compared in order to identify the best response solution matching the given situation.

Response option A applies the “no-action” strategy which results in limited mobility of the robot and ultimately in a loss in sales. As an alternative option B, a proactive change in the design and application of a more powerful motor is considered. This engineering change increases the weight of the system, affects the schedule (rework of P3) and costs.

For both response strategies, structure information is modelled using the provided matrix representation, while detailing descriptions of each element are conducted using standardized forms (simplified representation).

When stable solutions for both evaluated response options are achieved, the risk triplet is calculated (see Figure 4.3). For the final decision which response strategy is applied, a manual interpretation of the resulting risk has to take place, taking all company and marketing-strategic consideration into account as well as contract constrains.

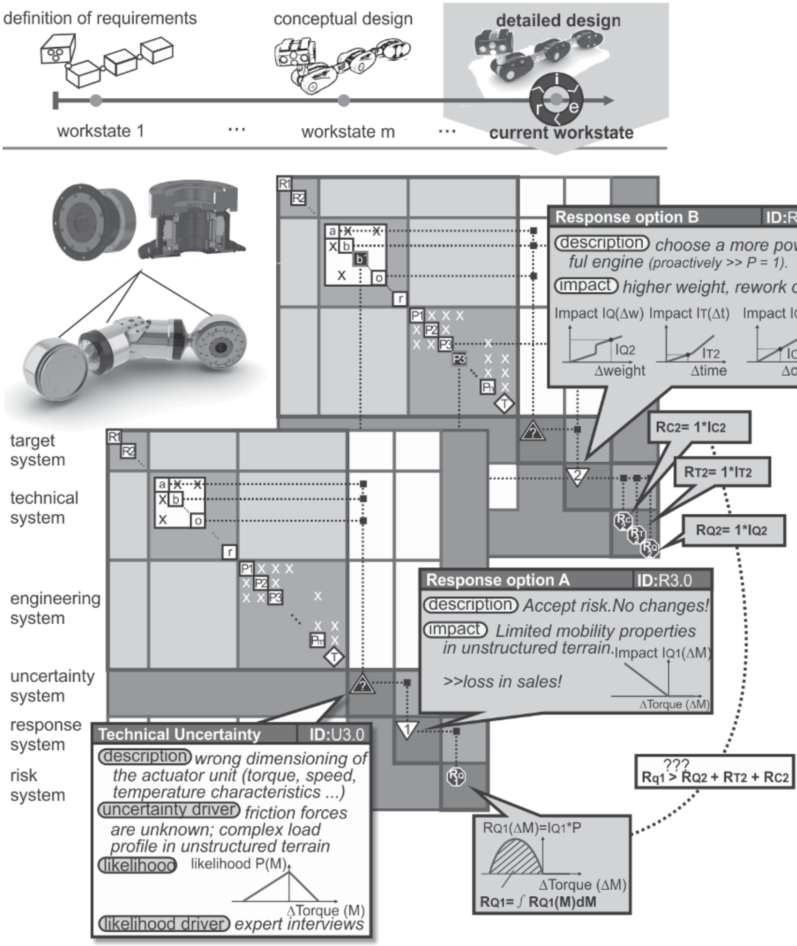

Figure 4.4. Model based risk management approach applied to the development of a search and rescue robot

4.6 Conclusions

Analysing risks early in the development process and treating them adequately with respect to effort and benefit is the key to effective risk management in new product development. This paper has presented the Model Based Risk Management approach, an integrated Multi-Domain approach to model risks and all aspects of system design explicitly in one consistent framework. The concept uses Multiple-Domain Matrices in order to integrate the product development point of view (represented by the domains target system, technical system and engineering system) and risk management (represented by the domains uncertainty system, response system and risk system). The approach can be applied to (1) model uncertainties and response options, (2) systematically evaluate those strategies and (3) support risk orientated decision processes in new product development.

The general applicability of the method could be demonstrated within an example. However, questions remain unanswered concerning the initial identification of uncertainties which is not supported by the approach up to now. Providing methodical support for uncertainty identification will therefore be subject to further research. We are planning to integrate established and well known methods, like Scenario Analysis or Delphi Method into the approach in order to establish a holistic framework. Furthermore, the demonstrated application of the method already indicates that practical usability is strongly related to the implementation of the method in a software tool. Prospective research therefore will consider the transfer of current research results into a software program.

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