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# Risk-oriented development of innovative products: a model-based approach

**Marc Neumann, Beate Bender**

*Chair of Product Development, Ruhr-Universität Bochum*
*neumann@lpe.rub.de, bender@lpe.rub.de*

**Abstract**

New product development is strongly accompanied by uncertainties which are understood in general as a consequence of insufficient experience and missing knowledge. Uncertainties occur at all stages of product development affecting the project success in a serious manner. Traditional engineering approaches do not address uncertainties sufficiently. Specific risk management approaches instead are rarely integrated in the development process. Models and methods of risk management either focus on the impact of uncertainty to quality, or the effects of uncertainties to schedule or costs, while an integrated view is not provided. Within this contribution a risk oriented development strategy for new products is proposed considering uncertainties in decision making on all stages of the development process. The suggested process is highly agile enabling immediate reactions to upcoming uncertainties by conducting risk oriented changes to both the product in development and the development process. The procedure is supported by an integrated modelling approach enabling the representation and analysis of product and process based uncertainties as well as potential response options. Competing response strategies can directly be evaluated with regards to the caused benefit and effort in the dimensions of quality, time and costs which makes them comparable to each other.

***Keywords: uncertainty, risk management, new product development, Multiple-Domain Matrices, change propagation***

## 1 Introduction

As product innovation is the result of a renewal process that broadens knowledge or applies available knowledge in a new context, innovation projects are accompanied by the presence of uncertainties. 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 the project success. This contribution describes a new development approach supporting a risk oriented development process of innovative products. In section 2 the theoretical background in the field of uncertainties and risks in new product development is given. Coming from a real-life scenario the challenges of new product development under the condition of uncertainty are elaborated in section 3. This is followed by a discussion of related work relevant in the presented context in section 4. The framework of the proposed methodological approach is described in section 5, followed by an explanation of the modelling-approach as part of the methodology. Finally, section 6 concludes by giving an overview about ongoing research related to the presented approach and future work.

## 2 Uncertainty and risk in new product development

Uncertainty as defined in decision theory relates to the information relevant for decision making. A decision made under uncertainty can 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 (Hastings and McManus, 2004). A decision based on uncertain decision criteria can be seen as uncertain itself. Following a system engineering approach, these uncertainties can be linked to the following three partial systems of product development described by (Lohmeyer, 2013): The *operation system,* which contains structured activities, methods and processes as well as the needed resources, the *system of objectives,* which describes the mental anticipated and planned attributes of the object system and finally the *system of objects,* which describes the realized solution of the system of objectives. Based on this interpretation of uncertainty three types of uncertainty are distinguished: *uncertainty regarding the system of objectives*, best elucidated by formulating open questions, as “does the system of objectives promise the expected customer value?”, *uncertainty regarding the system of objects*, as “does the system of objects and its subsystems satisfy the requested objectives?” and *uncertainty regarding the operation system*, elucidated by formulating open questions, as “is the operation system suitable to realise the system of objects in the requested manner?”.

In comparison to the term *uncertainty* Bitz 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). Following a cause based interpretation risk refers to the unpredictability of the future and the occurrence of disruptions (Gleißner, 2011). The effect based interpretation of risk (Hölscher, 1987) instead 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 of quantity providing information about the likelihood for damage as well as the expected impact of that incident. Here damage must be interpreted as a loss caused by not achieving schedule, costs and quality objectives. From an effect based point of view three types of risk are differentiated within this proposal: *cost risk*, defined as the uncertainty in the ability to develop the aspired design within a given budget and the consequences thereof (Browning, 1998), *time risk*, defined as the uncertainty in the ability to develop the aspired design within a span of time and the consequences thereof (Browning, 1998) and *quality risk*, defined as the uncertainty in the ability to achieve the aspired quality criteria and the consequences thereof (Browning, 1998)

## 3 Problem statement

In order to clarify the dominating influence of uncertainties in innovation projects, a scenario is presented in figure 1 reflecting experiences made within a German federal research and development project. The scenario considers the development of a snake-like robot 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 objectives, the technology in development and the design process itself, as indicated in figure 1. While in some cases uncertainties could be treated by local changes of the technical solution (e.g. oversizing critical components) or local modifications of the development process (e.g. frontloading of experiments), the majority of cases asked for macroscopic response affecting interrelated project parts in a significant manner. This observation is interesting in two aspects:

1. As the stakeholders intuitively conducted changes to the technical solution and the development process they implicitly influenced the associated risk. Within the scope of a systematical approach risk management activities therefore have to be integrated into the development process directly in order to identify uncertainties and to react immediately. Based on this observation the following research question can be formulated:

   *F1: How do risk management activities have to be integrated in the development process systematically in order to deal with uncertainties in new product development?*

2. 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: quality, costs and schedule. An uncertainty regarding the performance of the motor unit e.g. can be treated by oversizing the motor, which will affect the weight of the unit, the power consumption and therefore the operating time. Instead also a hardware-in-the-loop test can be conducted in order to acquire the uncertain properties proactively, but causes budget and schedule overruns due to the unexpected need for the test. Due to this identified demand the following research question can be formulated:

   *F2: How can the development process of innovative products be supported by a modelling approach, which objectifies decision processes?*

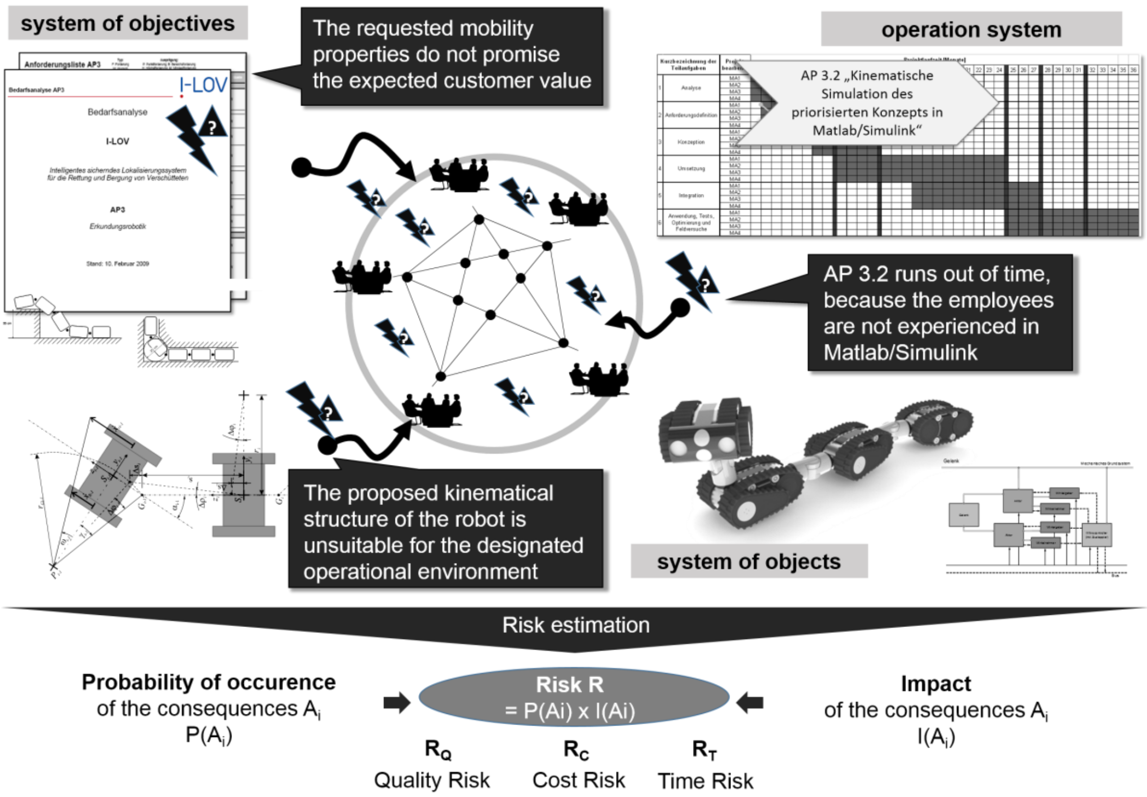


**Figure 1. Relation between uncertainties using an example of the robotics**

# 4 State of the art

Based on the identified demand a short overview about the state of the art in the fields of new product development as well as methods and modelling approaches in the context of risk management is given.

## 4.1 Dealing with uncertainty in new product development

Traditional engineering approaches often propose a sequential development process assuming that the entire system is developed top-down, while verification and validation activities are primarily carried out at the end of the development process. 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 levels of maturity. Approved incremental models are e.g. the Spiral Model and the V-Model (VDI 2206, 2004). Both were initially developed for software engineering and later adapted to other industries. 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 are established. On an operational level these models describe risk management 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 product development models.

## 4.2 Methods and modelling approaches supporting risk management in new product development

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). 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. In the field of change management approaches 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 while elements are not explicitly expressed.

# 5 Risk oriented development of innovative products

## 5.1 Framework of a methodical approach for risk-oriented development of innovative products

Due to the particular significance of uncertainties in new product development we ask for an integrated proceeding of product development and risk management considering uncertainties explicitly. 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 framework of the methodical approach is presented in figure 2.

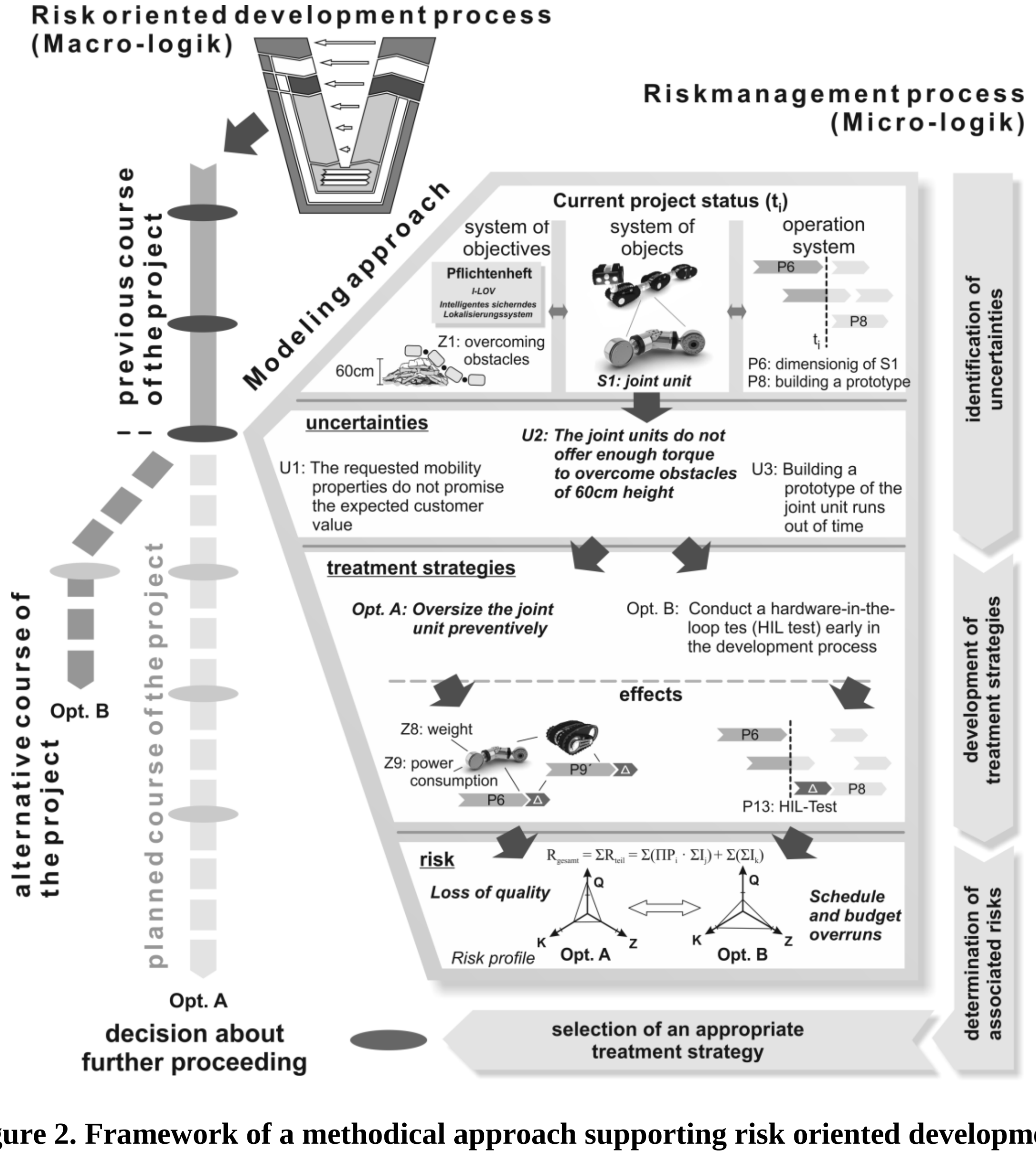


**Figure 2. Framework of a methodical approach supporting risk oriented development**

The proposed proceeding consists of two elements: a risk management process that can be conducted at all stages of the development process and the risk oriented development process itself. The risk management process serves as a recurring micro-logic, supporting the identification of uncertainties in the development process and controlling the decision processes of risk treatment. The risk oriented development process on the other hand describes the superior development process, serving as the macro-logic of the proceeding. The risk management process is supported by an integrated modelling approach that offers the opportunity to describe uncertainties in context of the system of objectives, the system of objects and finally the operation system as well as options for uncertainty treatment within one consistent model. The individual risk profile of each treatment strategy is determined by applying the modelling approach in order to select an appropriate treatment strategy that fits to the individual risk preference. The modelling approach is described below.

## 5.2 Modelling approach supporting risk oriented product development

As indicated before a suitable modelling approach supporting decision making in innovation projects has to integrate several domains, in particular the ones represented in the system of objectives, the system of objects and the operation system and has to manage the dependencies in between. Moreover, an adequate modelling approach simultaneously assesses the effects of uncertainties and response strategies within all three dimensions: quality, costs and schedule. 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. Figure 4.2 shows the topography of the model.

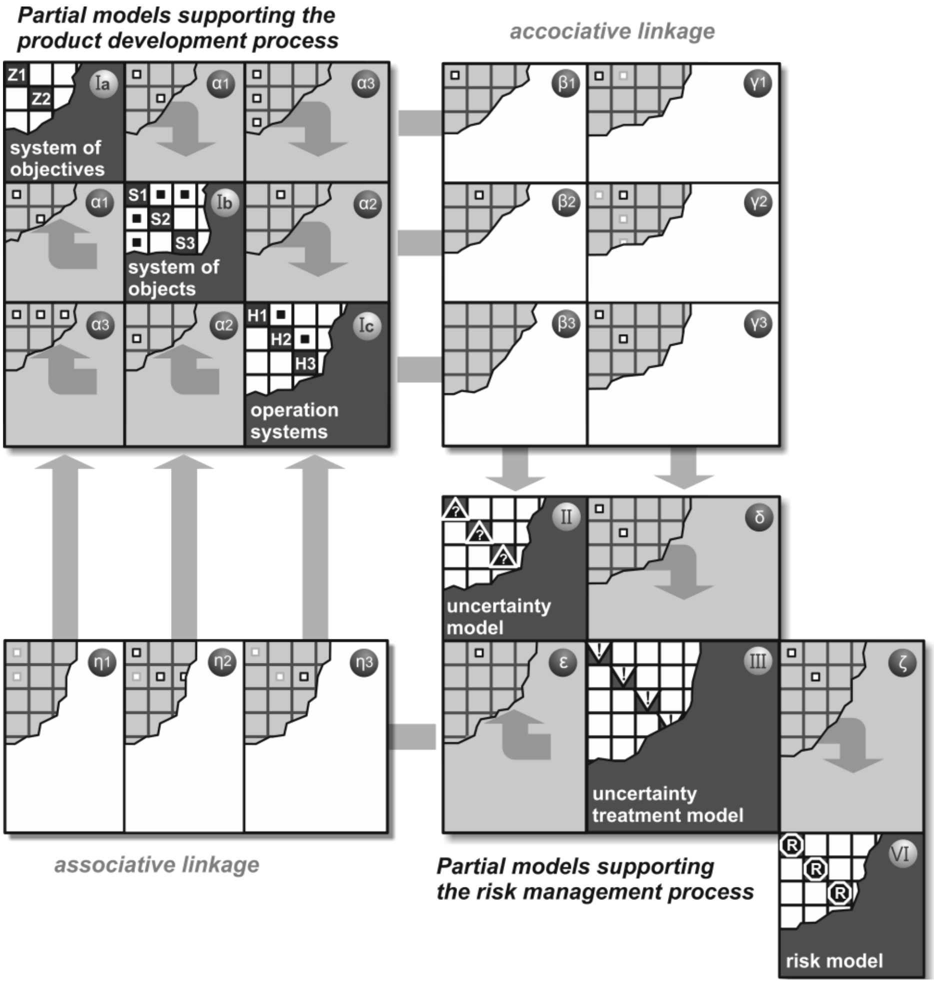


**Figure 3. Structure of the integrated model**

In the top left-hand corner the model contains three partial models, representing the system of objectives, the system of objects and the operation system. The system of objectives is used to describe and structure all requirements and restrictions, while functions, working principles, components and their relationships are modelled within the system of objects. The operation system finally represents the development process and its activities and details the information flow in between. Domain-Mapping Matrices are used to express cross-domain relations.

In the bottom right-hand corner the 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 system of objectives, the system of objects and the operation system. In the uncertainty treatment system potential treatment strategies are modelled. For each response option associated elements are marked in the appropriate Domain-Mapping Matrices. Finally, the risk system holds information about the risks that are caused by the response options.

In order to formalize the modelling principle the approach accesses one of the central ideas of the property-driven development approach (PPD) proposed by (Weber, 2012). PPD distinguishes between properties and characteristics. Characteristics are defined by the developer (e.g. the diameter of a drive shaft), while properties (e.g. the ability of the drive shaft to transmit a certain torque) are an indirect result of this choice. Weber applies the principal in context of system analysis (analyzing the properties resulting from a specific choice of characteristics) as well as synthesis (identifying a proper set of characteristics in order to fulfill required properties). Adapting the concept of properties and characteristics to the modelling approach at hand, in addition to the given definition of the term uncertainty (see section 2) the important convention is made that uncertainties refer to the properties of the system, while uncertainty treatment is achieved by changing the characteristics of the system. Due to the interdependences between properties and characteristics, the properties for their part are affected by changes of the characteristics. These effects have to be identified in order to determine the associated risk of the treatment option. For risk calculation the uncertain event is assigned a probability of occurrence P that either is given by statistical explorations or subject to the experience of the development team. The effects of the uncertainty treatment strategy on the properties of the systems on the other hand are evaluated regarding their impact I on quality, cost and schedule. In a simplified manner the risk can be calculated by determining the product of probability of occurrence P and impact I (in truth risk calculation differs with regard to the treatment option. Risk calculation is not subject of this contribution).

An example of how the modelling approach is applied is given in figure 4. The example refers to the scenario already commented in section 3. It depicts a motor unit as part of one of the joint units of the robotic system. The property in question is the torque provided by the actual dimensioning that can be influenced by changing the number of windings of the stator of the motor. In consequence the power consumption, the weight of the unit as well as its dimensions are affected negatively. The top right-hand corner of figure 4 indicates, how the described elements are represented within the ISRM-Model.

Especially in complex systems uncertainty treatment often is not locally confined. As the power consumption of the motor unit increases, now the suitability of the current dimensioning of the power electronics has to be called in question. For this incident the modelling approach offers the opportunity to formulate consecutive uncertainties that indirectly result from the primary uncertainty treatment. In this manner uncertainty treatment strategies can be disaggregated into detailed event trees that offer deep insight into complex risk situations, objectifying the choice of uncertainty treatment.

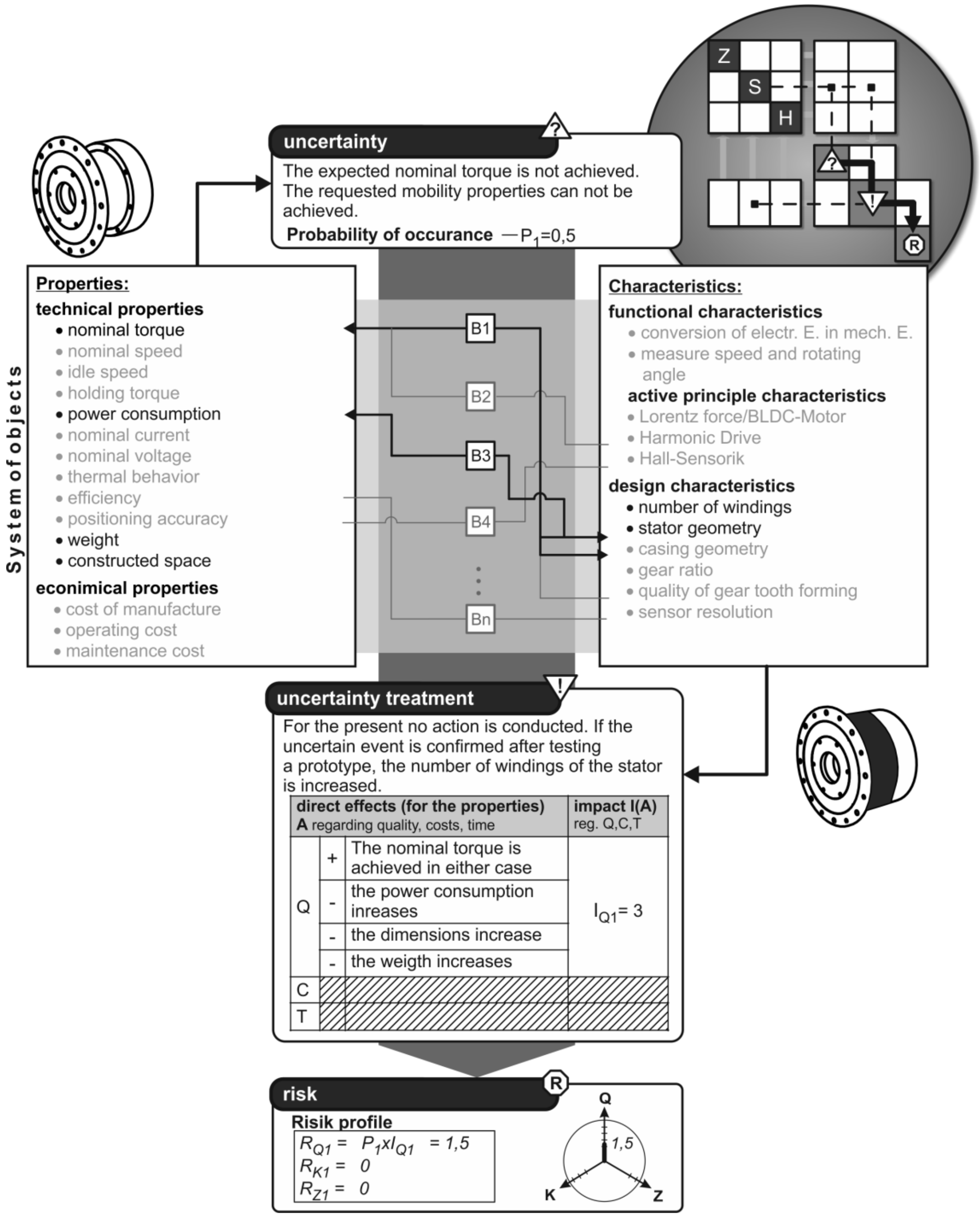


**Figure 4. Formalized modelling principle**

Abstracted to its essentials PDD bases on a formalisation of the causal relationship between decisions that have to be actively reached in the development process and consequences that indirectly result from this decision. The principle therefore also can be transferred to the system of objectives and the operation system as decisions have to be made here as well. From a generic point of view the proceeding, methods and deployed resources constitute the characteristics of the operation system, as this factors are directly determined during project planning, while a certain quality of the results of the conducted activities, a certain duration and finally costs for executing the activities follow. Similar analogies can be identified within the system of objectives. Here requirements and restrictions are defined by the stakeholders representing the characteristics of the system of objectives influencing value of the aspired product for the customer and the provider. Transferring the modelling principle to the both mentioned partial systems offers the opportunity to create comprehensive event trees including the perspectives of changes to all three partial systems. An example is presented in figure 5.

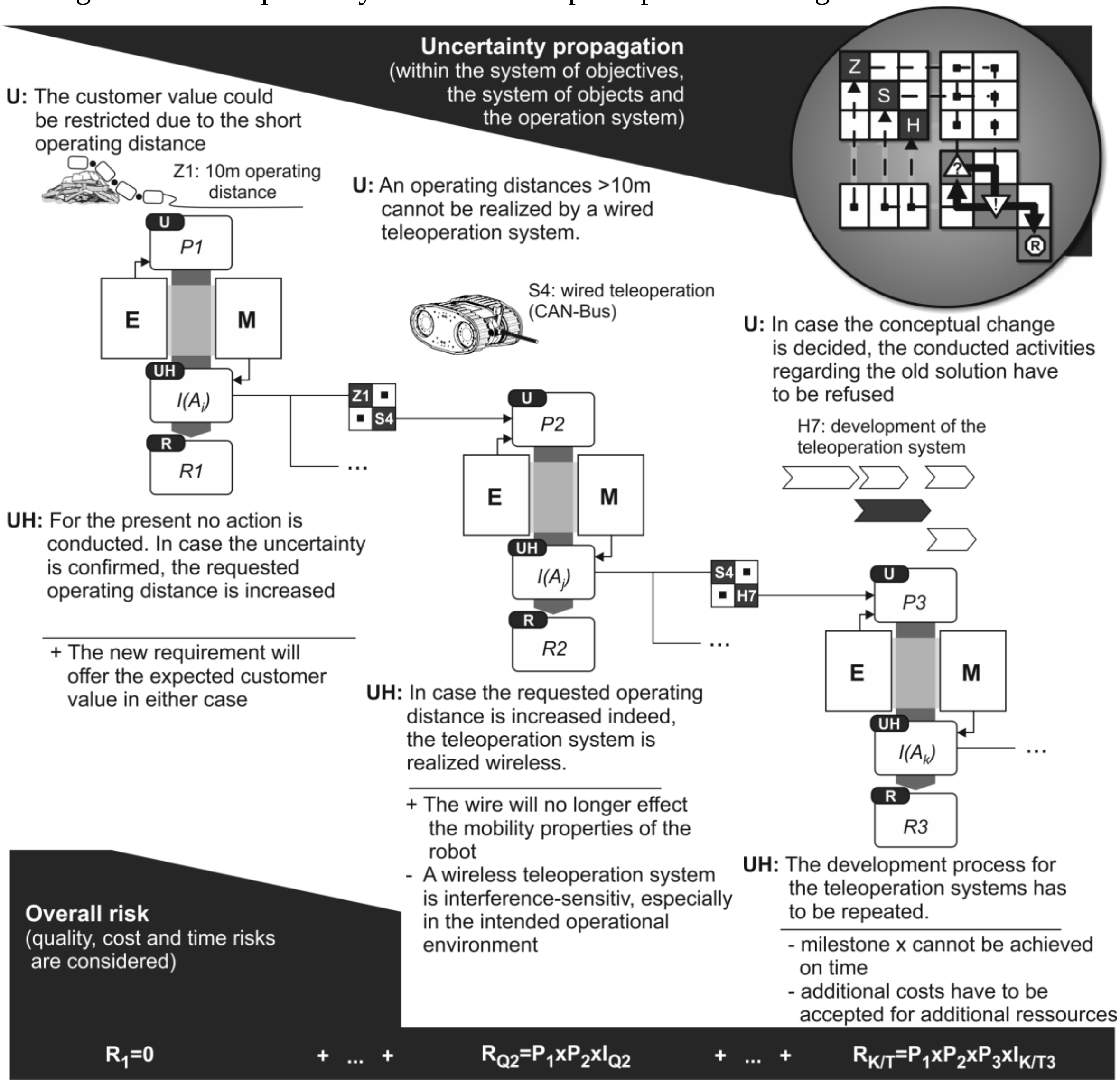


**Figure 5. Modelling comprehensive event trees using the formalized modelling principle**

## 6 Conclusion and future work

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 concept for a risk oriented development methodology, including an integrated 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 and risk management. The approach can be applied to model uncertainties and response options, systematically evaluate those strategies and support risk orientated decision processes. The formalized modelling principle bases on the concept of properties and characteristics, known from the PPD approach that is adapted to the system of objectives and the operation system in order to offer a holistic view on risks, including the quality, cost and time dimension. The general applicability of the approach could be demonstrated within several examples. 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.

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