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Enhancing University Research Project Efficiency through the Application of a Risk-Based Methodology

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ABSTRACT

University research projects usually aim to create innovations. All research and innovations inherit risks from uncertainties in the requirements or procedures. Risk management, therefore, has an important impact on the management of these projects to achieve objectives and ensure that risks are handled correctly. For this reason, this paper develops a risk management concept based on a single case study for university research projects. For this purpose, a 3D simulation of an innovative combustion process for a car engine is examined. The simulation focuses on meeting the challenges based on higher efficiency, lower emissions, and the use of alternative fuels. To investigate this at the management level, an adapted risk management procedure for the detailed combustion model is integrated into the project plan. This aims to determine if the developed model and the simulation can be used for forecasts. The project plan includes base costs (personnel resources, computer resources), uncertainties (physical model accuracy), and risks (new developments, incompatibility of the models). The model is validated using a Monte Carlo simulation, aiming to improve the handling of risks and the accuracy of the simulation. The relation between the simulation results compared to the development and computing times is examined. This procedure intends to optimise the decision-making process for models and simulations to meet the time and budget constraints, to improve the achievement of objectives, and the quality of the research results. In addition, the classification and resilience of the simulation results should be obtained and ensured.

1. Introduction

1.1. Background and Motivation

Globalisation and inherent complexity are increasing, which can be transferred to a special risk factor of today. This is attributed to technical progress and global networking. Therefore, the

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international and national competition among universities and colleges increased, aiming to search for a unique definition to attract students and academic personnel (Wæraas & Solbakk, 2009). This means the link to their value and characteristics must be perceived. To change the perception, not just the organisation itself must develop further, but also the management of university research projects must be improved to show the awareness of their research topics.

1.2. Problem Statement

The most important factors for the management of university research projects are displayed in the project management triangle, which includes time, cost, and scope constraints to achieve the goals (Gross et al., 2024; Wæraas & Solbakk, 2009). It always strives for balance (Smith & Magnusson, 2015). Nevertheless, priority is always given to one pillar. University research projects aim to develop innovative solutions for their research topic. However, the research is entitled to high risks due to its inherent uncertainty (Canals Casals et al., 2024). Sometimes the results are not predictable, which leads to unexpected results. To ensure the balance of the project management triangle, effective risk management is essential to achieve project objectives and to handle risks appropriately (DIN, 2018; Rismondo, 2022).

1.3. Research Objectives and Structure of the Paper

The paper aims to improve the decision-making process in university research projects to meet the budget and time constraints. This shall ensure the quality of the research results and the achievement of objectives. On the one hand, in the short-term vision, the simulation results shall be more reliable. This, in turn, positively impacts the project outcome and accuracy of the simulation progress. On the other hand, in the long-term vision, the success and resilience of university projects shall be improved. This strengthens the reputation of universities and can promote long-term collaborations with industry partners or other research institutions.

The paper develops a risk management concept based on a single case study. The special features of a 3D simulation of an innovative combustion engine are examined, focusing on higher efficiency, lower emissions, and alternative fuels. An adapted risk management approach is integrated into the project plan to assess the impact of risks on simulation accuracy and decision-making. Against this background, this study seeks to answer the following research question: “How can an adapted risk management approach for university research projects enhance the accuracy, reliability, and decision-making process using 3D combustion simulations?”

2. Theoretical Background

2.1. Risk Management in Research Projects

Risk management is not a new discipline. However, based on the publications, risk assessment and management in a scientific approach is not older than 30 to 40 years (Aven, 2016). The risk management process includes the following steps:

(1) risk identification, (2) risk analysis, (3) risk evaluation, (4) risk treatment, (5) continuous monitoring and review, and (6) communication and consultation (DIN, 2018).

The ISO 31000 is suitable because it is commonly used to implement risk management (Khaw & Teoh, 2023). In projects, it aims to work proactively with project stakeholders to minimise risks and at the same time maximise opportunities. The goal is not to avoid risks but to make informed decisions to ensure not exceed budget and schedule constraints to achieve the goal setting (Dziadkowiec & Niewczas-Dobrowolska, 2024). Especially in Research and Development (R&D) projects, the implementation of innovations faces technological challenges, which raises the need for an adaptive approach to risk management (Adepoju et al., 2025; Luppino et al., 2014). Therefore, a systematic literature review on risk management in university research projects was conducted. If no sufficient literature was found, the search was expanded by the keywords "innovative projects" and/or "R&D projects". The search was limited to:

(1) the platform Google Scholar, (2) papers available online, and (3) relevance identified based on the abstracts.

2.2. Literature Review

It is proven that a close link between project risk management and project success exists (Teller, 2013). Based on a prior literature review of Luppino et al. (2014) investigated some frameworks/methodologies for R&D projects. The main results focused on a Failure Modes and Effects Analysis (FMEA) and risk-based FMEA (RFMEA) technique. The FMEA technique expands the traditional risk evaluation by including detection, likelihood, and impact factors. RFMEA focuses on detection factors to measure and identify risks early and improve the reaction process. Luppino et al. (2014) conducted a study on the effectiveness of RFMEA to improve the risk management process. The RFMEA included key results areas, potential hazards, likelihood, severity, and risk score. This results in an improvement in identifying risk in R&D projects and reducing the critical risk rate. Moreover, expert interviews were beneficial for the risk identification process.

The investigated study of Bissels (2018) concentrated on different risk management methods for small research groups and used an expansion of the FMEA methodology. As a result of the research, he mentioned that the Failure Modes Effects and Criticality Analysis (FMECA) method is appropriate for identifying critical risks and prioritizing risks more effectively (Bissels, 2018). This is reasoned in the possibility of adapting quantitative assessments to the traditional FMEA to make forecasts and security-relevant risks more reliable. For the implementation and documentation process of risks, a checklist or risk register can be beneficial. Kwah (2022) conducted a literature review on common risk management in the higher education industry. The results display that most industries focused on general risk management or enterprise risk management. Enterprise risk management is foremost used for identifying, assessing, and mitigating risk holistically (Abaoud, 2019).

Another study focusing on pharmaceutical innovation in R&D projects showed the necessity of probabilistic risk analysis (Hoon Kwak & Dixon, 2008). This opinion is strengthened by using probabilistic methods, such as the Monte Carlo Simulation, to systematically evaluate the impact of uncertainty and risks in R&D projects (Taherdoost, 2024). Based on the results, a closer look at university research projects will be taken.

2.3. Challenges in University Settings

A study on important criteria for the management of university research projects based on interviews and a literature review was conducted. The key criteria can be summarized as follows: (1) allows high flexibility, (2) reducing technical complexity, (3) handling uncertain processes, (4) long and short-term objectives, (5) promote collegial interactions, (6) continuous and interdisciplinary collaboration, (7) adhere to project management constraints, (8) guarantee freedom for research and (9) compliance with moral and ethical standards (Gross et al., 2024).

This means a flexible and scientifically oriented management strategy plays a crucial role in the success of these projects.

Another study on managing risk and uncertainties in large-scale university research projects was conducted by Moore and Shangraw (2011). It focused on the special needs of university research projects and their academic nature. The main challenges that universities are facing are (1) an anti-management attitude, (2) the discovery of unexpected results, and (3) a lack of customised management methods (Moore & Shangraw, 2011). This opinion is supported by Ernø-Kjølhede (2000). He pointed out that risks and uncertainties are even more critical in university settings because, on the one hand, they want to achieve innovations and reduce risks, on the other hand, risks must be taken to be innovative (Ernø-Kjølhede, 2000). Methods are needed that promote creativity, free thinking, and at the same time enhance project management (Kerzner, 2023). Figure 1 summarises the key findings.

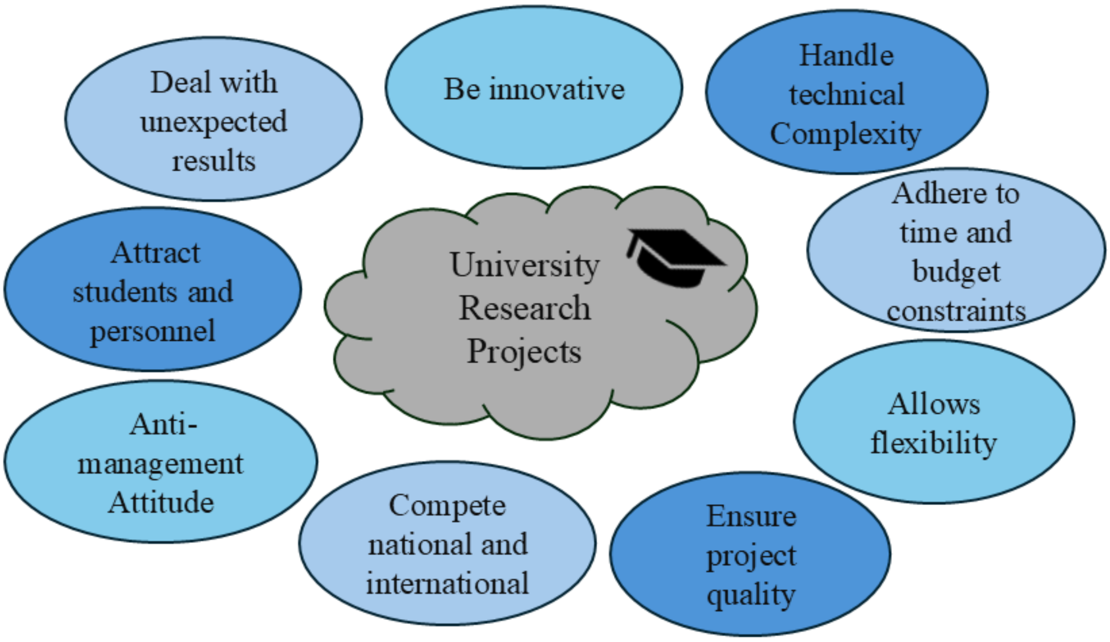

Figure 1. Challenges in University Settings

Note. Identified challenges in university settings

2.4. Choice of Risk Management Methods in University Research Projects

Based on the findings, it is important to incorporate the researchers into the management process to enhance the understanding, reduce conflicts of interest, and stick to the management constraints. Moreover, it's crucial to handle the technical complexity by establishing a framework that fits the requirements of university settings. The early risk identification and prioritisation are important. The literature mentioned the most variants of the FMEA and the stochastic scenario analysis. Therefore, this chapter compares these methods to find an adapted solution for university projects.

The risk management methods can be distinguished into collection methods and search methods. Collection methods are primarily used for methods that are already known. Search methods are further divided into analytical methods, e.g., the FMEA, and creativity methods, e.g., the stochastic scenario analysis. These search methods are used for unknown risks (Romeike, 2018).

Analytical methods focusing on identifying future and previously unknown risk potentials. However, creativity methods are characterised by divergent thinking to arrive at novel ideas and solutions flexibly. The FMEA/RFMEA can be counted as a foremost qualitative method. These methods are still often used to estimate the risks with descriptive words for their likelihood and impact (van Droogenbroeck et al., 2022). Quantitative methods, such as the stochastic scenario analysis, show that a three-point estimation depicts the reality better than a single value (Sander, 2012). When comparing the FMECA to the stochastic scenario analysis, it is noticeable that both methods use quantitative values, but the FMECA cannot aggregate single risks. This, in turn, means that critical risks are not considered concerning the entire project duration. This can lead to misjudgements and unexpected delays. Based on these findings, the stochastic scenario analysis is the preferred method because it is suitable for novel, creative, and unforeseen results to handle the complexity and uncertainty, which is crucial to university research projects. This methodology shall be supported by qualitative methods, such as the Delphi method or checklists, to enrich the risk management process. Therefore, the next chapter describes the adapted approach to risk management for university research projects.

3. Methodology

3.1. Project Structure

At first, the project structure is established. This procedure is based on the previously developed approach by Gross (Gross, Grundl, Wolf, et al., 2025). This means a bottom-up and top-down approach is included. Depending on the size of the project, a middle management approach is also included. Therefore, the top management gives the strategic direction to the overall goals. The project members are providing innovative ideas. The middle management is responsible for the implementation of the processes. To adapt this approach, the work breakdown structure (WBS) was structured to the special features of university settings. This means the scientific research questions are linked to different work packages (WP) to illustrate the dependencies. Every research question ends with a milestone to simulate the results and allows flexibility in goal setting.

3.2. Work Packages

A WP is used to divide desired objectives into smaller tasks (Deckro et al., 1992). It serves as the lowest element in the WBS. Costs and duration can be estimated and managed (Globerson et al., 2016). Small WPs can increase workload and complexity; however, large WPs can reduce concurrent processing (Li & Hall, 2019). Therefore, there is no one-size-fits-all solution. Still, there are some stopping criteria for further decomposition, where the top six are listed here in descending order: (1) organisation unit responsibility, (2) schedule estimation, (3) scope of work, (4) deliverable basis, (5) risk management, and (6) cost estimation (Globerson et al., 2016). Risk management, schedule, and costs are defined as stopping criteria for further decomposition for university research projects.

3.3. Identification of Risks

In this paper, the risks are investigated on different levels to include short, middle, and long-term goal achievement into the management strategy. By integrating a checklist from previous projects, the impacts on the whole project plan or different processes can be seen. This enhances the identification of already known or critical risks. Further improving the identification process, the Delphi method can be used, which is proven to be suitable, foremost for research projects (Häder, 2014). By including a three-point estimation and risk description in the work packages, the short-term goal achievement and awareness of potential risks can be improved. By linking relevant risks and aggregating them, the critical path can be seen, which additionally supports the "risk-thinking". Still, there are no known or identified risks. No risk surcharge according to university research projects could be found, but the potential risk surcharge is compared to data from tunnel projects. To make the risk potential of construction projects transferable, this is compared to the development phase. Here, the risk potential is assumed to be low at 26 % and high at 66 % (Bender, 2025). Therefore, for very critical processes, such as testing the development subject, a maximum total risk allowance in ranges is put on top.

3.4. Risk Categories

Risk categories are defined to better differentiate between risks in the project. Every risk still influences costs and/or time, but the origin can be differentiated. This makes it easier to analyse the impacts. Many literatures have different categories to which they assign certain risks (Diederichs, 2018; Dziadkowiec & Niewczas-Dobrowolska, 2024; Kasap et al., 2007). Most of them have in common that they distinguish between internal and external risks. To further divide internal risks into subclasses, the categorisation of Diederichs (2018) is used. Another category for unknown risks to complement the risk surcharge is included. Figure 2 depicts the structure.

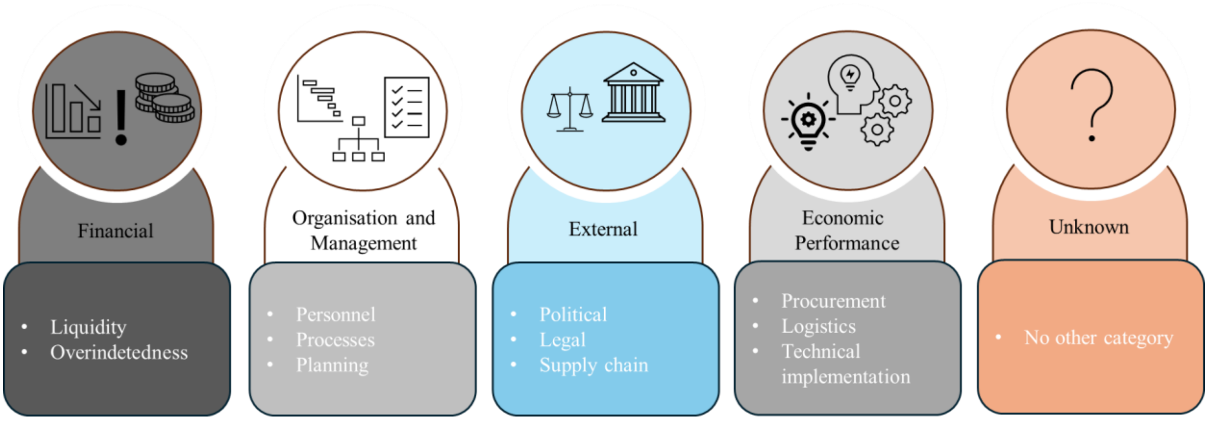

Figure 2. Defined Risk Categories

Note. The five defined risk categories, including the definition of each.

3.5. Used Program

The program used to implement the WPs, schedule, costs, milestones, and risk analysis is called RIAAT (RiskConsult GmbH, 2024). The software creates a digital risk twin of the project and uses a Monte-Carlo simulation to simulate the various scenarios. This tool has already been successfully tested in large-scale infrastructure projects. Like construction projects, university research projects involve a high degree of uncertainty. It is also possible to aggregate risks. This, in turn, makes the program suitable for research projects.

3.6. Integration of the Adapted Procedure in the Project Plan

In RIAAT, impacts on time and/or costs can be displayed. Therefore, two core elements exist. For the schedule-based durations, uncertainty and risks are considered, which makes the project's total timeline. The total project costs consist of base costs, risks, and escalation. In Figure 3, the cost and schedule elements are further described.

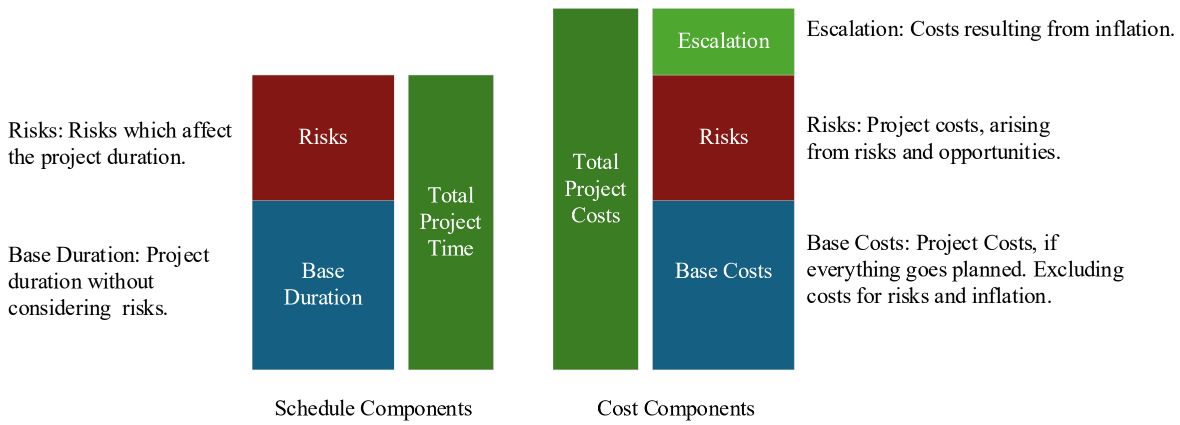

Figure 3. Schedule and Cost Components

Note. Showing the different schedule components (left) and cost components (right) as a bar chart.

4. Case Study: 3D Simulation of an Innovative Combustion Engine

4.1. Project of Investigation

A serial hybrid powertrain is being developed as a part of the Munich Mobility Research Project (MORE, 2025). One vehicle in this project will be powered by an internal combustion engine (ICE) using an innovative reactivity-controlled compression ignition (RCCI) process based on renewable fuels (Trapp & Böhme, 2022). A specific form of RCCI called homogeneous reactivity-controlled compression ignition (hRCCI) will be developed for the hybrid application (Grundl et al., 2023). The concept is shown in Figure 4. The selected fuels are ethanol and octanol, two alcohol-based fuels with properties comparable to conventional fuels like gasoline and diesel. They can be produced CO_2-neutral from renewable sources. Ethanol is injected in the port, and octanol is directly injected in the cylinder.

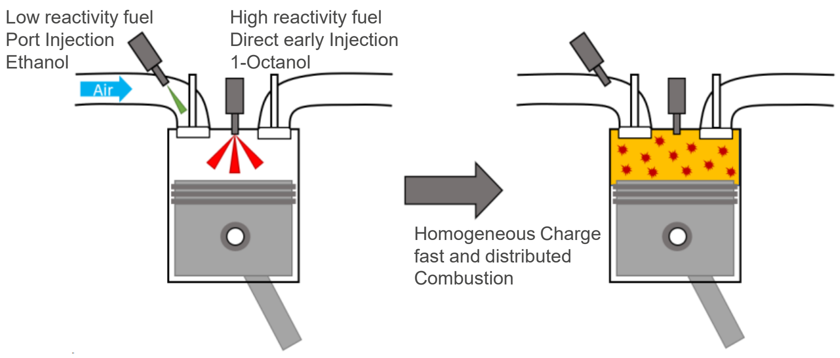

Figure 3. Homogeneous reactivity-controlled compression ignition concept

Note. Schematic illustration of the hRCCI combustion process.

The development of innovative and complex combustion processes like hRCCI presents significant challenges. This is mainly due to the strong interactions between fuel injection, turbulence, mixing, and chemical reaction kinetics. Simulation-based development methods are essential for understanding and optimizing these interactions.

One of the most powerful tools for this purpose is three-dimensional computational fluid dynamics (3D-CFD). CFD makes it possible to analyse the flow, temperature, mixture formation, and combustion behaviour inside the chamber. Unlike simplified models, CFD can provide detailed insights into local phenomena, such as ignition delay, in-cylinder mixing, heat release, and pollutant formation. In the context of hRCCI combustion, where multiple fuels are injected at different times and the ignition is mainly controlled by chemical reaction, this level of detail is crucial. CFD allows researchers and developers to virtually test and compare different injection strategies, piston geometries, or operating conditions long before a physical prototype exists. This reduces development time and cost while improving technical understanding.

In this project, CFD is specifically used to investigate the processes during gas exchange, fuel injection, compression, and combustion. The ability to visualise and quantify the dynamic processes in the combustion chamber helps identify key parameters that influence efficiency and emissions of the new combustion process. The knowledge gained from the simulations is used to optimise the process and to develop a combustion process that achieves maximum efficiency and minimal emissions.

4.2. Simulation in Combustion Process Research and Development

3D flow simulation (CFD) has been established as a key tool in engine research and development. Particularly when analysing complex phenomena such as charging, mixture formation, and combustion, it offers a high level of detail. With growing computing capacity and increasing model quality, CFD continues to gain in importance, although it is still in conflict with 0D and 1D methods, which are less accurate and faster to use (G. P. Merker & Teichmann, 2019).

The process of a numerical simulation is divided into modelling and simulation. It begins with modelling, in which a real problem is simplified with the help of suitable methods. To do this, the real process is broken down into sub-problems that can be described physically and formulated mathematically. The formulated model is numerically integrated, which means that the simulation is performed. This requires a relatively complex procedure. Computational meshes must be generated, and after defining the initial and boundary conditions, the actual calculation can be started. The analysis is also time-consuming due to the large amounts of data involved. The results obtained are compared with experimentally determined results. If there are deviations, the model is modified if necessary (G. Merker et al., 2004).

4.3. Key Challenges: Efficiency, Emissions, and Alternative Fuels

The development of new combustion processes is highly complex, and the use of alternative fuel leads to several challenges. A few challenges of the concept itself will be described. HRCCI has the potential to achieve high thermal efficiency because the combustion is based on controlled auto-ignition at high compression. This makes it difficult to avoid emissions. CO and unburned hydrocarbons can appear in cooler regions or near the cylinder wall. It is challenging to find a balance between efficiency and emissions (Grundl et al., 2023).

Another challenge is the use of ethanol and octanol. These alcohol-based fuels can help reduce emissions. But their ignition delay, vaporisation behaviour, and chemical properties are different compared to conventional fuels, e.g., the high vaporisation enthalpy cools the mixture in the cylinder (Bahri et al., 2013; Graziano et al., 2020). This leads to difficulties in achieving auto-ignition. The process is sensitive to minimal changes in cylinder conditions like temperature, pressure, air humidity, or exhaust gas content. A stable system needs advanced control strategies.

As hRCCI is very sensitive to the environmental conditions, it also faces difficulties when it comes to operating over a wide range of engine conditions. But this challenge will be tackled with the above-described control strategy of the vehicle. In the serial hybrid strategy, the combustion engine is only used to charge the battery. It is possible to operate the combustion engine only at a small number of operating points and to optimise these (Trapp & Böhme, 2022).

4.4. Description of the Simulation Model

The 3D CFD simulation model is structured as follows. The entire process of hRCCI can be divided into gas exchange, mixture formation, and combustion cycles. In each of the three cycles, the modelling of turbulence and heat transfer across the wall plays an important role. In the mixture formation cycle, the modelling of the fuel injection is added, and in the combustion cycle, the chemical kinetics play a crucial role.

As described in detail in the Paper (Gross, Grundl, Sander, & Trapp, 2025), the entire process of model development can be divided into three sub-tasks.

Concept of turbulence modelling strategy

Concept of spray and vaporisation modelling

Concept of ignition and combustion modelling

This basic structure, with the respective research questions, is used to define the WPs. For each sub-process, a work package with intermediate objectives is processed and combined into a simulation model for the entire process.

Due to the complexity and the fact that individual influences cannot be well investigated with the complex full engine model, simplified models for basic investigation are defined for each sub-process. Figure 5 shows the breakdown strategy into the sub-processes with the corresponding research questions. In addition, the simplified models used for gaining a deeper understanding of the defined sub-processes are shown. For the concept of turbulence modelling, a channel flow model; for the concept of injection modelling, a spray chamber model; and for the concept of combustion modelling, a homogeneous reactor is used. From these simplified simulations, a suitable setup for the complex problem should be developed for later use in the full engine simulation. The simulation settings from the sub-models are combined to form the overall model for the combustion process.

For the creation of each simulation, preliminary considerations must be made for the model setup, i.e. how should the geometry look like, how should the geometry be discretized, which initial conditions make sense for the study, which models must be used in the simulation, how should the solver settings be selected and how can the results be used for the full engine model. This is the first step in each sub-process, which is mainly based on literature research. Once the procedure has been defined, implementation in the CFD code begins. Depending on the complexity, various risks may arise. It may also be discovered during implementation that an error has already occurred during model development, and the setup needs to be revised.

Once the simulations have been made for all sub-processes, the knowledge gained is transferred to the full engine model. The transfer of the findings and the simulation of the entire engine model can lead to further challenges due to the complexity.

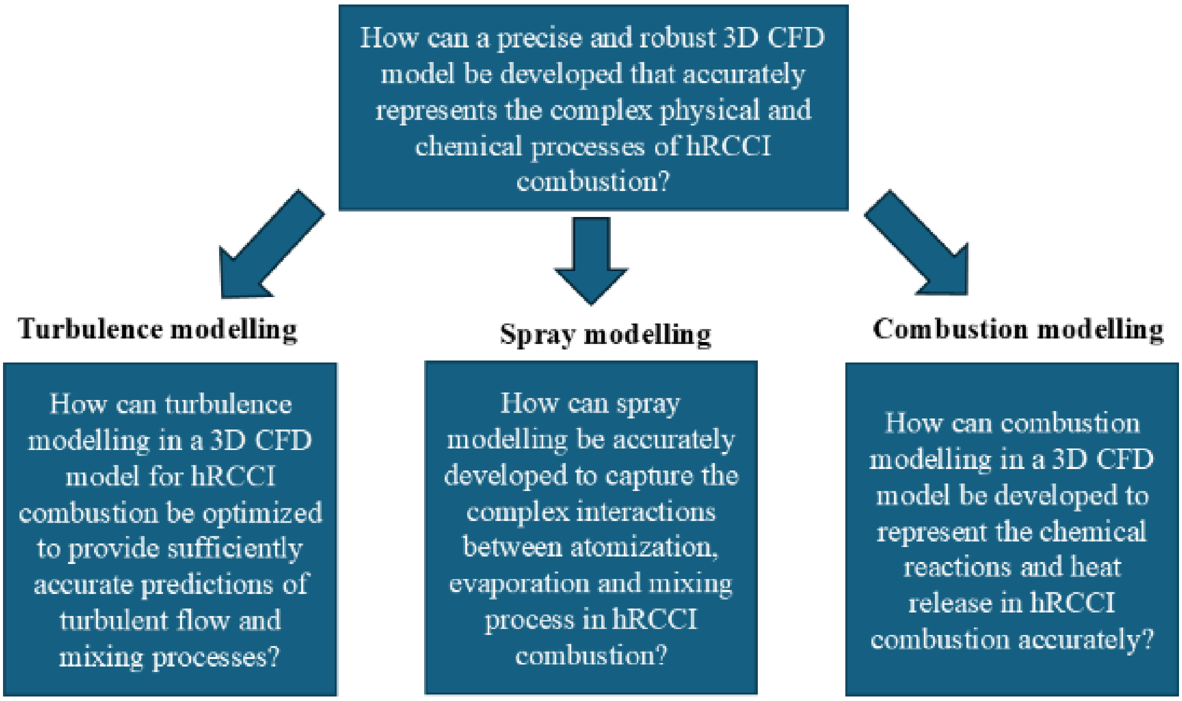

Figure 4. Definition of the different sub-processes

Note. Breaking down the overarching research question into the sub-research questions of the project.

4.5. Project Plan: Timeline, Costs, and Work Breakdown Structure

The above-described simulation model development process should be presented with the help of a project plan. Therefore, the structure of the project is drawn up. This is based on the previous simulation structure, which is already based on breaking down the overall research question into smaller sub-tasks with individual research questions.

Phase of the project/PSP Code:	Implementation	2.2
Project/work package title::	3D CFD Simulation	Building a spray chamber model
Responsible/last update:	Larissa Grundl	Modification Date Q1 2025
Start event/date:	Pre-selection of submodels for spray chamber simulation completed	20.01.2025
Problem statement:	The changed properties of octanol compared to diesel or gasoline influence the injection behavior. This can lead to the existing models not correctly reflecting the injection and this is reflected in the penetration length, spray width or spray angle. These uncertainties in the input parameters increase the uncertainty of the results and make comparison with the experimental results from the spray chamber more difficult.	
Hypothesis:	"If the injection jet break-up processes and the physical input parameters of the model are precisely adapted and optimized to real conditions in the experiment, the mixture formation in the engine simulation can later be accurately predicted, the results can be reliably transferred to real operating conditions and the optimization of the operating parameters can be significantly improved."	
Acceptance and rejection criteria:	Acceptance: The simulation enables an accurate prediction of the injection behavior under different operating conditions. The model provides reliable predictions for operating conditions that have not been directly validated and can be plausibly confirmed experimentally.	Rejection: The simulation is rejected if it shows significant deviations from experimental data (< 20 % error) for the parameters under consideration, i.e. injection length, width, cone angle, numerical instabilities or if it delivers physically implausible results. In addition, the model is inadequate if it does not provide plausible predictions for scenarios that have not been validated experimentally.
Target formulation (SMART-CR):	The physical input parameters of the model should be precisely adjusted so that the simulation results can reliably predict the experimental operating points. The results are measured in terms of penetration depth and spray width. This requires the computing cluster and experimental data from the cooperation partner.	
Intermediate goal 1:	Development of a suitable simulation mesh that can accurately capture the injection. Adjust the model setup based on the conditions in the experimental setup. Performing a grid study to evaluate the impact of grid size on the simulation results. Test the interaction of the different models.	
Intermediate goal 2:	Performing CFD simulations with different model parameters and their influence on octanol injection.	
Intermediate goal 3:	Analysis of the existing measurement data for octanol gasoline direct injection.	
Intermediate goal 4:	Comparison of the developed CFD models with the existing measurement data. Readjustment of the model parameters and adaptation to the measurement results.	
Duration in calendar days - minimum [d]:	30	
Duration in calendar days - expected [d]:	30	
Duration in calendar days - maximum [d]:	50	
Workload [h]:	full-time	

Figure 5. Excerpt from a work package for the spray modelling process

Note. Presentation of an excerpt from a specific work package from the sample project. Red marked are fields, which need the support of the project team; yellow highlighted are fields, which are filled out by the management.

The base durations, including uncertainty, can be formulated based on the defined duration in the work packages (see figure 6). Base duration constraints are scheduled times that do not inherit uncertainties and risks. The base costs of the project are also included. These are calculated from the costs for the scientists working on the project and the costs for the management throughout the project. The costs for the needed resources are also added. The employee needs a special simulation computer that can process large amounts of data quickly for fast post-processing of the results. Access to a high-performance computing cluster (HPC) and licenses for the simulation software are required. Due to the research context, there are no license costs, but the existing HPC cluster will be expanded for this and another project, and the costs will be credited proportionately to the project. One example of the WBS structure (left) and a cost element (right) is shown in Figure 7. Additionally, escalation costs are incorporated for different cost elements to integrate the inflation rate into the total project costs.

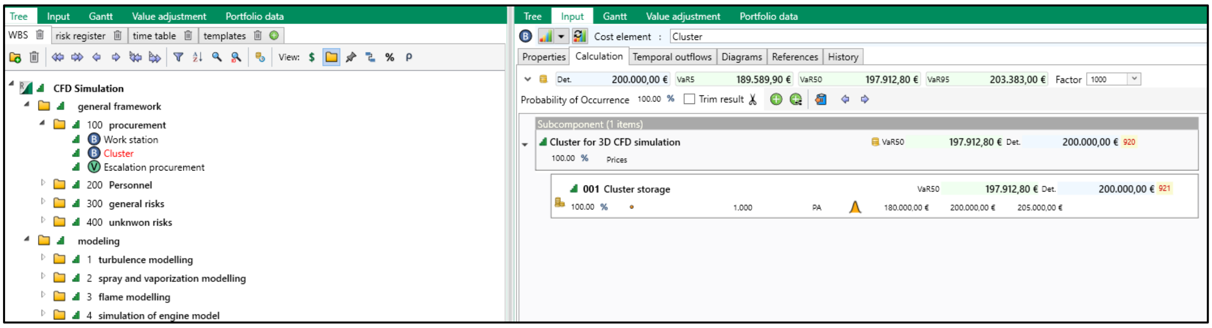

Figure 6. Cost Element HPC Cluster

Note. An excerpt from the WBS (left) shows the detailed base cost element (right).

4.6. Project-specific Risks

As described above, developing a new combustion process using 3D CFD presents many challenges. These specific risks are described as research-specific risks. To simplify the identification of risks, the risks were queried in each WP. Opportunities and risks, and their impact in terms of time and/or costs, were defined in each WP. Risks are identified in consultation with the scientific personnel, who are provided with a checklist for risk identification by the project management. Research-dependent risks are, for example, the non-availability of input data for the simulation, the definition of an incorrect simulation setup, and the associated revision of the model, or a very high, unforeseen computational effort of a simulation, or the wrong definition of initial and boundary conditions in the simulation. Opportunities include, for example, improvements in the quality of the entire engine model through the implementation and application of new models. The risks are included in the risk register, and the current relevant ones are linked to the WBS. If the risk impacts the time, they are connected to the project plan. An example of an economic performance risk can be seen in Figure 8.

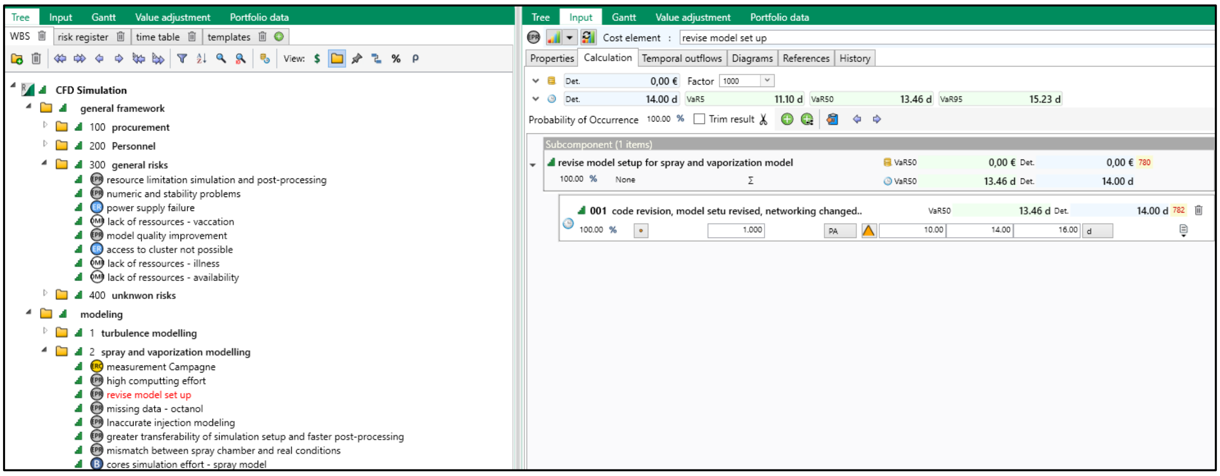

Figure 7. Economic performance risk element

Note. Excerpt of an economic performance risk (left), detailed as risk (right), impacting the project time.

The project also requires cooperation with several partners, which is also associated with specific risks. For example, the validation of the simulation in the spray chamber requires measurement data. This measurement data comes from an external party, and any risks that may occur are also considered as external risks of a cooperation partner.

General risks are also defined. These include any shortage of resources or limitations, whether in the personnel or calculation context. Staff resource limitations include, for example, illness, holidays, or other professional commitments of a project employee. In the calculation context, general risks are a shortage of resources concerning cluster availability. As the HPC is used by several scientists for their calculations, resources may be occupied by other calculations, and the calculation that has been started may be queued on the system until it can be started. Simulation problems, such as numerical and stability problems and modelling inaccuracies, are also included in the general risks, as these can occur in different work packages. The above-described sections show the necessity to adapt risk management to university settings.

Afterwards, the project plan is drawn up. The basic structure, integrating base durations, is incorporated into the project plan. Every research question ends with a milestone to be able to calculate the interim goals over time. This enhances flexibility and control to be on time and within a certain budget. The processes are linked where necessary. Every process must have a successor and a predecessor. Due to the novelty of development and other influencing factors, as described above, university research projects must deal with major uncertainties and risks. This is why the risks that affect the project duration are incorporated into the project plan.

5. Results and Evaluation of the Project

5.1. Project Results of the Two Milestones

The results are validated, creating a digital risk twin, which uses a Monte Carlo simulation to depict different scenarios based on the distribution functions. The project started on 16.09.2024 and is determined to end on 01.08.2025, with a planned total budget of € 334.000. At the moment, the third research question, " concept of ignition and combustion modelling", is under investigation. An excerpt of the current project plan can be seen in Figure 9. The base durations are displayed in blue, and the risks are shown in different red colours. The bright red colour depicts the external, and the magenta red colour the internal occurred risks. The dark red risks are risks that were identified but have not yet occurred.

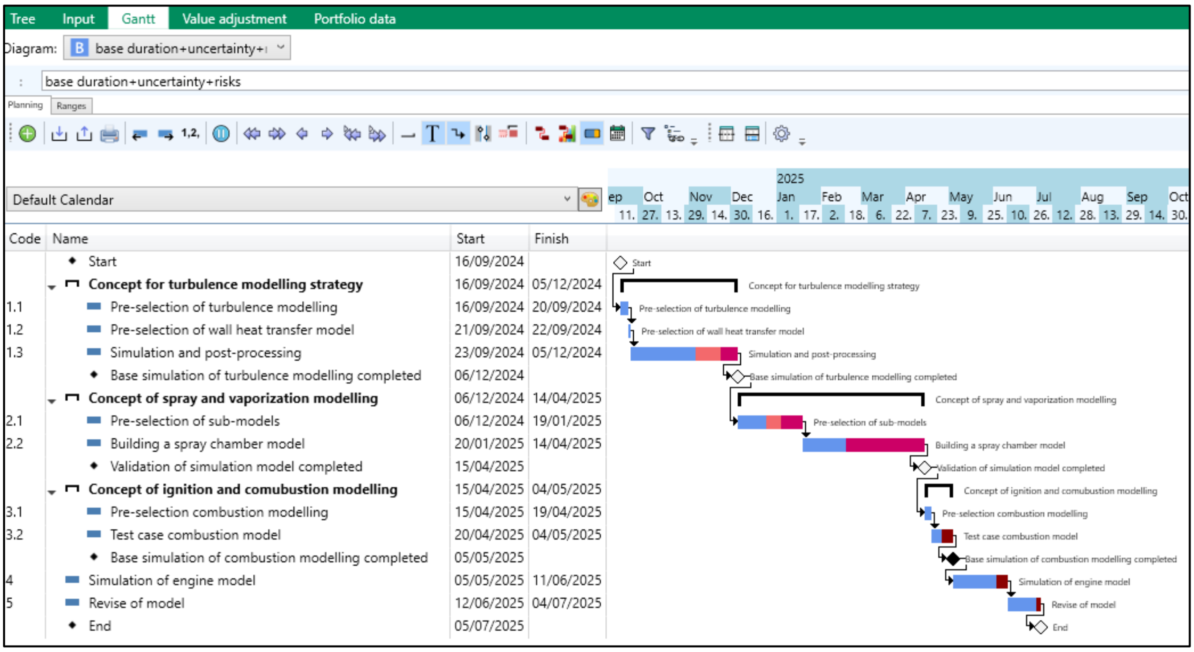

Figure 8. Project Plan

Note. Project Plan including base durations and risks.

By reviewing the target dates to the completion dates from the first two milestones, no time extension happened. The first milestone could be completed three weeks earlier, and the second milestone on time. This was due to including additional buffer times, uncertainties, and risks in the project plan. Therefore, the simulation displayed the results close to reality. As Figure 9 depicts, most risks occurred internally, and fewer risks occurred externally. The internal risks were due to unexpected results, lack of resources, and missing data. External risks, which could not be prevented, occurred due to access availability and power supply failures from the used cluster. With the high computing effort, it requires high resources, which makes it just possible to simulate it on an HPC. A risk buffer time was included from the beginning, which enhanced the accuracy of being on time. Taking the budget and the costs into consideration, € 250.000 is spent, which was the calculated budget for this project phase.

5.2. Prediction of the Future to the Third Milestone

To include the lessons learned from the first two milestones, the weighting is given more at the third milestone to internal risks; nevertheless, external risks are still considered. Figure 10 shows the probability of not exceeding a certain time, based on the target date of the third milestone. The three different graphs (1) base and uncertainty schedule – dark blue, (2) base + uncertainty + risk schedule -red, and (3) target date – light blue- show the influences on the total project timeline.

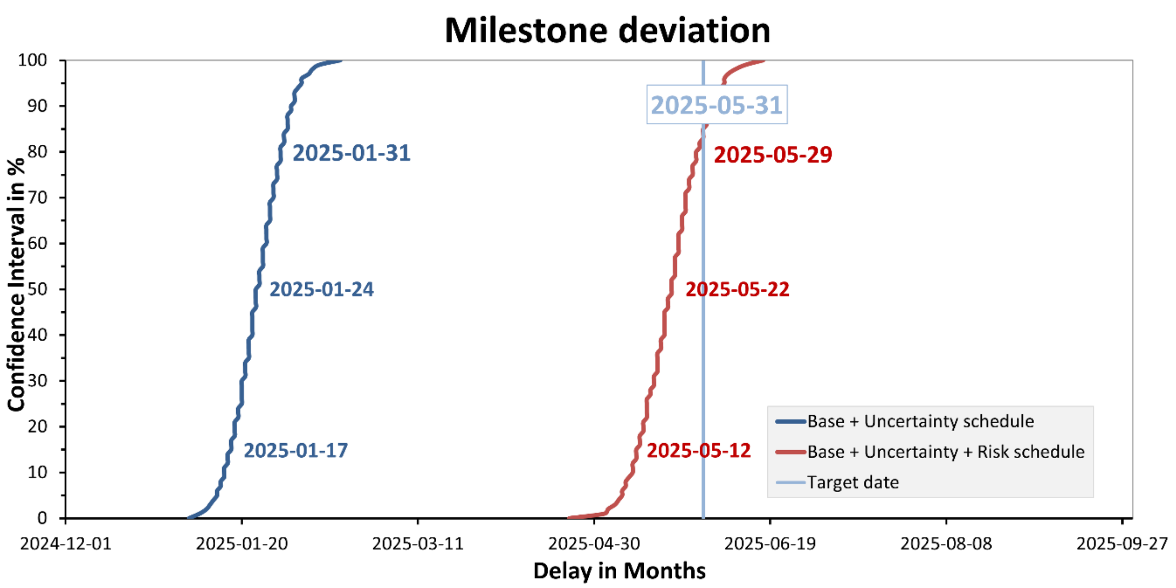

Figure 9. Milestone deviation - 3rd milestone

Note. Displaying the milestone deviation to the 3rd milestone of the project.

As can be seen to 83 % of the target date will not be exceeded by including base durations and risks. By simulating these different scenarios, changes can be implemented, and it enhances the early risk identification. This allows flexibility, risk-awareness, milestone controlling, and informed decision making. The accuracy of the forecast was therefore improved in this case by giving more weight to internal risks.

5.3. Prediction of Planned Budget and Time

To transparently show the impact on the whole project plan, not just on a single milestone, the simulation calculates the results to the project end. This means various scenarios can be displayed. Figure 11 shows the impact of base durations, uncertainties, and risks on the target date.

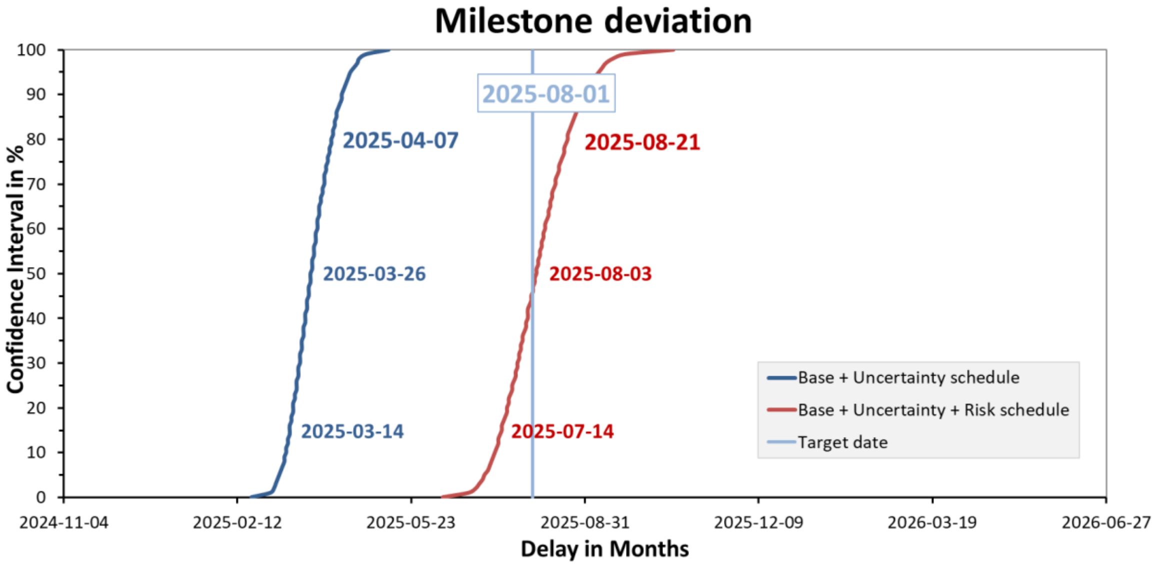

Figure 10. Milestone Deviation - Project End

Note. It displays the milestone deviation to the project end.

As Figure 11 depicts, with a probability of 47 %, the target date will not be exceeded. This means that just considering the single milestones, the overview could get lost. By a confidence interval of 47 %, the project manager must decide if the security level is enough. If not, additional workshops must be conducted to reduce risks or uncertainties, or goals must be changed.

A closer look at the planned budget versus the total costs is taken. Figure 12 depicts the probability of not exceeding a certain cost value. This figure shows the impact on the total budget, which includes base costs, risks, time-bound risks, and escalation. The red line marks the probability of 68 % that the budget will be enough for the planned project duration.

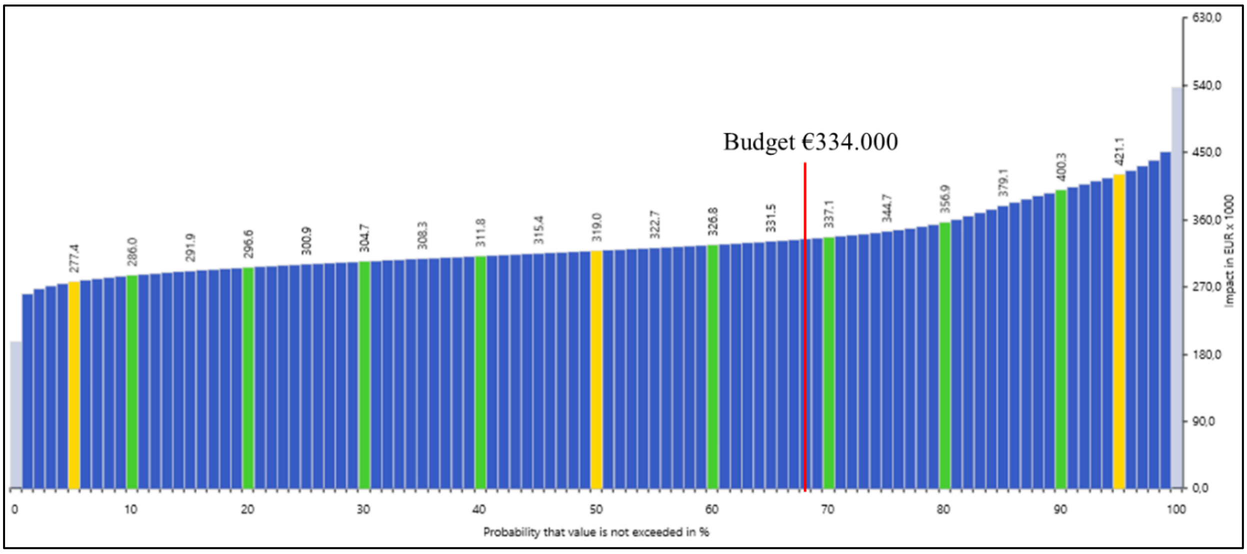

Figure 11. Total Costs

Note. Displaying the total cost compared to the planned budget.

6. Discussion

6.1. Impact of Risk Management on Research Quality and Decision-Making

Risk management has a high impact on the project duration and the planned budget. Because of the unknown and high risks, risks must be included from the beginning. This ensures a transparent documentation and assessment of risks early, which reduces conflicts of interest. The adapted risk approach by including a research question in the project plan ensures the compliance of the scientific personnel with the overall goal setting. This eventually can improve the motivation and productivity of individual researchers.

Moreover, evaluating the different milestones is important to make informed decisions, which impacts the researchers and the project goals. If more than one risk category is used, it is possible to evaluate individually each milestone where risks occurred the most frequently. By knowing this, quick measurements can be taken, which improves the goal achievement and, in the long term, the quality of the results.

6.2. Limitations of Research

The case study is limited to a single case study, which cannot be considered as the entirety of all. This means the study cannot generalise the results, but it counts as a first step for further investigations. The project is a technical project belonging to the engineering field of research. Therefore, it cannot be generalised to all other types of projects.

On the one hand, the small sample hinders reproducibility, but on the other hand allows a deeper analysis and understanding of challenges and risk factors. Gaining a deeper understanding of risks enhances “risk thinking,” which is necessary for university research projects.

6.3. Broader Implications to University Settings

Broader implications for university research projects can be drawn. The study points out that a clear structure of university research projects and a well-defined definition of objectives and requirements are crucial to the project's success. Moreover, breaking down complex issues into various tasks is important to ensure the transparency of the project's progress. The inclusion of work package-related risks in the project plan improves the accuracy of the estimation. This is due to involving the project personnel and management, ensuring the prevention of a lack of resources and a flexible framework. Providing this procedure is not just important for simulation models but also crucial for other applied research projects.

Continuous validation and quality assurance are also particularly important for the success of the project. The probabilistic project plan, with its structure of research questions and work packages ending in milestones, makes it easier to monitor the achievement of objectives. The methodology developed, therefore, addresses precisely the crucial areas for the implementation of all types of technical projects in research and industry.

7. Conclusion

7.1. Summary of Findings

As the findings prove, it is important to validate the current durations and costs so as not to exceed a certain budget or the planned schedule time. This means early simulations on different milestones can improve the early detection of delays or further risks, which has a positive impact on short and long-term goal achievement. Moreover, iterative processes make it possible to optimise the system step by step. This has a positive impact on the single milestones.

Most risks occurred in the internal context, referring to unexpected results, lack of resources, and missing data. The occurred external risks can be referred to as access availability, and power supply failures due to the dependency on a single company/institution. At highly uncertain processes, a buffer time (including risks) of 20-50 % was accurate, which was incorporated from the beginning.

By including research questions and WPs in the project plan, the processes can be directly linked to the researchers. This ensures compliance, transparency, and feedback loops. Moreover, incorporating the hypothesis into the WP’s measured criteria is included, where the management can validate the results. This enhances the ability to flexibly adapt to changes. The hypothesis-based risks support the risk-awareness thinking, which is crucial to identifying relevant risks.

Integrating this in a digital risk twin has many advantages. The detailed data of various scenarios makes forecasts more reliable and leads to informed decision-making. This enhances the resource allocation and control of technical and organisational decisions. Simulation results improve the communication of the status quo to management, stakeholders, and external cooperation partners. The risks can be aggregated, and the impact on the total project can be seen. This enhances the glance of the long-term vision.

7.2. General Implications for the Project Manager

The results of the research gave valuable insights to universities and the possibility to adapt this to the industry. Focusing on the project managers, it is crucial to reduce the technical complexity using appropriate methodologies. Therefore, for innovative projects, a combination of top-down, bottom-up, and middle management shall be used to include stakeholders at all levels. This means stakeholders have to be integrated into the project planning from the beginning to ensure alignment with the overall project goals and reduce risks at the same time. This enables cooperative and innovative collaboration with universities, funding organizations, or industry partnerships to reduce time delays and budget overruns. Regular workshops and meetings shall support a comprehensive understanding and enhance the transferability. Moreover, the digital risk twin displays various scenarios, which allows the project manager to make informed decisions and communicate critical risks early to the impacted stakeholders. This developed procedure enables an innovative approach to handling risk management efficiently, which leads to an improvement of the strategic direction, including innovative solutions.

For example, Industry 4.0 can benefit from this methodology to reduce its technical complexity, handle flexible resource allocation, reduce conflicts of interest, and create and improve the strategic direction of its development processes. This, in turn, makes it possible to combine theoretical results from researchers and practical applications from the industry to make informed decisions. As a result, the broader implication can also be used to shape the future for Industry 4.0.

7.3. Recommendations for Future Work

For future projects, the goal is to refine and further validate the methodology presented. The test in different application areas of the university research environment is particularly interesting. The aim is to investigate whether the risk categories relevant in this project can be considered generally valid for all projects at universities, or if there are differences in the relevant risks and their weight depending on the focus of the research.

It is also planned to test the methodology for larger projects with several project members. It is assumed that issues such as employee awareness of project management can play a crucial role in the success of the methodology.

The results obtained from the planned case studies should serve to develop a generally applicable approach for taking uncertainties and risks into account for university research projects. And from this, a guideline for future project managers can be created, which contains, for example, a risk checklist for risk identification and an approach for increasing the awareness of scientific personnel for project management. This should enhance future project managers to improve scientific research projects in terms of goal, time, and cost management.

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