Towards a risk management framework for construction projects

Analyzing the risk procedures in construction projects, and developing a risk management framework for EPC and EPCm projects at Tebodin

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Preface

This master thesis is the final result of the research I conducted at consultancy & engineering company Tebodin. With this report, I conclude my time as a student and finish the master Construction Management and Engineering at the Delft University of Technology.

During my studies it was one of my goals to explore the field of construction management in a different culture. During my internship in Kinshasa last year, I was taught many lessons about the construction world and was involved with safety risk management practices at project level. The research I conducted at Tebodin gave me the opportunity to investigate the company’s procedures and risk management practices at both corporate and project management level. The opportunity to become involved in the world of project managers in the construction industry has given me a detailed perspective on the company’s culture and has allowed me to make a couple of steps in my personal development. Therefore, I would like to thank Tebodin for giving me this opportunity. I sincerely hope that the results of this research will be beneficial for Tebodin in the future.

Special thanks are in place for all the colleagues that I interviewed and the ones who were involved in my research. You have helped me to gain insight into current risk management practices and communication flows at Tebodin. Thank you all for your time and openness.

This research would not have been possible without the supervision of my graduation committee and I would like to thank them for their commitment to my project and their guidance. I would like to thank Alexander Verbraeck, chairman of the committee, for his clear comments on the content of the report and for indicating the importance of comparing best practices. I would like to thank the supervisors, Jos Vrancken and Marian Bosch-Rekveldt, for their valuable thoughts and criticism about the research methodology and for guiding me towards a direction, which has helped me to conduct this research in a manageable time. I would also like to thank my supervisor at Tebodin, Duncan Goodall, for the useful and nice conversations and discussions, which made my work at Tebodin very pleasant. Thank you for the enjoyable cooperation and for the constructive feedback.

Last but not least, I would like to thank all my friends and family who have been there for me during this graduation process. Thank you all for your support. I hope you enjoy reading this report.

Ilca Italianer
The Hague, September 2014
Executive summary

Introduction
In the construction industry today, projects are exposed to a broad range of risks. It is important to manage risks because the success of a project is essential to both client and contractor. However, when considering the practical aspects of risk management, the construction industry generally shows low risk awareness. Although many tools and techniques exist for dealing with risks, there is a clear gap between what the literature suggests on the application of these techniques, and how particular tools and techniques can fit an individual company. To gain more insight into current risk management practices, this thesis focuses on the analysis of such practices at a company level, namely at consultancy & engineering company Tebodin.

Tebodin carries out projects that consist of engineering, procurement and construction management (EPCm) services. Their stated aim is to further professionalize their construction management services and communication flow. The research presented in this thesis consists of analyzing and improving Tebodin’s current risk management procedures for construction projects. To reach this objective, the following research question has been defined:

“How can a risk management framework in the construction industry be developed, and to what extent can this be implemented for EPC and EPCm projects at Tebodin?”

By combining theoretical knowledge and the analysis of current risk management practices at Tebodin, a suitable risk management framework is developed to provide insight into which techniques and tools can be used to integrate risk management into project management, and which offers guidance to manage risks during the entire project. Exposing the gap between theory and practice and introducing, by way of example, how risk management should be implemented at Tebodin can be seen as scientifically relevant.

Analysis
The first part of this research consists of a gap analysis. Theory from both a literature review and the risk management guidelines in the Tebodin manuals are compared with the reality acquired through interviews with project managers from Tebodin. The results of these interviews define the current way risk management is carried out for construction projects. Comparing this with literature provides insight into the conditions that must be met by the organization for a successful application of a risk management framework. From the literature a comparison is made between risk-related techniques used for construction projects, to define which techniques are suitable for the framework.

The second part consists of the development of a suitable risk management framework. The framework is designed by including the current risk-related procedures at Tebodin and relevant techniques from literature. The conceptual model of the framework is shown in Figure 5-1, and consists of three layers that are presented as a bottom-up approach:

- **Layer 1:** The bottom layer contains Tebodin risk related techniques that are placed on a timeline and that are used during the front end loading, the project execution, and the operation & evaluation phase. On the vertical axis of the model, the techniques are categorized into project drivers such as quality, safety, time and cost. Additional techniques from literature are added to the procedure.
- **Layer 2:** The second layer provides a more detailed overview of how the techniques are linked to each other, and to which risk management phase they belong.
- **Layer 3:** In the third layer three focal points of the method are researched in an in-depth study. The focal points are risk identification, quantitative analysis and post-project evaluation. These points are selected according to the areas for improvement identified at Tebodin and can be substantiated on scientific grounds. For each focal point an in-depth study is carried out to develop an improvement strategy for managing risks. The first two in-depth studies are explorative by researching literature about risk management techniques’ applicability and how they can be integrated in the framework, and the third
in-depth study uses an experimental set-up to evaluate the effectiveness and suitability of post-project evaluation.

The third and final part explains how to integrate the framework into the organization. Combining best practice from the literature with Tebodin’s existing procedures and company culture define the implementation plan. Several expert interviews are conducted to validate the framework implementation in Tebodin’s organization and to validate the framework by comparing it to other companies’ risk management procedures.

Conclusions
To answer the research question: “How can a risk management framework in the construction industry be developed, and to what extent can this be implemented for EPC and EPCm projects at Tebodin?” for each focal point of the risk management framework an improvement strategy is developed for Tebodin, by answering the following three sub-questions:

- **Post-project evaluation:** How can knowledge transfer between EPC or EPCm projects be improved?
  To improve knowledge transfer between projects and to avoid making the same mistakes twice, a ‘lessons learned’ database is suggested. In the database information retrieved from project evaluations can be stored and sent to relevant departments, and checklists in the database can be consulted by project managers when setting up a proposal, business concept and project plan.

- **Risk identification:** How can risk identification be improved?
  To improve risk identification, consulting the database for useful lessons learned and opportunities from previous projects is suggested. Expanding the brainstorm session by using a risk breakdown structure and consulting a process flowchart enables all project risks (instead of only safety ones) to be evaluated and identifies risk interaction. The project managers should be aware what drives a project, and in consultation with the client, trade-offs need to be made explicit regarding time, cost and quality.

- **Quantitative analysis:** Are quantitative analyses recommended to continuously improve projects?
  Research showed that it is recommended to use quantitative methods in the front end loading phase of the project, depending on the project’s level of challenge, project manager responsibility, focus and company’s maturity. However, as quantitative methods are not extensively used at Tebodin, a change in risk awareness and development of the risk maturity in the company is recommended.

The suggested techniques fit within the organization because of their practical application, but a limitation is that these do not change the culture of an organization. In order to benefit from the added value of these techniques, and to close the gap between theory and practice, a change in culture needs to be developed to be able to embed these techniques in the organization.
Recommendations

To implement the risk management framework into the organization, the following recommendations are given. On the short term, Tebodin should introduce the risk management framework to the project managers, as not all of them make use of existing techniques, in order to learn from each other. Most of these solutions are to be carried out at the start of a project and (as concluded by IPA\(^1\)) require early participation of members of the project team to succeed. Explaining tools and techniques can help to create awareness and improve the risk maturity of the company.

An example is described for the post-project evaluation: So far, lessons learned are not integrated because the added value of lessons learned is not recognized. The implementation plan that is described can work because it combines the modification of existing tools and information access with raising risk awareness within the organization. The post-project evaluation tool is an example of a means to store information such that everyone has access to it. A change in behavior and attitude is necessary, which is why training should be given to project managers on how and why a project evaluation session should be carried out. This change requires a small extra effort of the project managers at the end of a project and can lead to great value to the organization and future projects. The project evaluation session should be compulsory for risk-driven projects and project managers granted access to the database to consult lessons learned during the risk identification phase. Professional training should be provided to become familiarized with the tool, thus embedding it into the process. On the long term, the risk management performance within projects can be evaluated through performance interviews with project managers.

Quantitative methods are more difficult to implement, because they require a cultural change in the organization. The development of a knowledge center where different quantitative techniques are explored and suitable tools and procedures for the organization are developed is recommended. For future research, an investigation into how quantitative risk management techniques from other industries could fit in the construction industry is suggested and the need for a study on how risk response and control strategies can be integrated in the risk management framework is also identified.

Scientific contribution

- This research uses a unique approach to analyzing risk management in construction projects. Comparing theory from a literature review with the reality acquired through interviews with project managers from Tebodin were used to set up preconditions that must be met for a successful application of a risk management framework.
- This research exposes the gap between risk management theory and practice and concludes that the culture and mindset of a company and the training of individuals appear to be as important as the actual techniques that are used.
- A connection is made between the theory and practice. The proposed risk management framework not only focuses on the procedure and the detailed techniques that are used, but also includes the culture at Tebodin, which altogether provides input for the suggested implementation strategy. The strategy focuses on how risk management practices should be integrated with project management.
- A risk management framework has been developed with a potential for use in the construction industry.

\(^1\) Independent project analysis: a global research and consulting company devoted exclusively to the understanding of capital project delivery organizations in industrial megaprojects.
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<tr>
<td>AHP</td>
<td>Analytical Hierarchy Process</td>
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<tr>
<td>ATOM</td>
<td>Active Threat &amp; Opportunity Method</td>
</tr>
<tr>
<td>C&amp;E diagram</td>
<td>Cause-and-effect diagram</td>
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<tr>
<td>CII</td>
<td>Construction Industry Institute</td>
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<tr>
<td>CM</td>
<td>Construction Manager</td>
</tr>
<tr>
<td>C&amp;R list</td>
<td>Chances &amp; Risks list</td>
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<tr>
<td>DCN</td>
<td>Design Change Notification</td>
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<tr>
<td>EMV</td>
<td>Expected Monetary Value</td>
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<tr>
<td>EPC</td>
<td>Engineering, Procurement and Construction</td>
</tr>
<tr>
<td>EPCm</td>
<td>Engineering, Procurement and Construction management</td>
</tr>
<tr>
<td>EV</td>
<td>Expected Value</td>
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<tr>
<td>FEED</td>
<td>Front End Engineering Design</td>
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<td>FEL</td>
<td>Front End Loading</td>
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<tr>
<td>FMEA</td>
<td>Failure Mode and Effect Analysis</td>
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<tr>
<td>HAZOP</td>
<td>Hazard and Operability study</td>
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<tr>
<td>H&amp;S plan</td>
<td>Health &amp; Safety plan</td>
</tr>
<tr>
<td>HSE</td>
<td>Health, Safety &amp; Environment</td>
</tr>
<tr>
<td>IPA</td>
<td>Independent Project Analysis</td>
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<tr>
<td>LMRA</td>
<td>Last Minute Risk Analysis</td>
</tr>
<tr>
<td>MCDM</td>
<td>Multi Criteria Decision-Making</td>
</tr>
<tr>
<td>NCR</td>
<td>Non Conformity Report</td>
</tr>
<tr>
<td>PDRI</td>
<td>Project Definition Rating Index</td>
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<tr>
<td>PERT</td>
<td>Program Evaluation and Review Technique</td>
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<tr>
<td>P-I matrix</td>
<td>Probability-Impact matrix</td>
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<tr>
<td>PM</td>
<td>Project Manager</td>
</tr>
<tr>
<td>PMI</td>
<td>Project Management Institute</td>
</tr>
<tr>
<td>PRR</td>
<td>Project Risk Register</td>
</tr>
<tr>
<td>QOHSE</td>
<td>Quality, Occupational Health, Safety &amp; Environment</td>
</tr>
<tr>
<td>RBS</td>
<td>Risk Breakdown Structure</td>
</tr>
<tr>
<td>RIE</td>
<td>Risk Inventory &amp; Evaluation</td>
</tr>
<tr>
<td>TOPSIS</td>
<td>Technique for Order Preference by Similarity to Ideal Solution</td>
</tr>
<tr>
<td>TQS</td>
<td>Tebodin Quality System</td>
</tr>
<tr>
<td>TRA</td>
<td>Task-Risk Analysis</td>
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<table>
<thead>
<tr>
<th>Term</th>
<th>Explanation</th>
</tr>
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<tbody>
<tr>
<td>A-form</td>
<td>The form to be completed in case of a tender with a value over 1 million euros in order to acquire the prior approval of the Board of Directors. In case of EPC tenders with a value over 1 million euros and tenders for EPCm services exceeding a value of 5 million euros a completed C&amp;R list has to be submitted with the A-form.</td>
</tr>
<tr>
<td>B-form</td>
<td>The form to be completed in case of a tender with a value between 500 thousand and 1 million euros.</td>
</tr>
<tr>
<td>Business concept</td>
<td>A concept of the project drawn up during the FEL-1 stage.</td>
</tr>
<tr>
<td>CII</td>
<td>Construction industry institute: a learning organization with a wealth of knowledge and information for the engineer-procure-construct process that provides guidance on best practices discovered through research.</td>
</tr>
<tr>
<td>Close out report</td>
<td>Report with a checklist that has to be filled in to close a project.</td>
</tr>
<tr>
<td>FEL index</td>
<td>A measure for the level of project definition at a moment in time, developed by IPA.</td>
</tr>
<tr>
<td>Gate review</td>
<td>A checklist that has to be completed at the end of each stage.</td>
</tr>
<tr>
<td>IPA</td>
<td>Independent project analysis: a global research and consulting company devoted exclusively to the understanding of capital project delivery organizations in industrial megaprojects in the petroleum, chemicals, minerals, pharmaceutical and power industries. Whenever IPA is referred to in this thesis, a reference is made to Merrow, founder and president of the IPA.</td>
</tr>
<tr>
<td>Project plan</td>
<td>Plan that includes the scope of works, planning, procurement strategy, construction strategy, project organization, communications and time schedule.</td>
</tr>
<tr>
<td>Shareportal</td>
<td>Tebodin intranet system.</td>
</tr>
<tr>
<td>TQS</td>
<td>Tebodin Quality System containing the company’s processes.</td>
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Part I Problem

The first part of this research consists of chapters 1, 2 and 3. Chapter 1 introduces the research subject, chapter 2 describes the problem analysis and chapter 3 elaborates on the research objectives, questions and methodology.
1 Introduction

In the construction industry as it is known today, projects are exposed to a broad range of risks. It is important to manage these risks because both the client and the contractor want the project to succeed. According to Nicholas and Steyn (2012) the principles of risk management include having a risk management plan that specifies the risks, their symptoms and back-up plans; a risk officer responsible for identifying and tracking the risks; and a budget and schedule reserve. The plan must specify the ways to monitor risks and emerging problems, and to communicate them to the project manager. Risk management is to be carried out during the entire project and is about reacting to forecasted risk events, making contingency plans and carrying out actions. Schwalbe (2014) states that while risk management is often overlooked in projects, it can improve project success by helping select good projects, determining project scope, and developing realistic estimates. Risk management is the art and science of identifying, analyzing, and responding to risk throughout the life of a project and in the best interests of meeting project objectives (Schwalbe, 2014). The conclusions of empirical studies of 100 projects in different industries indicates that risk management is still at its infancy and that more awareness of the application, training, tool development, and research on risk management is needed (Raz, Shenhar, & Dvir, 2002).

This research is about risk management in the construction industry. The construction industry has a poor reputation in coping with risks (Edward, 1995). Particularly, the construction industry has been slow to realize the potential benefits of risk management in comparison with high-risk projects in the petrochemical, oil exploration and aerospace sectors (Flanagan & Norman, 1993).

The construction industry is regarded as being inherently uncertain and complex in its structure (Hasan, Ahamad, & Mohamed, 2011). It is therefore important to manage risk during each phase of a construction project. Change is inherent in construction work and cannot be eliminated, but by applying the principles of risk management, engineers are able to improve the effective management of this change (Smith, Merna, & Jobling, 2014). According to Kangari (1988), decision-makers should approach complex construction problems by applying systematic and professional risk management tools. This also appeared to be the conclusion drawn from British research among general contractors and project managers by Akintoye and MacLeod (1996), finding that risk management is essential to construction activities in minimizing losses and enhancing profitability. However, they also conclude that formal risk analysis and management techniques are rarely used due to a lack of knowledge and due to doubts about the suitability of these techniques for construction industry activities. There is a clear gap between the theory and practice of risk modeling and assessment (Taroun, 2014).

This research is carried out at consultancy & engineering company Tebodin. Tebodin offers engineering services from conceptual and feasibility studies to engineering, procurement, construction management, and validation (Tebodin, 2014b). It is active in a wide range of markets, including industrial, health & nutrition, energy & environment, oil & gas, chemicals, infrastructure and property. Figure 1-1 shows where Tebodin’s is involved within construction projects according to Blanchard and Fabrycky (1998) system life cycle phases.

![Figure 1-1 System life cycle phases (Source: Blanchard and Fabrycky (1998))](image-url)
Tebodin’s project management department is responsible for the design & engineering of a project in any of these markets where they act on behalf of the client organization as construction manager (CM) during the construction phase, also known as EPCm (Engineering, Procurement and Construction management) contracts. With EPCm contracts, Tebodin is also responsible for managing the construction executed by sub-contractors, as opposed to EPC (Engineering, Procurement and Construction) contracts, where Tebodin itself carries out the construction. With these types of contracts, the project manager (PM) is involved during the life cycle of the project. The feasibility design, conceptual design and basic design belong to the front end loading (FEL) phase, which is the phase that prepares a project for execution. During this phase Tebodin’s PM is involved but not responsible.²

Tebodin’s aim is to further professionalize their construction management services and communication flow between the office and site². This research focuses on the risk management aspect, and the challenge is to explore the use and added value of currently used risk management procedures, to compare this with literature findings by conducting a gap analysis between the theory and practice and to investigate how the results can be developed into a risk management framework.

1.1 Reading guide
This thesis is divided into four parts.

![Problem]

The first part is theoretical and includes three chapters. Chapter 1 consists of an introduction, chapter 2 describes the problem analysis, and chapter 3 identifies the research objectives, questions and methodology.

![Analysis]

The second part includes two chapters and concerns the analysis. Chapter 4 presents a literature review on the development of risk management as part of project management, and compares theories with practical performance. In chapter 5 the results of interviews conducted with PMs working at consultancy & engineering company Tebodin are summarized to obtain an overview of the currently used risk management tools and methods, and an assessment is conducted. The analysis of the interviews and literature are used as input for the risk management framework.

![Solution]

The third part of the thesis includes two chapters presenting the practical results. In chapter 6 the conceptual model of the risk management framework is presented and each of the layers are explained, including three in-depth studies. Chapter 7 elaborates on the verification and validity of the research and chapter 8 describes the implementation in the organization.

![Conclusion]

The fourth part consists of chapter 9, which provides answers to the research questions and defines the scientific and practical contribution. The chapter specifies short term and long term recommendations, future research and explains the limitations and personal reflections on this research.

² Interview with Tebodin project manager
2 Problem analysis

This chapter explains the background by defining ‘risk’ and describing responsibilities for risk management in the construction industry and types of trade-offs between project drivers that need to be made. Finally, risk management challenges are explained, followed by the challenges that consultancy & engineering company Tebodin faces.

2.1 Definition of ‘risk’

To manage risks efficiently it is important to clearly define the word ‘risk’, and to demarcate the scope at which this is used in construction projects. From the literature it appears that there is no uniform or consistent usage of the word ‘risk’ (Al-Bahar & Crandall, 1990). In addition, most definitions of risk focus only on the downside associated with risks such as losses or damages, and neglect the positives or opportunities such as profit or efficiency gains. Risks can therefore be divided in two categories: risk threats and risk opportunities. Furthermore most definitions associate risk with having a probability and a certain impact on objectives. The Project Management Institute formulates a clear description that is commonly used:

“A risk can be described as an uncertain, future event, with a negative or positive impact on project promises” (PMI, 2004)

Uncertainty is a term often associated with risk, but these two terms should be distinguished and seen as two independent complex issues of their own. Both have an individual influence on project performance, thus providing a basis for future research and facilitating the development of tools for project management (Perminova, Gustafsson, & Wikstrom, 2008). Risks are events subject to known probability, whereas uncertainty refers to events for which it is impossible to specify numerical probabilities (Knight, 1921). A risk can be a schedule delay because of a late delivery of material, and an uncertainty can be a lightning strike into the plant that is being built. Knight implies their difference in measurability, while the PMI refers to the content of the risk event, as it might take place, or it might not. Even though uncertainties are unpredictable, the goal of managing risks is to be able to forecast future circumstances and how to react to them. However, not all risks can be thought of in advance, which indicates that uncertainty occurs.

A frequently used term is the notion of a ‘Black Swan risk’. In addition to being unpredictable like other risks, according to Taleb (2007) Black Swans contain three attributes:

• **Rarity** (it is an outlier, as it lies outside the realm of regular expectations, because nothing in the past can convincingly point to its possibility)

• **Extreme impact** (although probability is low, the consequences are extremely high)

• **Retrospective predictability** (in spite of its outlier status, human nature makes us concoct explanations for its occurrence after the fact, making it explainable and predictable)

An example of a Black Swan, where the risk event had a low probability and large impact, is the 9/11 terrorists attacks in 2001. The difficulty of managing risks like these is that they make what you do not know far more relevant than what you do know. Beforehand, this risk event was not foreseen, as the architects of the twin towers did not make a design resistant to an airplane crash. Therefore, the retrospective predictability aspect of the Black Swan is one that is particularly important to understand. Together, all black swans are negligible, because the chance they occur is minute. However, Black Swans continuously occur and one should not exclusively be occupied with Black Swans, because risks with a higher probability might then lack attention.

Bruijne, Koppenjan, and Ryan (2010) identify that governments increasingly seem unable to adequately assess and predict the risks that modern day society is exposed to. More specifically they state that many risks that are inherently present in large-scale infrastructure projects remain unobserved or unknown until
they occur. An example is the way the Dutch coastal areas are currently protected with storm surge barriers and dams to prevent flooding. These measures resulted from recommendations of the Delta Commission that was set up after the 1953 flooding in the southwest of the Netherlands, which killed over 1800 people (Brinke, Saeijs, Helsloot, & van Alphen, 2008). Since then, major measures have been taken to decrease the possibility of recurrence.

To assess and predict risks in the construction industry it is key to understand how risks can be well managed. In this research, the term ‘risk’ is intended the way the PMI describes it. Apart from defining the concept of ‘risk’, it is also important to know who in the construction industry is responsible for managing risks and how risks can have impact on a project’s objective.

2.2 Risk responsibility
At a consultancy & engineering company, the client, contractor or other stakeholders involved are responsible for managing risks that a project faces. A stakeholder, according to Freeman (1984), in an organization is any group or individual who can affect or is affected by the achievement of the organizations objectives. Within Tebodin, the construction and the project manager have separate roles, so it is important to define who is responsible for managing risks during the project life cycle.

During the life cycle of a construction project, the PM is responsible for delivering the end product in accordance with performance requirements, within the limitations of the budget, and within the time schedule that the company has specified (Gaddis, 1959). The role of the CM starts at project execution and concludes at the end of the project. The CM is responsible for inter alia, the overall management of field activities including all construction activities, field engineering, administration, interfaces with the client, field organization and supervision of the contractors’ activities and safety (Tebodin, 2011b). Therefore, CMs and PMs at Tebodin are involved at different project levels. Figure 2-1 illustrates the interface between the PM and the CM. The PM has to perform his job throughout the whole project, whereas the CM’s involvement starts with the construction phase.

![Project & construction manager’s roles in a project life cycle](image)

Having identified the roles for the construction and project manager, the challenge is to ensure that suitable risk management is carried out in collaboration during project execution, taking into account that in project phases different types of risk occur. According to Stanleigh (2010), if a risk management system is set up as a continuous, disciplined process of problem identification and resolution, such a system easily supplements other systems such as organization, planning and budgeting, and cost control. This means surprises of new risks are diminished because the emphasis is now placed on proactive rather than reactive management. Early identification and assessment of risks is essential to effectively manage risks. To ensure that risks are well managed, collaboration within the project team and between stakeholders is necessary to understand who bears responsibility.

Risks occur not only in large capital projects: while size can be one of the major causes of risk, other factors include complexity, speed of construction, location of the project and the degree of unfamiliarity with the client (Perry, 1986). Complexity is often related to the involvement of different stakeholders in a

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2 Functional descriptions according to the TQS
single project and large engineering projects contain many stakeholders. Other parties that can be involved or for some reason are affected by the project may be other (industrial) companies, government parties, NGO’s and communities such as local residents. The relationship with the client can also be complex. Clients and contractors view projects from different perspectives making it difficult to believe they are looking at the same phenomena (Merrow, 2011).  

2.3 Trade-offs between project drivers
From the beginning and throughout the life cycle of a project, risk management is a vital contributing factor to the success or failure of a project. Frequently, to decide on the trade-offs, a choice on what drives the project has to be made. The impact of risks on project drivers can affect the direction of the project objective. The Triple Constraint is an instrument that consists of three important project drivers: time, cost and performance (or quality). This helps the PM to focus on the expectations that are typically important to the client (Rosenau & Githens, 2005). When the schedule, for example engineering, slips the need to slow down a project is absolutely mandatory, and concrete plans on how to intervene is what is called risk management (Merrow, 2011). Another important project management driver that needs to be safeguarded is safety. All of these project drivers have influence on the decision-making process and indirectly force trade-offs to be made, since it is difficult to let drivers equally influence the project objective. How trade-offs are made tells us a lot about how decisions around projects are made; when priorities are not clear, the project team has difficulty establishing target dates for key activities and is less likely to have established team roles and responsibilities (Merrow, 2011). He describes that making trade-offs constitutes a fairly complex optimization problem, because this depends on various factors, such as the type of project, time, and uncertainty. If for example a sub contractor is given more time, the quality may not necessarily improve, as it might be that the sub contractor is poorly organized.  

Flexibility & control
The management of large engineering projects is often a combination of planning and control on the one hand, and the ambition to be flexible on the other hand given the complexity and uncertainties that characterize these kinds of projects (Koppenjan, Veeneman, van der Voort, Heuvelhof, & Leijten, 2011). Two perspectives are distinguished: the first perspective - predict-and-control - concerns predicting expected outcomes accurately and not changing the scope, while the second perspective - prepare-and-commit - encourages change to actually help the project, and exchanging information is more open and demand-driven between different groups. To manage large complex construction projects a combination of both perspectives is needed since both pro-active and reactive behavior to manage risks is necessary. Perminova et al. (2008) state that projects are better described as journeys of exploration in a given direction, rather than strict plan-following endeavors. Because projects are complex, the need for flexibility is emphasized. In the construction industry, therefore, the stakeholders and perspectives need to be taken into account when assessing risks and when managing and controlling a project.  

2.4 Risk management challenges
A clear explanation of the main challenge for risk management is given by Flyvbjerg, Bruzelius, and Rothengatter (2003), who discuss the contracting format. Because contracting in the infrastructure sector has to a large extent been on behalf of the public sector, the contracting format was rule-based and not performance-based. The contractor’s task is to build according to technical specifications and not necessarily to achieve a certain level of performance. However, this also means that the incentive and scope for developing new techniques in order to reduce costs, to reduce certain types of risk, and so on are limited. According to Flyvbjerg et al. (2003), the challenge for making a risk management plan is to actually fully identify the scope for risk management. Consequently, they conclude that present  

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Merrow is the founder and president of the independent project analysis (IPA), a global research and consulting company devoted exclusively to the understanding of capital project delivery organizations in the petroleum, chemicals, minerals, pharmaceutical and power industries.
contracting techniques to a considerable extent exclude the possibility of managing risks. Obviously many different types of contract now exist, and to elaborate further on this subject, section 4.3 is referred to.

**Tebodin’s risk management method**

Tebodin makes use of risk management methods. For example in their construction projects, a project risk register (PRR) is kept up to date and the main concerns are reported to the project team. Additionally, the PM or CM is responsible for undertaking a Risk Inventory & Evaluation (RI&E) that includes the identification of safety risks and control measures to eliminate or reduce the safety risks to as low as reasonably practicable (Tebodin, 2013). In the Tebodin Quality System (TQS) it states that a Chances & Risks list (C&R list) has to be updated on a regular basis during project execution and attached to the monthly progress report. The PM is responsible for updates, appointing risk owners and distributing the analysis to the office director, the department manager and the lead discipline engineers (Tebodin, 2013).

A risk assessment flow chart describes what the procedure of a risk assessment is, who is responsible and what type of documentation is required, such as a Probability-Impact matrix (P-I matrix), where the probability of the risk event is multiplied with the impact, used as a risk ranking system to assess the level of risks.

Regarding safety and risks, Tebodin goes into some detail on this topic. Where more than one contractor is involved in the construction phase, an overall Health & Safety (H&S) coordinator must be appointed under European legislation (EU-OSHA, 1992). The H&S coordinator is responsible for updating the H&S plan, implementing the plans, and maintaining the related files. The CM supervises the H&S coordinator. The CM organizes safety kick-off meetings, advises on H&S plans, carries out safety inspections and takes immediate action in any unsafe situation, monitors contractors’ compliance with their Health, Safety & Environment (HSE) obligations, sees to it that all persons on site follow the H&S rules, imposes sanctions, and is entitled to stop work if necessary. Construction sites are inspected daily by the CM and/or safety supervisor, bi-weekly by the managers of the contractors, by the Office Directors of Tebodin and by the client (Tebodin, 2014a).

**Challenges facing Tebodin**

The work of Ward, Chapman, and Curtis (1991) and Dunphy (1990) suggests that the successful implementation of a management technique, such as risk management, is amplified when a fit with the structural and cultural characteristics of an organization can be achieved. Identifying and keeping risks and chances up to date with the correct method is an aspect that is in need of research. According to Perminova et al. (2008), newly emerging trends in strategy, complexity of projects and internationalization are today’s project challenges. That does not necessarily mean that the number of risks that companies face is increasing, or that uncertainty is higher: the changes are qualitative rather than quantitative.

Criticism on current practices for qualitative risk management is described in “the failure of risk management” by Hubbard (2009). Issues he defines that might cause risk management to fail are: excluding the biggest risk, belief that quantitative risk analysis is not possible and not seeing risk opportunities. The challenge for Tebodin is to discover if they are confronted with these kinds of issues. Other challenges include investigating if the kind of practices currently used towards managing risks is effective. PMs at Tebodin are responsible for risk management, and an interface between the tasks of the PM and the CM is present. To investigate risk management challenges, a closer look at the gap between risk management theory and practice has to be taken.

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\(^5\) Interviews with Tebodin project managers and consultation of the TQS
3 Research

This chapter explains the research objectives, and elaborates on the scope, limitations and relevance. The research questions are clarified individually, and the methodology is explained, including the corresponding phases followed by the deliverables.

3.1 Objective and questions

At Tebodin, the PM deals with many risk issues during the FEL, the detailed engineering, and the project execution phase, concerning safety, quality, time and cost. The research objective is to analyze and improve Tebodin’s current risk procedures for EPC and EPCm projects, and to present a risk management framework, including an implementation strategy. To reach this objective, the following main research question is formulated, including sub-questions.

“How can a risk management framework in the construction industry be developed, and to what extent can this be implemented for EPC and EPCm projects at Tebodin?”

a) What is the discrepancy between the theory and practice of risk assessment in construction projects?
b) What are Tebodin’s risk management procedures in the chemical construction industry and to what extent is this in line with the evolution of risk management?
c) What does the conceptual model of the risk management framework look like?
d) How can a continuous improvement strategy in Tebodin’s EPC or EPCm projects be developed?
e) What recommendations can be given regarding implementing the risk management framework in the organization?
f) Is the framework applicable for risk management in the field of all Tebodin’s construction projects?

Scope

Learning how to deal with the complexity of construction projects, as well as project management is part of the master program Construction Management and Engineering at the Technical University of Delft; therefore a clear link between risk management in construction projects with the master program is visible. A systematic approach defines how the problem definition fits in the broader context. As risk management itself is a very broad subject, the aim of this research is to define the subject and to focus on construction industries and how to form the framework. The goal is to build a framework to be used by the project management team, specifically by the project manager, as at Tebodin he is also the risk manager and has many responsibilities during the project.

The scope comprises techniques and tools that implicitly or explicitly have to do with managing risks in a construction project of an EPC or EPCm contract carried out by the consultancy & engineering company Tebodin, as the company does not have a separate risk management procedure. The scope entails developing the most important points of improvement, which will be defined in this thesis. This means only a part of the framework is going to be developed, where the most improvement is expected.

Tebodin mostly makes use of EPCm contracts. However, the framework can also be applied for EPC contracts. Tebodin can be involved in different phases of the project; sometimes they are already involved before the design & engineering phase and sometimes also including commissioning or maintenance. A framework is designed on risk management during the FEL, project execution and evaluation phases. For some projects the framework can be used for only a part of the project scope, and other projects can use the framework for the entire project.

Limitations

It will be explored how what has been stated in the Tebodin manuals is actually implemented in projects and to compare theory versus practice. Comparing the use of existing tools and methods by PMs in one
particular industry is used to design the framework. In this research, risk management is analyzed in the construction industry, with an emphasis on the chemical construction industry because Tebodin often constructs chemical facilities and to be able to compare results within this industry. Taking into account the limited time, interviews with PMs who have affinity with the chemical construction industry are carried out to obtain sufficient data to analyze.

Regarding limitations of the research, three in-depth studies are carried out, which has the advantage that specific characteristics can be extensively analyzed (Christiaans, Fraaij, Graaff, & Hendriks, 2004). The in-depth studies require a qualitative research method and a descriptive way of investigating. In one of the in-depth studies a part of a current project is tested in an experiment. The other two in-depth studies are based on interviews and literature, which means implementation of those research parts has not been tested yet. To validate the presented framework, meetings with internal and external experts are organized to provide feedback. The personal judgments that are consulted provide useful information about the feasibility of implementation.

Relevance
As described in section 2.1, a risk is an uncertain, future event, with a negative or positive impact on project promises (PMI, 2004). Since risks may prevent objectives from being achieved or may allow to exploit opportunities, managing risks can be seen of utmost importance when carrying out projects. Literature confirms that no satisfying answer yet exists about the perfect risk management method for construction projects. When used, risk management practices seem to be working, and appear to be related to project success (Raz et al., 2002). Different tools have been developed to support the various phases of the risk management process (Raz & Michael, 2001). Tools, techniques, powerful computers, and software have made many seemingly impossible tasks easy to do but, until now, there has always been one thing missing from the risk toolkit: that is how to apply risk management (Hillson & Simon, 2012). Furthermore, according to Hubbard (2009), most managers do not even know when risk management fails, because they do not know what to look for when evaluating a risk management method and can be fooled by a “placebo effect” and groupthink about the method.

It is of added value to undertake an analysis of Tebodin’s risk management procedures to be able to identify gaps between the theory and practice. By using theoretical existing knowledge and studying current risk management procedures at Tebodin’s project management department, designing a suitable risk management framework contributes to practical work in projects and is expected to improve communication between parties.

3.2 Methodology
Theory from both a literature review and from the risk management description in the Tebodin manuals are compared with the reality acquired through interviews. This research is a normative study, because it is mainly based on values and value judgments. A qualitative method is used to study human behavior and behavior changes and because the information needed cannot be obtained well with quantitative methods. Qualitative research focuses on the context where certain behavior occurs instead of only quantitative data (Christiaans et al., 2004). The values of the researcher influences and defines the conclusions because the researcher continuously is constructing the research reality (Lincoln & Guba, 1985). The objective is to gain an understanding of underlying reasons and motivations and to interpret social interactions. Findings of qualitative research are exploratory and investigative (Johnson & Christensen, 2008).

The form of data collection contains interviews, reflections, and open-ended responses of a small, preselected group. The investigative research includes literature research, where existing data and developments are researched and discussed to show innovation of findings throughout the years. It is also used to compare current and earlier interpretations of findings with each other to understand
development. Together this forms the first, theoretical part of the research. The second, exploratory research component consists of in-depth studies that consist of analyzing shortcomings in a descriptive way. The reason for carrying out in-depth studies is to be able to develop an improvement strategy, with the help of an experiment, literature review and in consultation with Tebodin employees.

Based on the book of Verschuren and Doorewaard (1999), a research framework has been defined to explain the structure and working sequence. This contributes towards gaining a clear picture of the research project. As can be seen in Figure 3-1, three phases are distinguished. Table 3-1 shows the main question classified into sub-questions that are investigated in these phases. These questions collectively give answer to the main question.

Table 3-1 Main and sub-questions for every research phase

<table>
<thead>
<tr>
<th>Question</th>
<th>How can a risk management framework in the construction industry be developed, and to what extent can this be implemented for EPC and EPCm projects at Tebodin?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Phase 1</strong></td>
<td>Literature review and current practice at Tebodin</td>
</tr>
<tr>
<td>A</td>
<td>What is the discrepancy between the theory and practice of risk assessment in construction projects?</td>
</tr>
<tr>
<td>B</td>
<td>What are Tebodin’s risk management procedures in the chemical construction industry and to what extent is this in line with the evolution of risk management?</td>
</tr>
<tr>
<td><strong>Phase 2</strong></td>
<td>Risk management framework</td>
</tr>
<tr>
<td>C</td>
<td>What does the conceptual model of the risk management framework look like?</td>
</tr>
<tr>
<td>D</td>
<td>How can a continuous improvement strategy in Tebodin’s EPC or EPCm projects be developed?</td>
</tr>
<tr>
<td><strong>Phase 3</strong></td>
<td>Organizational implementation</td>
</tr>
<tr>
<td>E</td>
<td>What recommendations can be given regarding implementing the risk management framework in the organization?</td>
</tr>
<tr>
<td>F</td>
<td>Is the framework applicable for risk management in the field of all Tebodin’s construction projects?</td>
</tr>
</tbody>
</table>

**Phase 1: Literature review and from theory to practice**

In the first phase, a literature review is carried out to understand the evolution of risk management over the past couple of decades with literature specifically related to risk management in construction projects forming the main focus. The apparent discrepancy between theory and practice is clarified and shortcomings in risk management are explored.

To gain a broad overview of how risk management is carried out at Tebodin, manuals are consulted and interviews are held with Tebodin’s PMs who carry out construction projects in the chemical sector. The interviews are semi-structured, giving the interviewee the advantage to interactively converse with the interviewer and formulate flexible questions. In the interviews questions are asked about the use of risk
management techniques regarding time, cost, quality and safety. A comparison is made between the type of tools and techniques that are used by the PMs.

The results of interviews provide an insight into the conditions that must be met by the organization and defines the current way of carrying out risk management for construction projects. Research then is conducted to find out Tebodin’s position in relation to the established literature. The information about the used risk tools and techniques, retrieved from the interviews and literature review, are tested against a set of criteria, to compare and select adequate techniques, which are used as the input for the risk management framework. Furthermore preconditions are derived from the interviews, and are compared to the literature that is taken into account when designing the conceptual model.

**Phase 2: Risk management framework**

In the second phase the risk management framework is developed. Figure 3-2 shows the structure of the framework consisting of different components. The framework is developed based on the information retrieved in phase one. A bottom-up approach is presented where the risk management timeline is shown at the bottom layer. The second layer consists of the techniques linked to each other. The third top layer comprises in-depth development of risk management techniques.

In the third layer of the model, three in-depth studies are conducted. The in-depth studies are used to explore how a continuous improvement strategy in Tebodin’s EPC or EPCm projects can be developed. Understanding the context as an explanatory factor in organizational behavior can be of added value for comprehending why risks are or are not managed the way they are. By carrying out an experiment in one of the in-depth studies, the effect can be studied and the positive and negative aspects in the model can be explored and adjusted. The in-depth studies are used to answer the following questions about how to develop an improvement strategy:

- How can knowledge transfer between EPC or EPCm projects be improved?
- How can risk identification be improved?
- Are quantitative analyses recommended to continuously improve projects?

The aim of the continuous improvement strategy is to create awareness to the employees on how to integrate a risk management framework as part of project management. Interviewing the PM and conducting a survey through a questionnaire for the project management team to evaluate the effectiveness and suitability of a risk management technique, conclude the first in-depth study. Personal observation during a meeting concludes the effectiveness of the technique. The other two studies are explorative by researching literature about risk management techniques’ applicability and how they can
be integrated in the framework, making trade-offs. The preconditions that are derived from the interviews are used to verify the framework. To validate the framework, expert interviews are conducted.

**Phase 3: Organizational implementation**

The integrated framework should contain suitable procedures and should clarify how it can be implemented in the organization, which is explained in the third phase. The implementation plan requires defining what support is needed to use the tools, in other words, which departments and employees are involved and how information is transferred. Finally, the conclusions are drawn and recommendations given, based on all information retrieved during the entire research.

**Deliverables**

The design and implementation of risk management frameworks needs to take into account the varying needs of a specific organization, its particular objectives, context, structure, operations, processes, functions, projects, products, services, or assets and specific practices employed (ISO, 2009). With a research schedule of six months, the goal has to be feasible and the research question well defined in order to be able to perform an in-depth study, with a clear focus, without straying from the initial goal. The aim of this research is to identify the gap between theory and practice of risk management procedures and to introduce a risk management framework that can be implemented at Tebodin. By comparing existing theories and analyzing parts of the framework through in-depth studies, the focus is to identify shortcomings in Tebodin’s current procedures and give recommendations on how to improve this. The results are validated by internal and external experts, and are presented in this thesis.
Part II Analysis

The research analysis consists of chapters 4 and 5. Chapter 4 reviews literature on risk management in construction, and chapter 5 describes the interview results, conducts a technique assessment and summarizes the analysis.
4 Literature on risk management in construction

The aim of this chapter is to explain how risk management has emerged as an issue over the last decades and how it has become integrated in project management. In this chapter, risk management in general will first be reviewed, followed by the risk management literature specific to the construction industry.

As risk management can be applied to any project, this research concentrates on a single industry. The construction industry can be considered complex, with various stakeholders, from client to contractors to end-user and the public at large and can encompass transport, materials supply, construction, demolition, operation, maintenance and even the recycling and up-cycling of used materials. Different tools and techniques to manage risks are discussed in this thesis, including both quantitative and qualitative techniques. Figure 4-1 summarizes early risk management principles to current risk management perspectives specific to the construction industry.

![Figure 4-1 Literature structure](image)

4.1 Risk management evolution

Explaining the evolution of risk management requires a thorough literature review. As many authors have attempted to identify the need for risk management in projects, a shift in the past decades can be identified from traditional risk management to strategic risk management.

![Figure 4-2 Risk management evolution (source: Talbot and Jakeman (2009))](image)

As can be seen in Figure 4-2, three phases can be distinguished. These phases are defined by Talbot and Jakeman (2009) from their book about security risk management. Traditional risk management focuses on risks with a negative effect. Risks had to be avoided, mitigated or transferred. Incorporating risk in an organization could be seen as unwise. In the 1990’s, many contractors considered the main objective of risk management to be insurance management to find the optimal economic insurance coverage for the insurable risks (Al-Bahar & Crandall, 1990). The solution was to purchase insurance to cover risks, so the company could concentrate on more important matters.

Shifting from traditional risk management, in the second phase of risk management a broader meaning is established and integrated into the project lifecycle. Companies act proactively to managing risks; instead of transferring risks the risk manager may now become the risk owner. Techniques and tools become integrated in risk management, such as the Risk Breakdown Structure, which describes how to understand
risks. This structure guides the risk management process and provides new insights into overall risk exposure on the project (Hillson, 2002). Another example is given by Mills (2001) where the effectiveness of a systematic risk management approach is shown, consisting of risk identification, analysis and response to increase the control of the process.

The shift from integrated risk management to the third phase of strategic risk management goes a step further and incorporates risk management strategically. The focus is on optimization and the ability to respond to, and recover, risks. Risk management has, until recently, generally been considered as an add-on instead of being integral to the effective practice of project management (C. Chapman & Ward, 2003). High risk might be associated with high benefits, so trying to eliminate the risk can also reduce the payoff, thus, better than trying to avoid risk is to try to reduce it to a manageable level (Nicholas & Steyn, 2012). In the same way dealing with strategic risks by focusing on strategic objectives, the threat-based process can also be modified to address opportunities by including upside risks (Hillson, 2006). The change of integrating project threats as well as opportunities strategically into risk management can be considered of utmost importance and today companies emphasize a more holistic approach by integrating risk management into the project lifecycle. Figure 4-3 depicts the proposed project management model of Dey (2001) where risk management is incorporated in several stages in the process.

Summarizing, some big steps have been taken to insert the risk management process into project management. In addition, risks currently seem to be managed iteratively. The following section explains which stages have emerged in managing risks and how this has evolved similarly into a holistic approach.

The importance of risk management stages
During the past decades, a development has also taken place in the risk management approach. Not only were shifts identified in the integration of risks into project management, also changes in the analysis approach and adaptation are evident. Figure 4-4 depicts the most commonly used stages in the risk management approach. Previously, Perry and Hayes (1985) only considered the first three stages of managing risks. No attention was paid to the control stage. The tools and techniques that are used in each phase are discussed in section 4.4.
Perry (1986) however, identified four different stages to reduce or eliminate the effects of risk or uncertainty, and to ensure that the remaining risks are allocated to the parties in a manner likely to optimize project performance. Thus the importance was risk response and not so much risk control. According to the Project Management Institute the importance of the control phase phase is to ensure the project is successful in meeting the predetermined goals (PMI, 2004). Raz and Michael (2001) investigate the use and benefits of tools for project management and in which stages these tools are used. They conclude that tools in the risk control phase are perceived as low contributors to the risk management process. PMs might be willing to invest time and effort in the earlier phases of risk management, whereas the latter phases are considered less of importance. Currently, the additional fourth phase may be considered an important one. In the Project Management Book Of Knowledge, risk management is included as one of the nine important chapters of project management (PMI, 2004).

4.2 Gap between theory and practice

In the literature many theories can be found about risk management describing different tools and techniques applicable to manage risks. In practice, however, there is a clear gap between theory and practice of risk modeling and assessment (Taroun, 2014). Taroun’s findings refer to a heavy reliance on practical experience and professional judgment when assessing construction risk. Moreover, the actual use of the available tools and decision support systems is quite limited. Literature elaborates on whether experience in an organization is truly a predominant factor in assessing risks properly and this topic is also investigated through interviews with PMs of construction projects in the following chapter.

Explaining how to conduct a risk analysis seems easier in theory than is executed in practice. In the 1990’s Ward & Chapman had already identified that despite its obvious relevance and considerable interest, risk analysis involves a number of management techniques that are not as widely exploited as it might be (Ward & Chapman, 1991). Furthermore they give seven arguments why risk analysis fails in Figure 4-5.

Although these arguments seem quite strong, they are outdated and some can be invalidated. To prevent getting trapped in these types of failures, below an explanation is given whether these arguments stand firm and how they can be tackled.

1. Lack of awareness & 3. Risk analysis is unnecessary

A lack of awareness can be combined with the argument that risk analysis is unnecessary. This depends on a company’s risk culture. If a company is risk-averse, it might only see risks as threats and try to avoid instead of facing them. When a company is unconsciously risk-averse, one might say that considering risk analysis unnecessary does not create awareness to the fact how risks can influence a project. If a company is risk tolerant, the culture encourages managing risks. One might ask what the consequences would be if no risk analysis were used. Even if a company’s culture does not have a risk tolerant mindset, unconsciously PMs...
are engaged in risk management. An example is setting up a schedule including ‘float and slack’ or procuring a type of material to reduce costs, which indirectly is controlling time or cost risks.

2. Lack of expertise
A lack of expertise can similarly be blamed on a company’s culture. A company’s risk culture is a critical element where employees need to understand how to make educated risk-related decisions to ensure consistent risk behavior throughout the organization (Hoon & Farrell, 2009). Without training, there is no basis for critical thinking and judgment around risk decision-making. Taroun (2014) mentions that assessing risks relies on experience. As literature reveals the amount of attention brought to risk assessment, it would seem that companies intensify the awareness significantly. With the current awareness and expertise, more companies integrate strategic risk management into their project management. However, risk management can also be seen separate from project management. Hillson & Simon have developed the active threat & opportunities method (ATOM) strategy. The ATOM is based on executing seven phases from identifying, to assessing and controlling risks within a project (Hillson & Simon, 2012). This management approach can be seen separately from project management. One can say it is debatable whether risk management should be integrated or treated separately from project management to prevent lack of expertise. This topic is discussed during the interviews conducted for this research as well.

4. Lack of time
Lacking time to sufficiently assess risks can mean companies do not consider the consequences. If a company does not provide a good risk overview, eventually this can lead to more costs when a risk is not foreseen. As it is possible to integrate risk assessment into project management processes, the extra time is probably outweighed by the benefits. As long as the awareness is there, risks are assessed and they are kept track of; this will benefit the project success. This argument was first presented 23 years ago; at the time there were different laws and regulation. In the Netherlands, more attention is now paid to for example safe working conditions. In 2005 the Dutch Working Conditions Act (Arbowet) was adjusted to comply better with the European Framework Directive on Health and Safety. Furthermore action plans were set up for working in a safe environment such as the Labor Safety Action Plan (Actieplan Arbeidsveiligheid) (Rijksoverheid, 2012). This plan was executed between 2010-2012 and elaborates on increasing the safety awareness and improving safety behavior and culture at work. A change can be identified in the amount of laws and regulation concerning safety, which has increased and forces companies to spend time on assessing certain safety risks.

5. Difficult- or impossible to quantify risks
Ward & Chapman proved that some risks are difficult to quantify. However, requiring risks to be quantifiable is not impossible. Several researchers have come up with fuzzy sets theories to be able to quantify risks. As Nieto-Morote and Ruz-Vila (2011) describe, many risk assessment approaches have been based on using linguistic assessments instead of numerical values, such as low probability, serious impact, or high risk. A fuzzy sets theory provides the means by which these terms can be formally defined in mathematical logic. Several models have been proposed, such as Carr and Tah (2001) who apply a formal model based on a hierarchical risk breakdown structure. They define risks using linguistic variables and using fuzzy approximation and composition, and doing so, the relationship between risk sources and the consequences on project performance measures can be identified and quantified consistently. In addition, Zeng, An, and Smith (2007) suggest a risk assessment model based on fuzzy reasoning and use a modified analytical hierarchy process to structure and prioritize risks considering three risk parameters. Besides risk likelihood and risk severity, a factor index is introduced to structure and evaluate factors that can lead to project failure and to integrate them into the decision making process of risk assessment. Using fuzzy sets theory can change qualitative risks into quantifiable numbers.

6. Mistrust of risk analysis
According to this argument, real risks are those that are unanticipated and are not included in any analysis. Analyzing the wrong risks indicates a lack of expertise. One of the aims of analyzing risks is to be able to get
an overview of all project risks and to include all of them and to come up with mitigation actions. Carrying out a thorough analysis already emphasizes the need to think about possible risk events.

7. Risks will be borne by other parties
In multiparty projects, any party may perform risk analysis, each with their own perspective of the project and its attendant risks (Ward & Chapman, 1991). When a project is tendered, contractually risks are allocated to the client or the contractor. Besides contractual risk allocation, during the project communication between parties ensure that the right party is responsible for the risk. It is therefore important to allocate the risk to the party that is most skilled in controlling and monitoring the risk. Within the project team, it should also be defined who is responsible for mitigation actions.

Identified gap
Responding to Ward & Chapman’s arguments, it seems that the gap between theory and practice should not be as big as thought. However, even though many tools, techniques, powerful computers, and software have made seemingly impossible tasks easy, until now, according to Hillson and Simon (2012), there has always been one thing missing from the risk toolkit, and that is how to apply risk management. Many researchers identify experience as an important tool when assessing risks. Risk management in most circumstances is an unstructured activity based on common sense, relevant knowledge, experience and instinct (C. Chapman & Ward, 2003).

The cause of this gap between theory and practice lies within the relationship between knowledge and behavior. According to Kwakman and van den Berg (2004), the assumption is that good knowledge, i.e. knowledge that is obtained through scientific research, is naturally applied in practice. At the same time, literature on organizational change has shown that this does not occur in this way, because action is not just influenced by knowledge, but especially by concepts. Knowledge concepts can be acquired through experience and lead to obtaining implicit knowledge. Implicit knowledge is personal knowledge that individual employees acquire through experience and which through the context specific character is difficult to transfer. This is also called tacit knowledge (Polanyi, 1967). The difficulty about tacit knowledge is that it is not easy to transfer. It is something one gains through years of experience. Although overlooked, human and social factors play vital roles in technological systems, real world risks are indeed often dominated by them (Freudenburg, 1988).

4.3 Managing risks in the construction industry
So far, risk management has been discussed regarding project management in general. This chapter explains why the construction industry in particular is interesting and why it actually lacks behind in risk management compared to other industries.

The Construction Industry Institute (CII) distinguishes three levels of project risk analysis; identification, deterministic and probabilistic analysis (CII, 2012). For each level, it is explained what the benefits and results of the analysis are. However, it also defines what the limitations are and which requirements are needed. Appendix A presents a table with project risk analysis levels, and is used as benchmarking later in this research.

Risk management is particularly pertinent to construction projects because risks occur during the execution of a construction project, not only for the contractor, but also the project owner and other stakeholders play an important role in risk management. The project-shaping role for risk analysis can be particularly
important in projects that involve more than one organization or contracting party, as in the case of most engineering and construction projects (Ward & Chapman, 1991). An integration manager in each team, which has to be staffed by experienced people who are excellent communicators, is very important (Merrow, 2011). Ward and Chapman (1991) explain that each party having their own risk management perspective can lead to a principal-agent relationship, which on the one hand can lead to an agency problem when the goals of the principal and the agent conflict. On the other hand it can lead to a risk-sharing problem when both parties have different attitudes to risk, leading them to prefer different courses of action. The client should be kept up to date with risk registers, and other stakeholders such as municipalities or nearby residents or firms should be informed. Communication between different parties and stakeholder management can be considered an important aspect when managing risks.

As multiple parties are involved in a construction project, Ward & Chapman depicted a figure demonstrating at which stages risk analyses could be carried out (Ward & Chapman, 1991). Figure 4-6 illustrates the possible locations for risk analysis in a multiparty project. It shows that the risk analysis is a recurring process during the project, carried out by both the client and the contractor.

The reason why it is interesting to investigate the construction industry is explained through its complexity. Another reason why this industry is interesting for research is because it seems to lag behind in terms of applying risk management. In the construction industry risk analysis is based on intuition and experience, and it is the least developed industry when it come to the application of formal risk pricing techniques, compared to the finance and insurance industry (Laryea, 2008). Several authors attempt to provide reasons for this. Perry and Hayes (1985) say that techniques for risk analysis have been theoretically established for a number of years, but their practical application to construction projects has been limited, confined mainly

Figure 4-6 Possible locations for risk analysis in a multiparty project (source: Ward and Chapman (1991))
to the larger multi-disciplinary clients in the private sector and a few specialist or large multi-disciplinary consultants. Uher and Toakley (1999) identify a relatively low level of application of risk management in the conceptual phase of a construction project. As reasons, they identify low knowledge and skill base, resulting from a lack of commitment to training and professional development. Risk analysis and management techniques are moreover rarely used by the Florida contractors due to a lack of knowledge coupled with doubts on the suitability of these techniques for the construction industry (Ahmed, Azhar, & Ahmad, 2004). The main barriers preventing implementation of formal risk management practices were found to be lack of knowledge and doubts about the suitability of these techniques, sophisticated nature of techniques compared to project sizes and human and organizational resistance (Azhar, Ginder, & Farooqui, 2008). It can be concluded that the construction industry lags behind, partly due to its complexity, and due to the lack of understanding the suitability of techniques. As multiparty projects contain multiple stakeholders, the following section explains two different types of construction contracts and the client and contractor’s roles.

Construction contracts
In the construction industry risks are managed in different stages depending on the type of contract and the responsibilities of the parties involved. A change can be noticed because of new types of contracts being used. The introduction of new procurement methods means that contractors have to rethink their approach to the way risks are treated within their projects and organizations (Carr & Tah, 2001). Two types of contracts commonly used for engineering projects are the EPC and the EPCm contracts. The basic structure of the two contracts are shown in Figure 4-7 and Figure 4-8 are depicted by Cullen and Higgins (2011). The difference is that under an EPCm contract, other parties construct the project; the EPCm contractor is not the builder/constructor, but he develops the design and manages the construction process on the owner’s behalf.

An EPC contract consists of Engineering, Procurement and Construction. The lump sum EPC option where the owner agrees to pay a contractor a fixed sum for completing work without requiring a cost breakdown, usually remains the most desired procurement route for owners (Loots & Henchie, 2007). EPC lump-sum contracts always include powerful incentives to minimize cost, as any money saved is profit earned for the contractor (Merrow, 2011). Figure 4-7 shows the owner-contractor relationship in an EPC contract.

![Figure 4-7 EPC arrangement (Source: Cullen and Higgins (2011))](image)

Loots & Henchie also identified that in recent years an increase in cost reimbursable contracts (usually with a target price pain/gain share mechanism built in) and a significant increase in the EPCm contract procurement route can be noticed for international infrastructure and major construction works inter alia in the petrochemical industry. Reimbursable contracting is by far the most flexible approach for owners, where they have complete control over schedule and quality (Merrow, 2011). The services to be performed under EPCm contract are Engineering/design, Procurement and Construction management.
Risk liability between client and contractor

The type of contract determines to what extent the contractor is liable for time, cost and quality concerns. Loots and Henchie (2007) explain that, depending on the contract, risk issues are managed differently. An EPCm contract is a professional services contract, which has a radically different risk allocation and different legal consequences. In an EPCm contract where responsibility is split for engineering and construction, the owner ought to be more pro-active in its management of the project. Projects with inherent risks are tilted toward reimbursable forms because owners and contractors are much less likely to be able to agree on a lump-sum price when execution is uncertain (Merrow, 2011).

Throughout the project, responsibilities are complied with and the contract is used as reference to fall back on. When it comes to perceptions of risk, owners and contractors live in separate worlds (Merrow, 2011). Owners complain that contractors do not want to take any risk, and when they do, they want inordinately high prices for it, while contractors believe that owners are pushing them to bet their business on every project (Merrow, 2011). It can therefore be concluded that the contractor party and client at the start of a project should be aware of their risk responsibilities and a clear distinction is made between risk liabilities.

Risks belong to a certain party during a project depending on the contract type. Two types are explained but there are more ways to transfer risks. Many clients for example continue to transfer risk to contractors through design-and-build contracts, arguably giving contractors greater control over projects. A target price contract has helped control costs on for example the £4.2bn Heathrow Terminal 5 (Building, 2007). Under target cost contracting, a fixed target cost is set based on given parameters at the outset. If this fixed target is exceeded or undercut, the outcome is split between the contracting parties in a pain/gain sharing fashion calculated using a share ratio formula agreed at the start of the contract (Wong, 2006). The contractor then has incentives to save money by being efficient and risks are divided within both parties.

The construction industry concerns wide-ranging risks to be shared between client, engineer and contractor. This research focuses on how Tebodin manages risks in EPC and EPCm contracts. In the next section the types of risk management methods, tools and techniques from the literature are explained, before defining the risk management procedures at Tebodin.

### 4.4 Risk methods, tools & techniques

In this section different risk methods, tools and techniques are described based on a review of the literature. The aim is to compare different existing risk management methods, and to summarize the most important risk management tools and techniques relevant for EPC and EPCm contracts. In the following chapter the results of the conducted interviews are described and are compared to the existing literature.

<table>
<thead>
<tr>
<th>Method</th>
<th>Technique</th>
<th>Tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>“A method is a particular procedure for accomplishing or approaching something, especially a systematic or established one.” (OxfordDictionary, 2013)</td>
<td>“A technique is a skillful or efficient way of doing or achieving something.” (OxfordDictionary, 2013)</td>
<td>“A tool is an implement used for a specific purpose. A tool can be a physical object or a technical object such as a software program.” (BusinessDictionary, 2014b)</td>
</tr>
</tbody>
</table>
Table 4.1 shows the definitions of a method, a technique and a tool. This distinction is made because in this chapter methods are looked at containing an individual methodology with steps to manage risks, whereas the tools that are described are instruments used in the form of fill-out forms, documents, software programs or workshops that are a guidance to the techniques used in a method. The techniques are ways to help conduct one or more steps of a method. For example a method could be ATOM (active threat & opportunity method), a technique that is used in that method could be Monte Carlo, and the tool used to simulate could be @risk (a software tool that supports Monte Carlo simulations).

**Risk management methods**
Methods are the guideline for every step that needs to be taken in the procedure. To present a risk management framework, research is conducted on several existing risk management methods, which are compared to each other. Of the numerous risk management methods that can be found in literature, four recently developed methods are discussed, and compared to each other. These are the Risk Management Process by PMI (2004), a Risk Management Process by Gray and Larson (2008), the ATOM by Hillson and Simon (2012) and the RISMAN method by van Well-Stam, Lindenaar, van Kinderen, and van den Bunt (2013). Every method includes the main risk management phases that were described in section 4.1. In Appendix B: Risk management methods, an illustration and explanation of these methods are given. By comparing the steps that are taken in the different methods, a global structure is created that fits the process of managing risks in the construction industry. Figure 4-9 depicts the risk management structure. The first four of these phases are described in the methods in Appendix B: Risk management methods. The fifth phase, risk review, is included because two of these methods (ATOM and the Risk Management Process by PMI (2004)) contain this phase, which closes the risk management loop.

![Figure 4-9 Global framework for a risk management method](image)

The global framework illustrates the phases that are included when managing project risks. To make a selection of tools and techniques that support the method, each phase is separately clarified. In literature, the most research is found on risk identification and risk assessment. Figure 4-10 illustrates the difference of outputs of qualitative and quantitative analyses that are connected to the risk identification and the risk assessment phase.

Qualitative risk analysis is described as addressing, assessing and prioritizing risks leading to quantitative risk analysis. Because these two analyses are used sequentially, **risk identification** describes qualitative risk management techniques and **risk assessment** describes quantitative risk management techniques. Useful techniques are researched by reviewing literature and consulting case studies on construction related tools and techniques from different researchers.
A. Qualitative risk identification tools and techniques

Numerous tools are available to support the various phases of the risk management process (Raz & Michael, 2001). As described in section 3.2, risk tools support the method used. From a literature review, a selection is made of qualitative techniques and tools that are frequently used to identify risks and which researchers have investigated as suitable. A distinction is made between techniques that are used to identify and assess risks, and the tools that can be used to support these techniques.

Techniques:

- **Project analogy** (Nicholas & Steyn, 2012)
  This technique consists of scrutinizing records, post-completion summary reports, and project team members’ recollections from earlier analogous projects to identify risks in new, upcoming projects.

- **Brainstorming** (PMI, 2008); (Nicholas & Steyn, 2012)
  This technique has the goal to obtain a comprehensive list of project risks. It is part of the risk inventory & evaluation (RI&E) method and is used at the conception phase of a project carried out collectively by the project management team members.

- **Delphi technique** (Dalkey & Helmer, 1963)
  This is a group survey technique where the opinions of several people are combined to develop a single judgment. Anonymous responses are given, and the process continuous until the group reaches a collective opinion. The method sought to obtain the most reliable consensus of opinion of a group of experts through a series of intensive questionnaires interspersed with controlled opinion feedback.

Tools:

- **Checklist** (Nicholas & Steyn, 2012)
  This tool is originally created from the experiences from past projects, and is updated as new experience is gained from recent projects. While a checklist cannot guarantee that all significant risk sources in a project will be identified, it does help ensure that the important known ones will not be overlooked.

- **Work breakdown structure** (Nicholas & Steyn, 2012)
  This tool contains a work breakdown structure (WBS), where every work package is scrutinized for potential technical hurdles or problems with management, customers, suppliers, equipment, or resource availability.

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6 Concluded from the articles and books of the following researchers: Perry and Hayes (1985); Ward and Chapman (1991); Akintoye and MacLeod (1996); Tah and Carr (2001); Chapman and Ward (2003); Zeng et al. (2007); PMI (2008); KarimiAzari, Mousavi, Mousavi, and Hosseini (2011); Thaleem, De Marco, and Barlish (2012); Nicholas and Steyn (2012); De Marco and Thaleem (2014).
• **Process flowchart (Nicholas & Steyn, 2012)**
  This tool illustrates the steps, procedures, and flows between tasks and activities in a process. Examination of a flowchart can pinpoint potential trouble spots and areas of risk.

• **Cause-and-effect diagram (Ishikawa, 1982)**
  This tool can be used to record risks and place them on a cause-and-effect diagram (C&E diagram). It can either give an identified, potential effect to identify potential causes, or it can give a cause to identify the effects.

• **Risk breakdown structure (Tah & Carr, 2001); (Hillson, 2002); (Mehdizadeh, 2012)**
  The risk breakdown structure (RBS) is a tool that is used to decompose risks. It arranges identified project risks by risk categories and subcategories that identify the various areas and causes of potential risks. It groups the identified risk events into different levels following a bottom-up approach.

These qualitative risk identification tools and techniques are a selection of the many in existence. Of the risk identification techniques, checklists, brainstorming and flowchart were most commonly used in a study of risk management in the Australian construction industry (Uher & Toakley, 1999). The selection is based on literature review and description by researchers about suitability and use in construction projects.

**B. Quantitative risk assessment tools and techniques**

Also quantitative risk assessment tools and techniques are explored that are frequently used in construction projects and seem to work well. The benefit of quantitative risk tools are that they can provide answers to questions like probability of reaching targets and amounts of contingency needed and no ambiguous categories are used but reports are based on numbers and facts to estimate probability and impact (Verbraeck, 2013).

**Techniques:**

• **Risk inventory & evaluation (Nicholas & Steyn, 2012)**
  The risk inventory & evaluation (RI&E) technique uses tools to identify risks, assess risks, plan risk response and track and control risks. To identify risks, a brainstorm session can take place. The probability-impact (P-I) matrix is used to assess risks, and rate the risks with a selected impact scale and identify the risk factor or risk consequence. The risks are placed in a risk register rank-ordered with the greatest risk consequence first. Risk actions are defined and controlled.

• **Expected value (Nicholas & Steyn, 2012)**
  The expected value (EV) technique represents the average outcome of a project if it were repeated many times, accounting for the possible occurrence of risk. Mathematically, it is the weighted average of all possible outcomes, where the weights are the likelihoods of the possible outcomes (EV=Outcome*Likelihood). The EV can be the risk consequence for time or cost.

• **Monte Carlo analysis (Perry & Hayes, 1985)**
  The Monte Carlo simulation technique can be used to account for risk in project scheduling, and to estimate additional time needed to compensate for risks in meeting project deadlines by running the project many times generating output on time and cost.

• **Program evaluation and review technique (Fazar, 1959)**
  The program evaluation and review technique (PERT) is used to account for risk in project scheduling. It accounts for risk by using three time estimates for each project activity (optimistic, most likely, pessimistic times).

• **Sensitivity analysis (Perry & Hayes, 1985); (Perry, 1986)**
  This technique seeks to place a value on the effect of change of a single variable within a project by analyzing that effect on the project plan. The effect of change on the final cost or time criteria is assessed in turn across the assumed ranges. A series of deterministic estimates is produced. The results indicate the most sensitive or critical areas for management to direct its attention towards.
• **Fuzzy approach** (Carr & Tah, 2001)
  This technique defines risks using linguistic variables and using fuzzy approximation and composition. The relationship between risk sources and the consequences on project performance measures can be identified and quantified consistently.

• **Technique for order preference by similarity to ideal solution** (Pohekar & Ramachandran, 2004); (KarimiAzari et al., 2011)
  The fuzzy technique for order preference by similarity to ideal solution (TOPSIS) approach is developed with an effective algorithm to improve the quality and effectiveness of decision-making. It is a multi criteria decision-making (MCDM) method based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest from the negative ideal solution for solving multi criteria decision-making problem. For benefit criteria the decision maker wants to have maximum value among the alternatives and for cost criteria he wants minimum values amongst alternatives.

• **Analytical hierarchy process** (Saaty, 1980); (Dey, 2001); (Pohekar & Ramachandran, 2004); (Figueira, Greco, & Ehrgott, 2005); (Zeng et al., 2007)
  The analytical hierarchy process (AHP) is used to structure and prioritize diverse risk factors. It uses pairwise comparisons along with expert judgments to deal with the measurements of qualitative or intangible criteria. A complex problem is decomposed into a hierarchy with goal at the top, criterions and sub-criterions at levels and sub-levels, and decision alternatives at the bottom of the hierarchy. It is a MCDM methodology that allows subjective as well as objective factors to be considered in project risk analysis. The AHP allows the active participation of decision makers in reaching agreement.

**Tools:**

• **Decision trees** (Perry & Hayes, 1985); (Perry, 1986); (Dey, 2001); (Nicholas & Steyn, 2012)
  Decision tree is a tool that uses diagrams where the tree branches represent different chance outcomes to assess which risk responses among alternatives yield the best-expected consequence. With the decision tree a decision is made between alternative risk responses. It shows the present possible courses of action, and all future possibilities, whereby strategies are compared to each other to resolve interrelated risks.

• **Payoff tables** (Nicholas & Steyn, 2012)
  This tool is used when no information is available about what might occur, then the best strategy is determined under uncertainty. With a payoff table, the outcomes for different combinations of strategies and alternative paths are represented. The tool summarizes pros and cons of a decision in a tabular form.

For these quantitative tools and techniques it appears that many more exist and the choice to include the selected ones is based on literature review and description by researchers about suitability and use in construction projects. To validate this choice the chosen techniques and tools are presented to external risk experts and feedback is asked, which is clarified in section 7, verification and validity.

**C. Risk response methods**

Figure 4-11 depicts that risk response can be categorized into a response for either a threat or an opportunity. Instead of suggesting tools and techniques, mainly strategies are discussed in literature. Depending on the probability and impact, threats can be avoided, transferred, mitigated or accepted and opportunities can be exploited, enhanced, shared or accepted (Hillson, 2004). When using the transfer response, risk can be transferred between customers, contractors, and other parties using contractual incentives, warranties, penalties, or insurance (Nicholas & Steyn, 2012).
The importance of risk response methods is that the correct measure is taken. Especially in construction projects, where an easy way out seems to transfer risks to the client or to insurances, having control enables the risk owner also the flexibility to react. It is economically rational for the contractor to seek to find ways of mitigating those risks (Merrow, 2011). For each risk a strategy should be selected. Secondary risks (risks driven by the strategies) should also be reviewed (PMI, 2008).

D. Risk control
To control risks, an iterative process has to take place. By using the RI&E method risks are monitored and controlled. By keeping risk registers up to date several times during the project, risks are continuously managed. Tools and techniques suggested by the Project Management Institute for risk control are risk reassessments, risk audits, variance and trend analysis, technical performance measurement, reserve analysis and status meetings (PMI, 2008).

Raz and Michael (2001) conducted a questionnaire-based survey among PMs from the software and high-tech sectors in Israel and investigated their use of tools in different phases of risk management. The tools in the risk control group are perceived as small contributors to managing risk. They concluded that either there are no effective tools or risk control, and that the tools offered in the literature are not adequate, or it is related to management culture according to which PMs might only be willing to invest time and effort in the earlier phases of risk management, which are carried out in conjunction with other project planning activities. Risk control tools are used sporadically or not at all, and their contribution is rated as low. The added value of risk control is to be able to monitor risks during the entire project to foresee situations and to prevent unexpected circumstances.

E. Risk review
The last phase consists of post-project reviews. This retrieves lessons learned and historical information. The strengths of post-project review according to Mehdizadeh (2012) are that it leverages previous experience, prevents making the same mistakes or missing opportunities twice and enhances organizational process assets. On the other hand, Mehdizadeh also identifies weaknesses regarding the limitation to risks that have occurred previously, the frequently incomplete information: details of past risks may not include details of successful resolution, and the fact that ineffective strategies are rarely documented.

Summary
In the global risk management framework, the fundamentals of risk management concepts and analytical tools and techniques were presented. For each of the five phases, the results from this research were presented and are summarized.
Risk identification: From the literature review, a selection of qualitative risk identification tools and techniques are explained.

Risk assessment: From the literature review, a selection of quantitative risk assessment tools and techniques are investigated and explained for modeling risk.

Risk response: To respond to risks, strategies are presented as opposed to techniques and tools. The strategies for risk response lead to measures that need to be taken.

Risk control: A few identified control techniques are mentioned from literature. The control phase follows up the response phase to see whether strategies are actually carried out and monitored.

Risk review: To review risks, in the literature post-project review has been suggested and the added value is explained.

The next chapter elaborates on the interviews that were conducted with PMs at consultancy & engineering company Tebodin, to identify how procedures and techniques are used in the industries for which the company functions as the EPCm contractor for a client. Subsequently, the described tools and techniques are assessed to discover their use and added value for the construction industry more generally, and to be able to compare them to each other to define what fits within Tebodin.
5 From theory to practice
The previous chapter provided an overview of the existing literature and theories on construction risk management. The current chapter presents the results from conducting interviews with PMs to gain a broad range of information on risk management in construction projects in the chemical sector within Tebodin, as this sector is one of the larger sectors for Tebodin.7

Besides the consultation of Tebodin manuals, interviews were carried out to understand how risk management is carried out in practice. The interviews add value to the overall analysis by revealing how risks are managed in practice and can be compared to theory derived from literature review.

5.1 Interview objectives
The interviews with Tebodin’s PMs focus on a single industry to ensure that the information used for comparison is coherent. Tebodin’s PMs are frequently required to carry out projects across multiple industries and have been selected according to their affinity and experience with the chemical industry. The chemical construction industry was selected, as the perception within Tebodin is that the willingness and ability to accept change is considered the norm in this industry.8 The primary aim of the interviews is to retrieve new information. The later interviews will predominantly serve to confirm the information previously gained. Whilst it is difficult to determine the exact number of interviews that need to be conducted, seven interviews with PMs who have affinity and experience with the chemical industry are considered sufficient to gather all the information required. Two reserve interviews have been specified should it become apparent that more research material is required.

The interviews are semi-structured, giving the interviewee the flexibility to interactively converse with the researcher. This interview technique uses a certain degree of predetermined order of questions but still ensures flexibility in the way issues are addressed by the informant (Dunn, 2005). The advantage of using semi-structured interviews, rather than fully structured or unstructured ones, is that the researcher is able to formulate flexible questions and explore in more depth certain topics about which the interviewee has particular knowledge or experience. The disadvantages according to Mitchell and Jolley (2004) are that data from follow-up questions can be difficult to interpret, as not all follow-up questions will be similar. Follow-up questions may provide the researcher with more scope to introduce bias, shaping further questions to obtain particular answers. The researcher therefore has to stay as neutral as possible. One of the risks of conducting a semi-structured interview is the production of biased information. To eliminate this risk, the results of each interview are summarized and returned to the interviewee after the interview. The interviewee can then comment on the summarized interview, and the comments are taken note of. With the interviewees’ feedback, the summary is rewritten and sent back.

Table 5-1 Tebodin interviewees

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Current project</th>
<th>Sector</th>
<th>Tebodin experience</th>
<th>Interview date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>A</td>
<td>Health &amp; Nutrition</td>
<td>6 years</td>
<td>04-04-2014</td>
</tr>
<tr>
<td>2.</td>
<td>B</td>
<td>Chemicals</td>
<td>8 years</td>
<td>08-04-2014</td>
</tr>
<tr>
<td>3.</td>
<td>C</td>
<td>Chemicals</td>
<td>16 years</td>
<td>11-04-2014</td>
</tr>
<tr>
<td>4.</td>
<td>D</td>
<td>Chemicals</td>
<td>6 years</td>
<td>14-04-2014</td>
</tr>
<tr>
<td>5.</td>
<td>E</td>
<td>Chemicals</td>
<td>32 years</td>
<td>16-04-2014</td>
</tr>
<tr>
<td>6.</td>
<td>F</td>
<td>Chemicals</td>
<td>25 years</td>
<td>16-04-2014</td>
</tr>
<tr>
<td>7.</td>
<td>G</td>
<td>Chemicals</td>
<td>1 year</td>
<td>16-04-2014</td>
</tr>
</tbody>
</table>

The interviews were conducted with Tebodin’s PMs who have affinity with the chemical sector. In Table 5-1 the list of seven interviewees is given in the sequence the interviews were taken. The sector at which the PMs are carrying out their current project is mentioned, as well as the years of experience the PMs have, working at Tebodin.

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7 The Tebodin sales results of the second quarter in 2014 present the chemical sector with the highest sales
8 Interview with Tebodin project manager, see Appendix D: Interview summaries
The aim of the interviews is to objectively retrieve information about Tebodin’s current risk management practices. The subjects that are discussed in the interview can be found in Appendix C: Interview structure, and act as a guideline for the interview. The subjects concern managing risks in safety, cost, time and quality of the project. Tebodin often acts as the link between client and sub-contractors. To understand what their role is and how they, as PMs, interact with those parties, they are questioned about their experience and opinions. Depending on the interviewee’s responses, certain subjects may vary per interview. With this inductive research approach, specific observations are interpreted to formulate broader generalizations and theories. Results are evaluated, summarized and developed into a set of preconditions, which the interviewees have acknowledged as representing improvements for important shortcomings in the current risk management procedures. Comparing these preconditions with the literature tests the extent to which the information retrieved from the interviews are integrated as input for the risk management framework.

5.2 Overview of Tebodin’s risk-related techniques
This section presents the main findings about the risk management techniques used at Tebodin and explains their added value. The interview summaries can be found in Appendix D: Interview summaries. The interviewees approved these summaries, after having given their feedback. Consequently, preconditions from the interviews are adopted and explained, after which they are compared to literature findings.

During the interview, the PMs identified techniques that they use to manage risks. Some not always explicitly manage risks; therefore, both techniques that explicitly and implicitly manage risks are included, but only those where the PM is actively involved are discussed. Techniques like failure mode and effect analysis (FMEA) or hazard and operability study (HAZOP) for example, which engineers carry out in the design phase to examine the safety and robustness of the design, are not included in the technique list.9

Timeline
The techniques used by Tebodin are summarized in a project’s timeline, shown in Figure 5-1. In the timeline the techniques are positioned according to their project drivers. Throughout the time course of a project, the level of detail increases (for example cost estimates). To complete the overview, Tebodin management has been asked to give feedback on the figure.10 This resulted in the insertion of five additional currently used forms that have a section that talks about risks, and for which the explanation the List of abbreviations and terms on page vii is referred to:

- A-form & B-form
- Business concept
- Project plan
- Gate review
- Close out report

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9 Interview with Tebodin project manager, see Appendix D: Interview summaries
10 Personal communication with Tebodin’s head of project management department
The first three phases of the overview consist of FEL phases. FEL refers to the work process needed to prepare a project for execution, and is typically divided into phases with a pause for an assessment and decision about whether to proceed (Merrow, 2011). It is the process by which a company develops a detailed definition of a capital project to meet business objectives (van Elderen, 2009). During the FEL, questions like “Why? What? When? How? Where? Who?” are answered by setting up a feasibility design, a conceptual design and a basic design. Depending on the contract type, Tebodin can be involved at the start of one of the FEL stages or at the project execution. All techniques are clarified by giving a short explanation based on the information retrieved from the conducted interviews with PMs (for the interviews, see Appendix D):

- **Risk inventory & evaluation as part of the health & safety plan**
  The risk inventory & evaluation (RI&E) is a technique that is included in the health & safety plan (H&S plan), which describes safety risks during construction. Before the start of construction the RI&E session is conducted and risks are kept up to date in a Project Risk Register (PRR) until the end of the project. A probability-impact (P-I) matrix indicates the risk rate and ranks the risks. Then mitigation actions are connected to the risk event and action holders are appointed to those actions.

- **Task-risk analysis**
  A task-risk analysis (TRA) is conducted when the CM, safety supervisor and contractor conclude that a high-risk task is present. It is carried out for a specific task that concerns safety risks. It is then defined how to mitigate or eliminate the risks. TRA’s are carried out in order to receive a permit.

- **Last minute risk analysis**
  A last minute risk analysis (LMRA) is carried out right before the start of a task, concerning safety aspects of that task.

- **Constructability review**
  A constructability review is carried out before the start of construction during the design & engineering phase, to limit risks during construction. With multidisciplinary projects a constructability

---

**Figure 5-1 Timeline of Tebodin’s risk-related techniques**
review defines if the object is possible to build and what the consequences for other workforces are (interface management).

• **Design review**
  During a design review representatives of every department (lead engineers) go through the design to see if there are any mistakes. Design mistakes can have effect on costs, but also on quality and safety.

• **S-curves**
  With S-curves the financial forecasts are made to identify the weekly used hours. Throughout the entire project this is compared with the forecast to analyze the progress and to identify a trend, whether for example too little hours are used, or if too little or too many employees are in the team. S-curves are used to control large projects.

• **Cost estimates**
  Cost estimates are made to forecast the costs for different aspects like construction costs, engineering costs, insurances and contingencies. It calculates a percentage score of level of completeness. With cost estimates the chance is forecasted that project costs are within a certain range. Depending on the project phase, more accurate forecasts are made. Starting from the concept phase with a forecast of +40% to +25%, with the detailed engineering the range will be +10% or even +5%. This indicates the costs for the entire project. The level of detail and after the FEL phases the cost estimates increases and after the cost estimates turn into cost control.

• **Monte Carlo simulation**
  This technique is used to calculate a percentage of which the project is going to be within a certain budget or schedule. Monte Carlo is not frequently used, but when it is, it is used to convince the client of the accuracy of the budget or schedule.

• **Risk inventory & evaluation for all project risks**
  The RI&E technique is used for all project risks, including safety, scope, quality, budget, environment, permits, technical and schedule. An experienced facilitator leads the risk management session where the project management team and the client participate. With a brainstorm session the risk, consequence, action, and the probability-impact rating are determined. The RI&E is kept up to date several times during the project design & engineering phase in a Project Risk Register (PRR). Also new risks can be identified and the group can change when for example construction, operation or maintenance engineers are involved.
  A chances & risks list (C&R list) where the PM identifies internal risks and chances has to be submitted to the board of directors monthly when an EPC contract has a value over 1 million or when an EPCm contract has a value over 5 million euros (Tebodin, 2011a). For each risk a cause, consequence and action is specified. The list includes the date when the action has to be completed and allocates a responsible person. The PM roughly updates the C&R list once a month during the entire project.

• **Project evaluation**
  In a project evaluation the lessons that are learned from the project are included where project errors and project success aspects are mentioned that need to be taken into account for the next project. This report is sent within the project team after the session has been taken place.

• **Project definition rating index**
  A project definition rating index (PDRI) is a comprehensive checklist of scope definition elements presented in a score sheet format that allows an integrated project team to critically evaluate the status of an industrial, infrastructure or building project during front-end planning and determine a score that evaluates its level of definition early enough to do something about the shortcomings identified (CII, 2014). It is a gate review that is held by an external party. A score is given before the project continues to the next phase, after feasibility, after concept and after detailed design.
Table 5-2 displays whether the technique is quantitative or qualitative, which project drivers the techniques are used for and at which stages the techniques are used. The techniques are ranked according to the intensity of their use.

### Table 5-2 Identified risk management techniques and specifications

<table>
<thead>
<tr>
<th>Techniques</th>
<th>Specifications</th>
<th>Use by PMs</th>
<th>Quantitative/ Qualitative</th>
<th>Project drivers</th>
<th>Use in risk management stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. RI&amp;E (part of H&amp;S plan)</td>
<td></td>
<td>Qualitative</td>
<td>Safety</td>
<td>All stages</td>
<td>Risk assessment/response</td>
</tr>
<tr>
<td>2. TRA</td>
<td></td>
<td>Qualitative</td>
<td>Safety</td>
<td>Risk assessment/response</td>
<td></td>
</tr>
<tr>
<td>3. LMRA</td>
<td></td>
<td>Qualitative</td>
<td>Quality</td>
<td>Risk identification</td>
<td></td>
</tr>
<tr>
<td>4. Constructability review</td>
<td></td>
<td>Qualitative</td>
<td>Time &amp; Cost</td>
<td>Risk identification</td>
<td></td>
</tr>
<tr>
<td>5. Design review</td>
<td></td>
<td>Quantitative</td>
<td>Cost</td>
<td>Risk assessment/monitor &amp; control</td>
<td></td>
</tr>
<tr>
<td>6. S-Curves</td>
<td></td>
<td>Quantitative</td>
<td>All</td>
<td>Risk assessment/monitor &amp; control</td>
<td></td>
</tr>
<tr>
<td>7. Cost estimates</td>
<td></td>
<td>Qualitative</td>
<td>All</td>
<td>All stages</td>
<td></td>
</tr>
<tr>
<td>8. RI&amp;E (all project risks)</td>
<td></td>
<td>Quantitative</td>
<td>All</td>
<td>Risk review</td>
<td></td>
</tr>
<tr>
<td>9. Project evaluation</td>
<td></td>
<td>Qualitative</td>
<td>Time &amp; Cost</td>
<td>Risk assessment</td>
<td></td>
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<tr>
<td>10. Monte Carlo simulation</td>
<td></td>
<td>Quantitative</td>
<td>All</td>
<td>Risk review</td>
<td></td>
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<tr>
<td>11. PDRI</td>
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</table>

As Table 5-2 indicates, not all PMs use the same techniques. All of them use safety risk techniques, which means safety is much more integrated in project management than other project risks techniques. Quantitative techniques are less used than qualitative techniques. PMs do not like making the same lists multiple times. The table also identifies in which stages of the risk management process the techniques are used.

### Linking the techniques

An overview of the risk management phases and how the used techniques are linked to each other has been designed for this thesis. Figure 5-2 presents the Tebodin risk management method, which has been presented to and confirmed by Tebodin management.\(^\text{12}\) The phases are taken from Figure 4-9 that shows a global framework for a risk management method. The tools Tebodin uses for their techniques (such as a PRR and the C&R list) are not included, as they are part of a technique. From Table 5-2 two types of RI&E techniques are shown. In the figure this technique is only included once, because some PMs only carry out a session for safety risks, and others identify all project risks in this session. The figure includes brainstorm as a separate technique, because in literature it is described as a separate technique (PMI, 2008), whereas in the table it is included in the RI&E session. Finally, the PDRI is not included in the figure, as this is a technique performed by an external party, not related to any other techniques.

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\(^{11}\) In this public version this information is intentionally left out as it contains information sensitive to Tebodin

\(^{12}\) Personal communication with Tebodin’s head of project management department
The following tools are omitted in Figure 5-2 because these are part of the procedure, and not part of risk management techniques:

- **A-form & B-form:** These forms determine whether Tebodin tenders for a project and are therefore not related to risk management techniques.
- **Gate review:** This is a TQS checklist that has to be complied with continuously at the end of each stage, but which is not connected to other techniques.
- **Close out report:** This is a TQS checklist that has to be complied to at the end of the project, but which is not connected to other techniques.

5.3 Preconditions compared with literature

For a successful application of a risk management framework preconditions are defined. A precondition is *a condition that must be fulfilled before other things can happen or be done* (OxfordDictionary, 2013). Besides the risk management techniques that are used during a construction project, the interviews also retrieved information from Tebodin’s PMs on risk culture, documentation, awareness, project drivers, information transfer, risk liability, safety link with risk management, risk management in practice, quantitative risk management techniques, the use of techniques in different industries, and risk opportunities. For each subject, a summary is given and preconditions are identified and used as input for the risk management framework. To substantiate the preconditions, comments are given from literature review.

**Culture**

All interviewees consider risk management to be part of project management. It is the PM’s task to foresee, estimate and carefully handle risks as soon as possible for both Tebodin and for the client, who is part of the team. During risk inventories a facilitator is selected and the PM monitors the session. There is no risk manager involved; the PM is responsible for risk management and assigns actions to other team members to help assess the risks and carry out mitigation actions. Although most interviewees agree that risk management is used to monitor projects, one perceives risk management as an additional item. Even though risk management is seen as mandatory it should play a more important role to monitor projects.

**Precondition:**

In a risk averse culture, where the PM is the risk officer, risk management should play an important role, which should be integrated in project management, when monitoring projects.
Documentation

According to the interviewees, PMs with experience act more with their intuition, while PMs with less experience act more with required documents. Documents are registered according to Tebodin standards, unless the client wants differently. The H&S plan is made according to Dutch legislation and the RI&E session is carried out according to Tebodin standards. During construction the PRR is updated several times by the PM, and the state of the PRR is discussed during progress meetings. At the end of a project a close out report is distributed internally and sent to the board of directors including ‘lessons learned’.

Precondition:
The lessons learned from a post-project evaluation should be carried out more often and should be accessible to everyone.

Literature comments:
“An environment must be created where data can be stored and organized so that individual and teams can access it easily and intuitively, evaluate it using tools, share that analysis with colleagues and act upon those findings effortlessly.” (Tah & Carr, 2001)

Awareness

According to the interviewees, depending on experience and communication, risks are managed better or worse. Financially the client is responsible, so there is less awareness for bigger risks in the project in general, but the client wants a team with experience. The problem with documenting ‘lessons learned’ is that it requires discipline and incentives should be put at the right place.

It would be useful to create a team perspective rather than an individual perspective and to document more than thinking about it. To provide the client a high-quality service, risks and chances should be looked at qualitatively. Tebodin has many disciplines and can judge risks.

Precondition:
Discipline is needed and incentives should be triggered at the right place to create awareness among the entire project team about the importance and added value of risk management.

Literature comment:
“Risk culture is not something that can be changed overnight. It requires constant, consistent messages to employees that managing risk is a part of their daily responsibilities, and that it is not only valued, but critical to the company’s success and survival.” (Hoon & Farrell, 2009)

Project drivers

The most important project driver according to the interviewees is safety because accidents are unwanted. Safety standards should be strictly applied, since European legislation demands minimum safety requirements. If employees are of danger for others, they are removed from the site. According to the client, safety is so important they would rather have a 2-month project delay than having someone injured.
After safety, the triple constraint (time, cost and quality) is ranked as the second most important project driver. Quality, cost & time is what the client wants and it depends on the project what the main driver is. There are time-driven and cost-driven projects, depending on the client. Often initially quality and time are important, which then shifts to quality and costs. Even though a project is cost driven, in practice time can be just as important. Sometimes when time is achieved, the driver becomes cost, and later it becomes time again. Time is often scheduled with the program MS Project, so contractors can add their schedule. Quality is about delivering a validated end result. It is important that the plant starts working on time and that profit is made, but also that the quality is good enough for the coming 30 years.

**Precondition:**
Besides risk management techniques for safety, other techniques that comprise project drivers such as time, cost and quality should be developed.

**Literature comment:**
“Is it worth a slight increase in expected cost significantly to reduce risk, or a slight decrease in expected cost for an associated increase in risk? In this manner, risk analysis can play a major role in shaping a project during the design phase and in the planning of the execution.” (Ward & Chapman, 1991)

**Information transfer**
Depending on the client’s demand and how soon Tebodin is involved in the project, it may start from scratch, extend a plant or start with a green field. When the client gives a ‘request for quotation’, Tebodin makes a proposal where some aspects are taken into account. The project execution plan is used for smaller projects and includes a fact sheet from the client with all the studies they think need to be done including scope, responsibilities, HSE, strategy and a section for risks.

The client sets up process related requirements, user requirement and a basis for design. When Tebodin is not responsible for the front end engineering design (FEED), it is transferred as a package the consistency of which depends on the client. Tebodin judges the package to see if they agree with the FEED. In the package however, no risk management documents are transferred, so usually Tebodin starts from scratch.

**Precondition:**
Tebodin receives a request for quotation and process related requirements, but besides, managing risks starts from scratch at the start of a project. During the FEL risks should already be identified and analyzed.

**Literature comment:**
“The very basis of risk management is sound basic practice around things such as clear business objectives, team staffing and integration, and thorough FEL. In the absence of those things, layering on risk management practices is a futile exercise.” (Merrow, 2011)

**Risk liability**
The client wants Tebodin to have experience in the project field and therefore demands pre-qualifications including certificates and certain procedures to be completed. The legal department checks the contract. Contractually risks are allocated before the start of a project. In the H&S plan all the risks that Tebodin thinks the contractor should take into consideration are included. With Design Change Notifications (DCN’s) the contract can be adjusted when for example the scope expands and the contract fee increases. The contract is then adjusted or a new proposal with additional conditions is added to the contract. For medium sized projects normally no adjustments are made in the contract.

The relation with the client needs to be maintained, but Tebodin’s self-interest is also taken into account. Client relation is very important for the project. Only when things go differently than expected the contract is invoked. Through mediation this is avoided, that is why client relation is so important.
Safety link with risk management

The interviewees identify a development and culture change in construction safety; it has become a separate expertise where a safety supervisor is always present. It took years before safety was accepted and integrated while in foreign countries the safety awareness is at another level. Now safety is under control and accepted by using toolboxes, carrying out TRA’s to receive permits, conducting audits and making safety certificates compulsory when working on a building site. Harming a person is the biggest risk concerning safety. In the design phase attention is paid to make a H&S plan, which at the end of construction is checked. The system is set up such that these tools are unavoidable.

The awareness for safety is higher than for other project risks. Safety is integrated in project management. As soon as there is a safety risk, other project risks are less important. The RI&E session for safety is compulsory, but should also be linked to other project risks. The client is very aware to pay attention to safety, because if an accident happens, it is always the client who will be mentioned in the news, not the contractor. In addition to the H&S plan that describes safety on the construction site, there is also end result safety. During the design phase many studies are held to ensure end result safety. Safety is number one so if a project can be faster or cheaper, but unsafe, this is not accepted.

Risk management in practice

In practice, most time is spent on risk identification and risk monitoring & control. When risk actions are not complied with, this is due to human failure. In the brainstorm session the project team identifies risks together, which works as a form of team building since every discipline has a different worldview and is of added value. The PM is responsible for delegating actions, keeping the PRR up to date and organizing follow-up sessions.

During the project, it can occur that risks are not identified. For safety there is a responsible supervisor to which both CM and PM talk to on site. When unforeseen situation occur, the remaining timeframe is used to find a solutions. Before construction, the CM is already involved in the safety RI&E sessions and the constructability reviews. The CM is only involved full-time at the start of construction.
Quantitative risk management techniques

One interviewee identified Monte Carlo as time consuming and inadequate because of the manipulative character and subjectivity of the input. A risk management session is also considered subjective but it is a group effort and the chairman is neutral so that is considered to work well. Monte Carlo or other quantitative methods are only considered useful maybe for larger projects.

Interesting quantitative data that provides feedback about the quality and risks are subject field changes (DCN’s during construction), more work as percentage of contract fee during construction and delay in planning during the engineering and construction phase. By collecting quantitative information, a trend can be seen and focal points can be detected.

Comparing industries

Apart from the chemical construction sector, all interviewees have experience at other industries too and were asked about whether tools from other industries could be used in the chemical construction industry. While one interviewee indicates all the industry risk management approaches are consistent, others identify differences.

The chemical construction industry is considered more complex than commercial construction because there are many stakeholders and many potential risks. Time spent on maintenance and safety is higher and more complex. With commercial construction, probably the client does not participate in the RI&E session, while in the chemical construction industry his presence is essential. In the chemical industry and the oil and gas industry risk tools are used the most, but they can be used anywhere. Depending on the client certain risk methods are used. A HAZOP is a simplified way to make a risk inventory that is mainly used in the chemical and pharmaceutical industry. Now HAZOP’s are not only used in the petrochemical sector but also in the food industry. In the food construction industry more guidelines are used that previously were used in the pharmaceutical industry. The use of a V-model where every step down is validated and checked with the concept phase offers the chance to perform well.
In the pharmaceutical construction industry where medicines are made the requirements are high. Products need to be validated by qualifying the installation, and qualifying the operation. This is very structured because of strict legal requirements. During the design phase documents are already set up to check whether the requirements are complied with, which has the advantage that the chance that the correct instructions are prescribed is higher. This approach is less used in the chemical construction industry. The construction team sets up test packages at the beginning of the construction phase. Adopting the pharmaceutical-approach could contribute to quality improvement of projects in other sectors.

In data centers a comprehensive Monte Carlo is used to simulate the probability of downtime. Every second of downtime is extremely expensive. There is no gut feeling or experience there so you have to simulate it. In the chemical construction industry it is not considered necessary to use Monte Carlo simulations.

**Precondition:**
Although the chemical construction industry is complex, strict guidelines, validation methods and quantitative tools that are used in other industries should be explored on their utility for the chemical construction industry.

**Literature comment:**
“The application of risk analysis and management in the construction industry is relatively low compared to other industries. To widen their integration into the current estimating and forecasting process, the researchers need to find ways of seamlessly building them into existing methods in common use.” (Abdou, Lewis, & Alzarooni, 2004)

**Risk opportunities**
The interviewees state predominantly identifying risk threats. In the C&R list mainly risks are looked at, and there is less emphasis on chances. When a proposal is made, chances are discussed with the client by for example identifying whether the client has a plant at another location or more work can be added to the contract. In the preliminary phase of a project, chances are looked at to make the project cheaper (modular building example).

**Precondition:**
Opportunities are often overlooked and should therefore be included in risk management because it can save money and time.

**Literature comment:**
“In the same way that the typical tactical risk process can be extended to deal with strategic risks by focusing on strategic objectives, the threat-based process can also be modified to address opportunities by including upside risk.” (Hillson, 2006)

**Summary**
The results of the interviews correspond with the subjects identified in literature, because the preconditions are substantiated by literature comments. The preconditions are used as input for the risk management framework. Table 5-3 presents and overview and summarizes the preconditions that are taken into account when making a framework for Tebodin.
Table 5-3 Summary of preconditions

<table>
<thead>
<tr>
<th>Preconditions for the risk management framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Risk management integration: In a risk averse culture risk management should be integrated in project management.</td>
</tr>
<tr>
<td>• Accessible lessons learned: The lessons learned from a project should be accessible to everyone.</td>
</tr>
<tr>
<td>• Incentives for risk management awareness: Incentives should be triggered to create risk management awareness among the entire project team.</td>
</tr>
<tr>
<td>• Risk management for all project drivers: In addition to risk management techniques for safety, other techniques that comprise project drivers such as time, cost and quality should be developed.</td>
</tr>
<tr>
<td>• Risk identification during FEL: During the FEL risks should already be identified and analyzed.</td>
</tr>
<tr>
<td>• Communication within the project team: Communication between client and contractor, and within the project team should be well managed.</td>
</tr>
<tr>
<td>• Unavoidable risk techniques: Risk tools should be set up in such a way that they cannot be avoided but also such that do not require double work.</td>
</tr>
<tr>
<td>• Iterative risk management: Risk management should be an iterative process.</td>
</tr>
<tr>
<td>• Development of quantitative methods: The use of quantitative analysis for large projects should be developed to show trends and detect focal point.</td>
</tr>
<tr>
<td>• Techniques used in other industries: Techniques used in other industries should be explored on their utility for the chemical construction industry.</td>
</tr>
<tr>
<td>• Opportunities in risk management: Opportunities should be included in risk management.</td>
</tr>
</tbody>
</table>

Regarding the gap between theory and practice, researchers have criticized the way in which particular tools are used. The PRR for example has been identified as being an inadequate tool because it fails to capture the inter-relationships between risks and the systemic structure within the risks (Tah & Carr, 2001). Comments are also given on the P-I matrix that is used. Cox (2008) has examined some mathematical properties of risk matrices and shows that they have limitations like poor resolution, errors and containing ambiguous inputs and outputs. It is therefore interesting to pinpoint other tools from literature too.

The interviewees consider some tools superfluous. The main issue with documentation is that PMs do not appreciate undertaking double work, when they have little time. Documenting itself is not that much an issue, as long as it is not repeating the same documents multiple times; it needs to be efficient. Furthermore in practice, it is encouraged that all project team members contribute to giving input for a more comprehensive risk management approach.

Tebodin as a company makes use of different risk techniques. In the literature many other techniques were found that are useful for managing risks in the construction industry. Whether the difference between Tebodin’s techniques and the techniques retrieved from literature review is due to the company culture, is undefined yet. However, all identified techniques from literature as well as from the interviews have been taken along in the assessment of criteria in the following section. The preconditions are also taken into account to ensure that the conclusions from the interviews are used as input for the conceptual model.

5.4 Comparative assessment of techniques

In this section the tools and techniques identified from the literature review as well as the techniques retrieved from the conducted interviews are assessed. This combination is used to provide a complete overview of risk identification and assessment tools and techniques and to make a comparison and identify which ones are useful and should be used as input for the risk management framework.

Comparing practice with literature

The assessment provides an insight into the quality, use and added value of tools and techniques. It gives an overview of which ones comply best with the criteria and which ones are useful to take into account when designing a risk assessment framework. Both qualitative and quantitative tools retrieved from literature review and from the interviews are assessed and differences are identified.

With a multi criteria decision-making table, the tools are assessed to criteria. Multi-criteria decision making is a well known branch of decision making which deals with decision problems under the presence of a number of decision criteria (Pohekar & Ramachandran, 2004). The scale displays three different colors. A
red box classifies the tool as non-compliant with the criterion. The yellow box classifies a medium compliance with the criterion and a green box classifies full compliance with the criterion. By scaling, the multi-criteria analysis establishes a quick overview of each tool and technique and its compliance rate. However, the compliance rate does not necessarily indicate that the highest rate is the best one. It compares to what extent they comply with the proposed criteria. For example, if a tool is time consuming, it does not mean it is an inadequate tool, or if a tool is used during every project phase, it does not mean it is a perfect tool. Every criterion has its advantages and disadvantages. The table indicates which tools and techniques score similar, so they might have the same purpose and one can be eliminated, or they can be combined for example.

**Criteria**
To identify the set of criteria, three sources are consulted. By reviewing literature, research describes what criteria are important for assessing a tool or technique. By mind mapping these criteria are complemented. Finally, by going through the preconditions, the list is completed and two final criteria are added: the post-review and opportunities criteria.

1 **Decision-making support (Garvey, 2008)**
The tool/technique provides the necessary information and is detailed enough to support decision-making. In other words, the information retrieved from using the tool/technique is the input for the decision-making process.

2 **User accessibility (Garvey, 2008)**
The tool/technique is accessible to all users and key stakeholders, that is, the project management team. It does not mean that all users are involved in the decision-making process, but that they are able to see the results and use the information retrieved from the tool/technique.

3 **Data availability (Garvey, 2008)**
Data is available as input for the tool/technique. If there is not enough data, information retrieved from the tool/technique might be unusable.

4 **System engineering integration (Garvey, 2008)**
The tool/technique supports integration with other program management/system engineering processes so it can be used in other programs too.

5 **User friendly**
Assessment tools/techniques are only as effective as the people using them. Proper training is essential, and some tools require more expertise than others. Depending on the difficulty, the tool/technique user-friendliness is defined. If an expert is needed, it is classified with a red box. If experience is required, the tool/technique must be taught to the users.

6 **Stakeholder participation**
The level of stakeholder participation defines the range of people that use the tool/technique. Certain stakeholders are involved in the assessment process depending on group or individual assessment. If many stakeholders are involved, this criterion is classified with a green box.

7 **Reliability**
Quantitative data is more reliable because fixed numbers are used, whereas qualitative data more often is associated with a sense of feeling, instinct and experience. Whether the tool/technique is reliable depends on the subjective or objective type of data.

8 **Iteration**
The tool/technique is repeated at several phases during the project. During the lifetime of a construction project the phases include initiation, planning, design & engineering, execution & control and closure. Iteration implies that the tool/technique provides strategies for the following phase. With the information retrieved either the assessment is repeated or a task is carried out in the next phase.

9 **Time consuming**
A tool/technique that consumes time mostly is unfavorable to use, because time is money. However, this depends on the added value to managing project risks. A time consuming tool/technique is classified with a red box.
10 Caging Black Swans (Dodson & Westney, 2008)
An important phenomenon discussed in the introduction is the black swan, which are risk events that have a low probability and high impact. Improving project predictability requires finding Black Swans by developing strategies that avoid the risk entirely, mitigate the impact if it should occur, or provide the funding for risk coverage.

11 Post-review available for other projects
The tool/technique provides a post-review to evaluate the current project, which is then taken into account when a new project starts. The information retrieved from lessons learned is available for other project teams.

12 Opportunities
The tool/technique not only focuses on risk threats, but also exploits opportunities.

Assessment
Now that the criteria have been identified, qualitative risk identification tools/techniques are assessed in Table 5-4 and quantitative risk assessment tools and techniques are assessed in Table 5-5. For both assessments the tools and techniques are compared to each other.

Table 5-4 Multi-criteria analysis for qualitative tools and techniques

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Project analogy</th>
<th>Checklist</th>
<th>Brainstorm</th>
<th>WBS</th>
<th>Flowchart</th>
<th>C&amp;E diagram</th>
<th>Delphi</th>
<th>Constructability</th>
<th>Design review</th>
<th>TMA</th>
<th>LMRA</th>
<th>Project evaluation</th>
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</thead>
<tbody>
<tr>
<td>1. Decision-making supportive</td>
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<td>2. User accessibility</td>
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<td>3. Data availability</td>
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<td>4. System engineering integration</td>
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<td>5. User friendly</td>
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In Table 5-4 the selected qualitative tools and techniques are assessed. Both project analogy and checklist seem to fulfill the same criteria. Checklists, however, are used as an iterative tool that can be updated when new experience is gained from recent projects. Checklists can be used as a tool to support project analogy, generating checklists by experience from the past, and by recollecting post-completion summary reports, while keeping them up to date with the recent project. Brainstorming is a technique frequently used at Tebodin as well as in literature when it comes to identifying risks. Together with the first two tools, this can help, especially in a group session, to retrieve a complete risk identification overview. However, these tools remain subjective and do not necessarily cover all risks. Another risk identification tool is the Delphi technique. The disadvantage is that it is time consuming because the tool requires several rounds to be completed.

The WBS has the same characteristics as the process flowchart and the C&E diagram. Both WBS and flowchart represent the project tasks and their advantage is that risks between tasks and activities can be pinpointed. The C&E diagram is different because risks are recorded and the potential effect or cause is determined, separately from project tasks. The RBS can be compared to a WBS but it is specifically aimed at decomposing risks. The advantage of the RBS is that decomposing risks establishes a clear overview of all
identified risks and this categorization can be used in tools that require risk actions to be taken (such as the PRR).

A constructability review and design review are techniques to ensure the required quality is complied with, used during the design & engineering phase. Participants need to take distance to see shortcomings or deficiencies in the project. The lead engineers from different disciplines should attend these two meetings. TRA’s and LMRA’s are compulsory techniques that are used for multiple tasks in the construction phase. A TRA is necessary to obtain a permit to start the work. These techniques are meant for the workers concerned with the task.

Neither Black Swans i.e. calamities are allowed for, nor do these techniques include post-review sessions. One exception is the project evaluation session, which is an infrequently used post-review technique. This is a time consuming technique but might cage Black Swans afterwards and is very useful to reflect about a project and to remember lessons learned for upcoming projects. In addition identifying project weaknesses, it also includes opportunities that throughout the project were successful.

Table 5-5 Multi-criteria analysis for quantitative tools

<table>
<thead>
<tr>
<th>Criteria</th>
<th>R&amp;E (all project risks)</th>
<th>RI&amp;E (part of H&amp;S plan)</th>
<th>EV</th>
<th>Decision trees</th>
<th>Payoff tables</th>
<th>AHP</th>
<th>Monte Carlo</th>
<th>PERT</th>
<th>Sensitivity analysis</th>
<th>Fuzzy approach</th>
<th>TOPSIS</th>
<th>S-curves</th>
<th>Cost estimates</th>
<th>PPN</th>
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<tbody>
<tr>
<td>1. Decision-making supportive</td>
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Table 5-5 illustrates the multi-criteria analysis matrix where the selected quantitative tools and techniques are assessed to the criteria. Conclusions are drawn similarly as for the qualitative analysis. The RI&E for all project risks is the extended RI&E technique that is part of the H&S plan so could be combined. These user-friendly techniques are decision-making supportive and are used several times during a project.

The expected value (EV) is a technique to gain insight in the risk consequences regarding time and cost. It indicates the effect on the project as a whole. Decision trees and payoff tables are tools used to compare strategies and choose between alternative risk responses, which can be used as support for the EV technique. Decision trees and payoff tables take opportunities into account. Payoff tables do not have data available from prior experience but look at pros and cons when indicating the likely outcome for each state of nature (Nicholas & Steyn, 2012). Increasing the project schedule and budget to account for the expected risk time or risk cost is no guarantee of adequate protection against risk (Nicholas & Steyn, 2012). The AHP considers subjective and objective factors. This technique allows active stakeholder participation and structures and prioritizes risks in a hierarchical structure with decision alternatives at the bottom of the hierarchy (Pohekar & Ramachandran, 2004).
The Monte Carlo analysis, PERT and sensitivity analysis are decision-making supportive. If not enough data is available; the technique can become too subjective when unconsciously the user manipulates the results.\textsuperscript{13} Furthermore the tool is time consuming, and requires a simulation program. PERT remains not completely reliable since assumptions are made regarding optimistic, most likely and pessimistic times in the project schedule. Sensitivity analysis identifies the most critical areas, and like the Monte Carlo and PERT requires many data on different variables. The downside is that it only treats variables individually. This leads to severe limits on the extent to which combinations of variables can be assessed directly from data (Perry & Hayes, 1985).

Using the fuzzy approach implies that all the variables have to be made linguistic, which is time consuming, which leads to not all stakeholders participating. With the fuzzy approach, risks are identified but this does not support decision-making. TOPSIS is a MCDM method that requires benefit criteria and cost criteria (Pohekar & Ramachandran, 2004). It also looks at the positive ideal solution, which implies specific knowledge on how to define this, improves the quality of decision-making.

S-curves, which are used to keep track of man-hours and costs spent, is an adequate technique that in addition to looking at risks of using too much man-power, also takes into account opportunities regarding chances for more work. The technique is reliable and used multiple times to control the project. While S-curves are used to keep track of man-hours, cost estimates are used to forecast the total costs. Cost estimates are used to calculate a percentage score of level of completeness. The reliability becomes more accurate towards the end of the project, when most costs are already defined.

The PDRI is a technique that is carried out by an external party, which makes the results more reliable because no project members are involved in the assessment. Originally the PDRI is developed by the CII and used in industrial and building projects to measure and manage the level of scope definition as project planning progresses (Dumont, Gibson, & Fish, 1997). At every project phase the PDRI rates the project and gives a useful post-review to identify shortcomings.

5.5 Summary of gap analysis
There are several shortcomings found from the literature review as well as from the interviews that were conducted with the Tebodin PMs. Literature revealed gaps between the theory and practices of certain tools that are used, such as the PRR discussed by Tah and Carr (2001) and the P-I matrix discussed by Cox (2008) in section 5.3, which are both tools Tebodin uses. It is therefore interesting to pinpoint other tools from literature too and discuss their added value.

From the comparative technique assessment, a selection is made which tools and techniques from literature to include in the conceptual model, in addition to the techniques that Tebodin already uses. The tools Tebodin uses as support for their techniques (such as a PRR and the C&R list) are established and therefore not included in the tables. Table 5-6 shows the qualitative and Table 5-7 shows the quantitative techniques and tools. An explanation is given why additional techniques and supporting tools from literature are suggested, why they fit within Tebodin and why others are defined out of scope.

<table>
<thead>
<tr>
<th>Techniques used by Tebodin</th>
<th>Additional tools and techniques from literature</th>
<th>Tools and techniques out of scope</th>
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</thead>
<tbody>
<tr>
<td>Techniques</td>
<td>Techniques</td>
<td>Tools</td>
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<tr>
<td>TRA</td>
<td>Project analogy</td>
<td>Checklist</td>
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<td>LMRA</td>
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<td>RBS</td>
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<tr>
<td>Constructability Review</td>
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<td>Flowchart</td>
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<td>Design Review</td>
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<td>Brainstorm</td>
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<td>Project evaluation</td>
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\textsuperscript{13} Interview with Tebodin project manager, see Appendix D: Interview summaries
Project analogy is suggested because it is useful to identify risks from previous similar projects. The better the documentation of past projects, the more useful this is as source for identifying risks (Nicholas & Steyn, 2012). There are several tools that are identified to support the project analogy. A complementary tool that is suggested to use project analogy is the checklist, as it can be updated with new experiences from recent projects. The RBS is considered useful as it can group risk events into different levels, this is already used by some PMs. The process flowchart is useful to define the flows and sequence between tasks and activities, which can be useful during the brainstorm session to identify risk interaction.

The techniques that are not useful for the framework are the Delphi technique, the WBS and the C&E diagram. Although its anonymity is relevant when sub-contractors identify risks with another sub-contractor, and do not want to discuss this in public, the Delphi technique consumes too much time. The process continues until the group reaches a collective opinion (Nicholas & Steyn, 2012). The question remains whether it is necessary to retrieve anonymous input from different stakeholders about the potential risks, or if open group sessions are sufficient. To reflect on this issue, one interviewee mentioned that a group session to brainstorm about risks effectively works as a team building activity. Working in multidisciplinary teams is common practice at TeboDin providing a good fit with the company culture. To discuss and identify risks brainstorming is already used which works well as team building. The WBS compared to the RBS is considered less important in this context, as it does not identify risks, while the RBS focuses on risk identification. If a WBS were used to identify risk interfaces, this would be time consuming, while the aim is to easily identify the most important risks. Although the C&E diagram requires structural thinking, according to Mehdizadeh (2012) the diagram can quickly become over-complex. Due to the multidisciplinary projects in the organization, any technique proposed needs to be simple and understandable for a broad range of stakeholders. That is why the process flowchart fits better with the organization.

Table 5-7 Quantitative tools and techniques for the conceptual model

<table>
<thead>
<tr>
<th>Techniques used by TeboDin</th>
<th>Additional tools and techniques from literature</th>
<th>Tools and techniques out of scope</th>
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<tr>
<td>Techniques</td>
<td>Techniques</td>
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<td>S-curve</td>
<td>Cost estimates</td>
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<td>RI&amp;E (part of H&amp;S plan)</td>
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<td>RI&amp;E (all project risks)</td>
<td>Sensitivity analysis</td>
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<td>Monte Carlo</td>
<td>PERT</td>
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Regarding the possible use of quantitative tools, the company’s culture needs to be taken into account. Quantitative tools are decision-making supportive and therefore of added value when it comes to assessing risks in construction projects.

Tools like S-curves and cost estimates are included, because they control the project. The RI&E tool is one that must be used to assess all project risks, where all project risks should be included. The EV tool can be used to identify which actions to take when looking at the effect on the project as a whole, or when broken down into work packages. Decision trees are useful to define how to respond to risk events and are preferred over payoff tables, because its layout is simpler and easier to understand. Its layout represents the events for each alternative course of action through a set of branches and nodes, as opposed to a payoff table in the form of a matrix. The AHP, as explained in section 4.4, relies on expert judgments. As it is uncertain whether these experts are available at TeboDin, and the framework designed is to be used by the PMs, the technique is out of scope.

Techniques that use quantification with respect to time and budget like Monte Carlo, PERT and the sensitivity analysis depends on the type of project whether they are useful. The focus of introducing new

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14 Interview with TeboDin project manager, see Appendix D: Interview summaries
15 In this public version information sensitive to TeboDin is intentionally left out

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tools like these needs to be on collecting sufficient data, to make the tool efficient and useful. These techniques are included in the framework because many researchers, described in section 4.4, suggest using quantitative tools to manage risks. The next step is to explore whether data is available to carry out quantitative analyses, and whether these techniques can be developed to fit within the culture of the organization.

Techniques like the fuzzy approach have mainly had a theoretical instead of a practical orientation resulting in a low take up in practice (Laryea, 2008), and is therefore not likely to fit with the organization, because as an industry, engineering and construction professionals look for practical solutions to practical problems. The TOPSIS is a time consuming tool. The PDRI technique is one that is carried out iteratively by an external party, and can possibly contribute important feedback when a project is moving from one phase to the next. The aim of this research is to provide a framework that creates risk awareness and that Tebodin can use, so the PDRI tool is left outside the scope of this research, as it requires an external party to perform the assessment and rate the project.

This part of the research has provided an overview of the current risk management procedures at Tebodin, their limitations in practice, and the risk culture. The suggested tools and techniques from literature are a way to develop risk maturity in the organization, but also the company culture needs to be addressed when developing practical solutions. The following part of this thesis addresses these issues, and provides a solution as to how a risk management framework in the construction industry can be developed.

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16 Checked with Tebodin project managers through personal communication
Part III Solution

The research solution consists of chapters 6, 7 and 8. Chapter 6 presents the conceptual model of the risk management framework, and explains each of the included layers. Three in-depth studies are carried out for risk identification, quantitative analysis and post-project evaluation. Chapter 7 describes the verification, validity and reliability of the conducted studies and chapter 8 describes the framework implementation into the organization.
6 Risk management framework

From the previous chapters, a need for change in risk management at Tebodin has been identified. This fits with Tebodin’s aim to professionalize their construction management services and communication flows.\(^1\)

This research, focusing on risk management in EPC and EPCM contracts, has identified what shortcomings are found in risk management practices. The PM is completely responsible for risk management practices, and the ways risks are managed differ between PMs. In the TQS a section is dedicated to risk management focusing on the procedure. Each PM has its own interpretation on how to integrate risk management procedures in project management.

This chapter provides a solution based on the research, and describes the proposed risk management framework. To respond to the identified clear gap between the theory and practice of risk modeling and assessment, by Taroun (2014), the framework is designed based on the current situation at Tebodin, their identified needs, and an additional chapter is dedicated to the implementation in the organization. The presented framework can be used during EPC and EPCM projects and functions as a guidance to manage risks during entire projects. According to Merrow (2011), the very basis of risk management is sound basic practice around elements such as clear business objectives, team staffing and integration, and thorough FEL. He concludes that in the absence of those elements, layering on risk management practices is a futile exercise (Merrow, 2011). The CII describes the three levels of project risk analysis, explaining the benefits and limitations of risk identification, P-I matrices, and probabilistic risk modeling, shown in Appendix A: Project risk analysis levels. Taking into account these aspects, a framework is designed to develop an improvement strategy, focusing on improving knowledge transfer between EPC or EPCM projects, improving risk identification and looking at the added value of quantitative analysis in the FEL. Chapter 8 is dedicated to the organizational implementation, taking into account the company culture.

A framework is a real or conceptual structure intended to serve as a support or guide for the building of something that expands the structure into something useful (Rouse, 2005). Figure 6-1 presents an abstract conceptual model of the proposed risk management framework, which consists of three layers, depicted through a bottom-up approach. The bottom layer presents a timeline of risk-related techniques used at Tebodin, including suggested techniques from literature that can be of added value. The second layer consists of the techniques from the first layer that can be related to each other. The third layer consists of an in-depth development of the techniques, which is a more detailed indication of what the technique consists of, including the input and output and use of tools. Each of the layers is explained in the following sections.

\(^1\) Interview with Tebodin project manager
Figure 6.1 Conceptual model of the risk management framework
6.1 Layer 1: Timeline
The first layer consists of techniques identified from the literature, integrated in the current procedure at Tebodin, presented in a timeline. The identified techniques taken from the literature (explained in section 5.5) are included in the current Tebodin risk management procedure (presented in section 5.2). An overview of the timeline is shown in Figure 6-2. The techniques have been added to the overview but tools are not included because they are used as a support for the techniques. This is further explained in the third layer of the conceptual model where in-depth studies are conducted and a more detailed description is given of the techniques.

The added techniques from literature are: project analogy, sensitivity analysis, EV and PERT. These have been chosen upon their fit within Tebodin’s organization, as explained in section 5.5. The explanation why these are placed in a certain project phase is the following. Project analogy is placed at the start of FEL. It is a technique that is useful for input for the business concept, cost estimates and the project plan. This technique can be used to search for useful information from earlier projects. The sensitivity analysis is placed in the same box as the Monte Carlo because sensitivity analysis can be efficiently carried out in Monte Carlo simulation (Fu & Hu, 1995). Projects tend to enter FEL-1 with a large number of possible options (Merrow, 2011). The EV technique can be used to decide what option to build looking at the feasibility and comparing the costs of each option. This technique is placed in the FEL-1 phase, where the possible options can be evaluated, and the chosen option should be then frozen (van Elderen, 2009). PERT is used to plan the activities and to know what is going to be the critical path in the project (Cook, 1966). Successful projects are much more likely to have developed detailed schedules as part of their FEL, more than 80 percent of the projects that succeeded in labor-short environments had resource loaded their engineering and construction schedules as part of FEL (Merrow, 2011). In FEL-3 the scope, plan and budget is defined (van Elderen, 2009), so this makes the use of PERT suitable in that phase, to define the schedule.

Figure 6-2 Layer 1: Timeline presentation of risk-related techniques
6.2 Layer 2: Linking the techniques

In the second layer the techniques used in the FEL, project execution and evaluation phase are linked to each other. An overview of the integrated techniques added to Tebodin’s current risk management procedure (presented in section 5.2), is presented in Figure 6-3. An arrow means one technique provides input to another. The following explanation is given on how the added techniques are linked in this figure. Project analogy is used to gain input for the RI&E session and cost estimates, and should be consulted during the risk identification phase. A sensitivity analysis shows the effects of changing one or more variables on an outcome (Schwalbe, 2014), so changes in variables such as costs can be used. The PERT and EV techniques can give input for the RI&E session as these techniques can help identify risks for planning of activities using PERT, and risks for certain choices that are made using EV.

![Figure 6-3 Layer 2: Linking the techniques](image)

So far, the timeline with the techniques, and how the techniques are linked to each other are explained; the first two layers of the risk management framework. The following section zooms in on Figure 6-3 and three in-depth studies are carried out to come up with an improvement strategy that is presented in the third layer of the risk management framework.

6.3 Layer 3: In-depth studies of the techniques

The third layer of the risk management framework is designed from the knowledge retrieved from in-depth studies. As concluded from the literature review the real gap between theory and practice is not caused by the techniques or methods used, but rather by the individuals who put it into practice. The culture and mindset of a company and the training of individuals appear to be of importance too apart from the actual assessment type. This is taken into account when analyzing the studies by testing techniques and tools and asking for feedback afterwards to understand project team members’ experience, and by benchmarking with organizations such as IPA and CII.

The third layer of the conceptual model consists of identifying three focal points that are shown in Figure 6-4. This model has been designed by using the input of interviews and literature review as described in section 5.5. Risk management techniques, which are used during the FEL, project execution and evaluation phase, are linked to each other. By focusing on parts of the model and carrying out in-depth studies, the aim
is to develop an improvement strategy for current risk management procedures at Tebodin. The result of the in-depth studies from the conceptual model is used to design a third, more detailed layer of the risk management framework.

The following three parts of the model can be distinguished in Figure 6-4 and are illustrated in green: risk identification, quantitative analysis and post-project evaluation. The choice to focus on these three focal points is on the one hand explained by the shortcomings that have been identified at Tebodin, and can on the other hand be substantiated on scientific grounds:

- **Post-project evaluation**: The project evaluation technique is used to review risks and to evaluate the project. The added value of looking into this technique is that it transforms the current system into a clear, efficient tool of which the results are considered in future projects.
  - Scientific substantiation: The importance of post-project evaluation (described in section 4.4 - E: Risk review) is to prevent making the same mistakes twice, which in projects can contribute to process improvement. When using a methodology that is applied repetitively, lessons learned become an important source of information for future improvement (Serpell & Alarcon, 1998).

- **Risk identification**: At this point Tebodin only applies brainstorm sessions as a technique for risk identification.\(^\text{18}\) The identification of risks is an important aspect as it is the initiation of risk management.
  - Scientific substantiation: As this literature has revealed many techniques and tools that are available for identifying risks (as described in section 4.4 – A. Qualitative risk identification tools and techniques), analyzing this focal point is beneficial for the success of the entire project. Of all the stages of the project risk analysis and management process, the risk identification and assessment stages have the largest impact on the accuracy of any risk assessment (R. J. Chapman, 1998).

\(^{18}\) Interview with Tebodin project managers, see Appendix D: Interview summaries
• **Quantitative analysis:** These types of methods are seldom applied at Tebodin.
  
  ➢ Scientific substantiation: Also from the literature review many quantitative tools have been discussed and seem to be adequate and add value to manage project risks (as described in section 4.4 – B. Quantitative risk assessment tools). In addition, risk modeling is considered useful by the IPA (Merrow, 2011).

For the construction industry, the literature does not define which tools and techniques suit best. From the five phases presented in section 4.4, the first two phases (risk identification and risk assessment techniques) are included in this research and compared with the current procedure at Tebodin. These phases are chosen because of the chronological order of use. The researcher wants to provide an understanding of risk identification techniques and explain the added value of quantitative risk analysis. To close the loop of the risk management process, the researcher wants to develop a solution for the infrequently used post-project evaluation technique. These phases are considered important in the context of this study.

The risk response and control phase are left outside the scope of this research, as the aim of the risk management framework is to provide a strategy on how to integrate risk management with projects by focusing on tools and techniques, and not a strategy on how to mitigate risks. Risk response and risk control are phases that should be the focus of subsequent research once a strong framework with risk identification and assessment techniques exists, making it then functional to research which strategies fit with types of risks and how this should be controlled. In the context of this study, these phases require investigation at a later stage.

The order of researching the focal points does not necessarily follow the chronological order of a project. The first technique that is researched is the project evaluation, as the results can be used as input for new projects. Furthermore because a current project now has come to an end, a potential solution to the shortcoming can be tested in an experiment, as most projects last longer than the time scheduled to carry out the complete research. Next, risk identification and quantitative analysis are explained according to their current use, identified shortcomings and recommended adjustments found through literature and interviews with Tebodin employees.

The research plan of the in-depth studies consists of zooming in on the three focal points and analyzing the current situation, the shortcomings and what the literature reveals about the usefulness of certain tools. The reason for carrying out in-depth studies is to discover how the techniques from the conceptual model can be integrated in the risk management framework and be supported by tools. As concluded in the previous chapter, the practical part of research can provide invaluable insights into the implementation of the techniques when compared to the theory derived through the literature research, and can thereby contribute to a comprehensive way of investigating the use and added value of these techniques. The in-depth studies also identify a technique’s strengths and weaknesses, which leads to conclusions about the suitability.

### 6.3.1 Post-project evaluation

The first in-depth study has been carried out through design-based research. **Design-based research** is used to study learning in environments which are designed and systematically changed by the researcher (Barab & Sawyer, 2006). It is less a method than a collection of approaches that involve commitment to researching activity in naturalistic settings, with the goal of advancing theory and at the same time directly impacting practice (Barab & Sawyer, 2006). The research structure to answer the question: “**How can knowledge transfer between EPC or EPCm projects be improved?**” is shown in Figure 6-5. First, a closer look is taken at the current situation as it is at Tebodin, identifying gaps. Then the designed method is explained, followed by an experiment. Subsequently, the results are clarified, and finally, conclusions are drawn. This
structure is chosen because conducting an experiment is suitable to explore the opinions of participants, and to discover which departments of Tebodin need to be involved.

**Current situation**
The way a project is reviewed at Tebodin, is by executing an evaluation session with the project team members at the end of the project. In the TQS manual the post-project evaluation is not compulsory. Whenever a session takes place, the positive and negative project aspects are discussed. Either a summary is made of positive and negative topics, or they are divided into categories such as budget, schedule and organization. The lessons learned, summarized into a report, are then sent to the project team members. So that everyone can benefit from each other’s experiences, the lessons learned need to be communicated with the rest of the organization.

**Designed method**
Instead of keeping project evaluation reports within the project team, all PMs should benefit from important knowledge about success and fail aspects of a project. Implementation of the lessons learned is key to continuous improvement. Lessons learned are important because it can close the loop as shown in the conceptual model and because techniques such as project analogy (as identified from the literature review in section 4.4) are useful for risk identification when information about lessons learned is available.

The aim of post-project review, as Mehdizadeh (2012) states, is to leverage previous experience, prevent making the same mistakes or missing opportunities twice and enhance organizational process assets. Proper project documentation from past projects furnishes lessons learned, and forewarns managers about potential risks in upcoming projects (Nicholas & Steyn, 2012). Figure 6-6 zooms in on part of the conceptual model that is shown in Figure 6-4, and focuses on the post-project evaluation. During the project, different tools are used to keep track of risks and manage them. After the project is finished, these tools are an input to reflect about the project and lessons learned. To close the loop, the conceptual model proposes to consult the lessons learned at the start of a new project.

Several steps are proposed instead of having one step that initiates writing down the lessons learned. Figure 6-7 illustrates the steps that are suggested to introduce a new way of reviewing risks in a project evaluation and subsequently every step is explained.
Step 1
The first step is approximately similar to the current way of working, that is, to organize a project evaluation session. However, it should be part of the procedure and made compulsory for every project. The focus of this method concerns both sessions, as a summary is made of all fail and success aspects of the project that were encountered and that are turned into lessons learned, which is useful for future projects.

The following structure is set up to discuss every project specific reviewed issue, and should be followed as shown in Table 6-1. Per topic all the difficulties during the project should be reviewed and the lessons learned should be written down until all team members have had the opportunity to express their opinion. The aim of the group session is that every participant can communicate with each other about the causes and how to prevent this in the future. The facilitator should keep track of what is said to prevent losing information. By communicating in a group, one can contribute to another’s viewpoint. An apparent aspect of memory in groups is that the group has many more memories than an individual acting alone (Hinsz, 1990). To evaluate the project, both positive as negative aspects should be included in the session. Although risk threats are the most important, also opportunities that are overlooked can contribute to lessons learned. The threat-based process can also be modified to address opportunities by including upside risk (Hillson, 2006). The complete list of lessons learned then should be summarized in a report.

Table 6-1 Project evaluation structure per subject

<table>
<thead>
<tr>
<th>Structure to evaluate the project</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td></td>
</tr>
<tr>
<td>Positive/negative problem description</td>
<td></td>
</tr>
<tr>
<td>Cause</td>
<td></td>
</tr>
<tr>
<td>How to stimulate/prevent this in the future (lesson learned)</td>
<td></td>
</tr>
</tbody>
</table>

The categories suggested to use are based on previous project evaluation sessions within Tebodin. The topics included are shown in Table 6-2. Since the aim is to integrate the knowledge of lessons learned in future projects, a structure is set up for the project evaluation that can be used in a database too, so lessons learned can easily be searched for in a database. Advantages and limitations of this checklist are discussed in Appendix F: Risk breakdown structure.

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19 Communicated with the facilitator of the project evaluation session
Table 6-2 Project evaluation topics

<table>
<thead>
<tr>
<th>Categories</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>Suppliers/subcontractors</td>
<td></td>
</tr>
<tr>
<td>Budget</td>
<td>Legal (procurement/regulatory)</td>
<td></td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organizational</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Another functionality, apart from providing a clear overview where topics are distinguished, is to make sure that the project evaluation meeting is time-bound and time is spent on each category. This prevents spending too much time on one subject and the facilitator must ensure that all categories are discussed and a structured schedule is followed. Furthermore the use of a spreadsheet can ease the process of summarizing the meeting and create a useful overview.

**Step 2**
Once the facilitator has finished the report, it should be sent to an individual who is not part of the project team, but who is able to critically select and prioritize, which lessons learned are going to be included in the database. This is done by expert evaluation. The reason why someone from outside the project team should be responsible for this task, is because this person should not relate the lessons learned to the specific project, and by pointing out someone who is responsible for doing this after every project evaluation, the skills to identify independent useful lessons learned will enhance. It is important for the expert to first select which lessons learned are useful and to afterwards prioritize per topic according to the importance of the lesson learned. As more input is given to the tool every time a project evaluation session is completed, the selection of only the essential ones who contribute and who create new knowledge should be taken along.

**Step 3**
Now that a selected list of lessons learned has been created, the next step for the expert is to make a translation from the lessons learned that are specific related to the project to project independent worth knowings. Knowledge should be generalized, so that cross-project learning is possible (Dikmen, Birgonul, Anac, Tah, & Aouad, 2008). At the end of this step the output is going to be a document where all the lessons learned are translated and summarized into independent statements and comply with criteria. The criteria, shown in Table 6-3, are set up to which the facts must comply with so they are useful for future projects.\(^{20}\)

<table>
<thead>
<tr>
<th>Criteria for project independent lessons learned</th>
</tr>
</thead>
<tbody>
<tr>
<td>The lesson learned should not state the obvious</td>
</tr>
<tr>
<td>The lesson learned is independent from the project</td>
</tr>
<tr>
<td>The lesson learned should contribute to new knowledge</td>
</tr>
</tbody>
</table>

Every lesson learned is converted into a project independent statement and is confirmed by consulting the established criteria. By generalizing lessons learned, but keeping them separately categorized, its added value becomes larger to be useful for other PMs.

**Step 4**
The last step consists of including the defined lessons learned into a database. By integrating the lessons learned in a software tool that sends the information to departments or employees that is filled in by the expert, the right people are aware of important lessons learned. In addition to this one-time update, an incentive should be created to integrate the tool well in a future project. It is suggested to consult the database as a compulsory part of setting up the business concept in the FEL-1 stage and in the project plan

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\(^{20}\) The criteria are composed in consultation with Tebodin’s QOHSE coordinator
in the FEL-3 stage. The tool should be accessible for PMs and made compulsory by making it part of a checklist during these stages. In this way an incentive is given to integrate the lessons per category when setting up a new project, and no lessons are neglected. Furthermore, the database should be consulted during the project to ensure new lessons learned are taken along, and the project plan is actually followed.

Figure 6-8 gives an overview of the post-project evaluation tool improvements that are suggested to improve the old way of using lessons learned from a project evaluation.

![Figure 6-8 Project evaluation tool improvements]

*Note: The disadvantage of conducting the session after the project is that some events might be forgotten or ended up well while the way to reach success entailed difficulties. Therefore it is desirable that the database is used iteratively so that during the project the PM can keep being informed about the latest developments regarding new lessons learned. Consulting database should occur on a continuous basis throughout the life of a project.*

**Experiment**
An experiment has been set up to test the steps that were suggested above on how to use the information of a project evaluation. A project evaluation session has been prepared with the PM and analyzed, and the participants have been asked to give feedback by means of a survey. The suitability of a new software tool (Active) to insert lessons learned has been tested. The steps that have been taken and the results are described in Appendix E: Experiment.

**Conclusion**
The design-based research consisted of observation, a questionnaire and an attempt to close the loop by integrating the software tool Active into the procedure. The following conclusions are drawn, each followed by recommendations.

Through the observation of the project evaluation session:
• *The participants should be instructed on how to prepare for the evaluation session.*
• *The discussed topics in detail should be sent around beforehand.*

Through the questionnaire:
• *The session should be organized right after the project has been finished, and it should be made compulsory in the TQS, and in the close-out report.*
• *Every project should organize a project evaluation session and everyone should be given access to the lessons learned database.*

Through discussion with the expert of the Active software program:
• The *Active* system works if input is given by project evaluation reports.
The quality department should implement the project evaluation report in the Active system.

- Tebodin employees can only benefit from each others experience and information if they are updated with the lessons learned that are relevant for them.

The Active program should send lessons learned to specific departments/employees.

- When PMs set up a proposal, business concept or a project plan, Active can be consulted and the lessons learned that are registered under a category, can be found as a checklist in the database.

The database should be accessible for all PMs and it should be compulsory to consult the Active tool when setting up the proposal, business concept and the project plan. An existing manual for lessons learned consultation exists, and can be used as a concept procedure.

To conclude, to answer the question “How can knowledge transfer between EPC or EPCm projects be improved?” a ‘lessons learned’ database is suggested to benefit from the lessons learned from previous projects, and transfer knowledge within the company to prevent making the same mistakes twice. In the database information retrieved from project evaluations can be stored and sent to relevant departments, and checklists in the database can be consulted by PMs when setting up a proposal, business concept and project plan.

6.3.2 Risk identification

The second part of the in-depth study consisted of analyzing risk identification techniques, which is the first level of project risk analysis (CII, 2012). Risk identification is the first step in a complete risk analysis, given that the objectives of the decision makers have been well defined (Vose, 2008). The study emphasizes the importance of a good project start, by involving all project team members in the process and reaching general consensus on moving into the same direction.

The structure to answer the question: “How can risk identification be improved?” is shown in Figure 6-9. First, the current way of identifying risks at Tebodin is explained, including possible gaps. Then, a description is given on how literature tools and techniques can be integrated in the risk management framework, followed by trade-offs that have to be made, and finally conclusions are drawn.

![Figure 6-9 Risk identification study framework](image)

**Current situation**

Many PMs choose to organize a RI&E session at the start of a project, at the design & engineering phase, and occasionally prior to the construction phase.21 During this session the project team brainstorm risks, either to identify safety risks, or to ascertain all project risks. Tebodin uses experienced facilitators to lead this session, which, for appropriate project risk analysis, is a requirement by the CII (2012). Literature shows that brainstorming by itself is not the only technique for risk identification, and that many more techniques are available (De Marco & Thaleem, 2014). It is important that the risk identification process should be systematic and include details not only what could happen, but also where and when the risk might happen as well as why and how they might happen (McGeorge & Zou, 2013). The focus traditionally is on identification of potential problems, entering those problems into a risk register, assigning a person as a ‘risk manager’, and forgetting about it (Merrow, 2011). Tebodin does not make use of a risk manager, but chooses the PM to be responsible for risk management during the project. This means that the PM is responsible for assigning tasks to carry out mitigation actions and to keep track of the PRR. To enhance the current risk identification procedure, a number of alternative tools to support techniques have been consulted during the literature review, and are used to design the method.

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21 Interview with Tebodin project manager, see Appendix D: Interview summaries
Designed method
As discussed in section 5.5 the risk identification techniques that are incorporated in this research are project analogy and brainstorming. Figure 6-10 is a zoomed in part of the conceptual model that was shown in Figure 6-4 focusing on risk identification. A task that many engineers find very difficult, is to communicate about what they do not know (van de Poel & Royakkers, 2011). To facilitate this, the use of multiple tools is suggested. The additional tools that are presented for project analogy are the database and the cost control report. For the brainstorm session a Risk Breakdown Structure (RBS) and the process flowchart is suggested, based on the cultural fit with Tebodin as explained in section 5.5. The output for both project analogy and the brainstorm session is a PRR including all project risks, which is shared with the client, and a C&R list with internal risks for Tebodin.

![Diagram of risk identification as part of the conceptual model]

**Project analogy**
Project analogy is a technique to find post-completion summary reports, and project team members’ recollections from earlier analogous projects (Nicholas & Steyn, 2012). The Active database is suggested because of the research conducted for post-project evaluation, where a database is created with lessons learned from previous projects. A checklist analysis is based on accumulated historical information from previous similar projects. The checklist is complementary to the database, as the database can generate list of topics with lessons learned. Some examples of categories are schedule, safety or procurement. By searching through the database of the software tool Active, lessons learned from previous projects can be categorized and generated into a checklist. The database can be consulted when setting up the proposal, business concept and project plan, and can be helpful identifying related risks. Furthermore the cost control report from similar projects can be consulted to make cost estimates.

Too often when a previously identified problem occurs, the project director and team are not prepared to respond because the response has not been worked through in advance (Merrow, 2011). By consulting the database, this tool can help to foresee certain situations and suggests proposed improvements on how to respond to risk events. The limitation is that not all situations can be found in the database, and that it takes time before the database is filled with information.

**Brainstorming**
Brainstorming is a technique by which a group attempts to generate ideas or find a solution for a specific problem by amassing ideas spontaneously and without judgment (Osborn, 1963). An experienced facilitator external to the project should run the brainstorm session to identify risks (CII, 2012), which is also the case at Tebodin. In addition to the already identified checklist from previous project, for brainstorming the aim of the group session is that every participant reflects about risk events outside their own expertise and amplifies each other through group discussion. Important is not to only look at risk threats, but also to include risk opportunities. It is also possible, if time is permitted; to beforehand already individually interview the lead engineers of every department to gain information about very discipline’s point of view. From an interview with a Tebodin consultant this is confirmed to add value to the RI&E session. To include expertise on construction risks, the CM should also be involved in this session. The most common problem, according to Merrow (2011), is that the person needed is not available, furthermore he suggests that the CM starts to be involved from FEL-3 (Merrow, 2011).
Regarding the output of the project analogy technique, researchers are critical on particular tools that are used. The PRR for example has been identified as being an inadequate tool because it fails to capture the inter-relationships between risks and the systemic structure within the risks (Tah & Carr, 2001). That is why a process flowchart is suggested. A process flowchart, which illustrates the steps, procedures, and flows between tasks and activities in a process, should be consulted when defining risk interaction between project tasks. The process flowchart can consist of the tasks and activities that are described in the planning. Tebodin makes use of MS project to keep track of the planning. Because risk events also can interact with each other, it is necessary to indicate what risk interactions can occur when identifying risks. Chauveau (2006) identifies three main types of risk interdependencies that can be distinguished that are shown in Figure 6-11.

![Figure 6-11 Risk interdependencies (Source: (Chauveau, 2006))]  

For every risk it should be thought of if any type of interaction is possible and only when it appears, this should be reported. The tool should not be too time consuming by designing a matrix to identify all interdependencies between risks. If it is the case that one risk event has effect on another, this can be mentioned in the PRR.

Chances and risk identification is a team activity and the project team should have a mutual understanding of the specific risk events. To obtain a clear overview, the positive and negative aspects of the project should be categorized into categories. Not only negative risk threats but also opportunities should be discussed. A tool that is helpful during the brainstorm session is the RBS. The RBS is a common and very practical tool, widely used during the various stages of project life in risk management such as the risk identification stage and risk assessment and risk response (Mehdizadeh, 2012). For risk identification a table is designed to break down risks. The goal of subdividing the categories is to take all project risks into account. The RBS should be designed in a conservative way to make it usable and not complicated. The first layer will be internal versus external risk categories, which are then subdivided into the categories used to evaluate the project.

Mehdizadeh’s proposed approach consists of tailor made RBS which is used iteratively throughout the project, and which facilitates the dynamic process of risk identification. It is necessary for any organization wishing to use the RBS as an aid to its risk management to develop its own tailored RBS (Hillson, 2002). The suggested RBS categories are depicted in Table 6-4 and are chosen upon their mutual exclusivity, and by comparing RBSs from several researchers, which is clarified in Appendix F: Risk breakdown structure. An organization may wish to produce a single generic RBS covering all its projects, or there may be several different RBS structures applying to particular project types (Hillson, 2002). The suggested RBS categories are proposed as a single generic RBS, and serves as the input for the brainstorm session. For each topic, more categories can be added if necessary.

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*Appendix D: Interview summaries*
Table 6-4 Suggested risk categories

<table>
<thead>
<tr>
<th>Categories</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td></td>
<td>Suppliers/subcontractors</td>
</tr>
<tr>
<td>Budget</td>
<td></td>
<td>Legal (procurement/regulatory)</td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An overview of the main improvements using several risk identification tools is shown in Figure 6-12. However, implementing theoretical frameworks correctly in practice requires good instructions and understanding of the procedures, and sometimes trade-offs need to be made.

**Trade-offs in practice**

The proposed method suggests consulting four tools and combining them to identify risks. As explained in section 2.3, the iron triangle (time versus quality versus cost) consists of project drivers that influence the project objective. There are many examples of non-achieving time, cost and quality of projects due to absence of risk management techniques in project management (Dey, 2001). Depending on the project driver, different strategies are discussed.

**Time driven**

When a project is time driven, risks can be identified through a brainstorm session. Although it requires the entire project team to be involved, it is the most common way at Tebodin to identify risks. Consulting a checklist from the database to integrate lessons learned from previous projects and derive them into project risks requires little time, if the database is set up in such a way that checklists are easily traceable. Merrow (2011) identifies that the priority, independent of a contract type, after safety should be on schedule, because in execution, if the sponsor is watching it carefully, lagging schedule is the key leading indicator of trouble ahead. If a schedule is planned well, also in a time driven project time can be invested in designing a tailor-made RBS to structure risks (unless one that fits the project has already been used) and to consult a process flowchart.

**Cost driven**

Costs are closely connected to time, as time in a consultancy & engineering company is money, and man-hours have to be declared to the client. As it is hard to define whether using a tool is expensive, costs are expressed in man-hours. When a project is cost driven, trade-offs have to be made regarding the amount of time spent on a tool. Cost comes to depend on meeting schedule because there is an optimal schedule that is an indicator of being on budget (Merrow, 2011). As with a time driven project, costs are reduced when less time is spent, so the same tool discussion applies for this project driver.

**Quality driven**

Quality is a project driver that requires delivering a validated end result. Surprisingly, Merrow (2011) identified that the use of substantially new technology was associated with less slippage, not more. The
reason for this is that clients set longer engineering schedules when technology is new. The process flowchart and RBS enhances identifying risk interaction, which can increase the quality of risk identification, but requires time (and implicitly cost).

Conclusion
To answer the question: “How can risk identification be improved?” consulting the database for useful lessons learned and opportunities from previous projects is suggested, and expanding the brainstorm session by using an RBS and consulting a process flowchart improves covering all project risks (instead of only safety ones) and identifying risk interaction. The PMs should be aware what drives a project, and in consultation with the client, trade-offs need to be made explicit regarding time, cost and quality. Then the risk identification process can be improved by choosing which tools to consult.

6.3.3 Quantitative analysis
The final in-depth study consists of quantitative methods used to analyze the project planning and budget estimation. This is described in the third level of project risk analysis in Appendix A: Project risk analysis levels, by CII (2012). The structure to answer the question: “Are quantitative analyses recommended to continuously improve projects?” is shown in Figure 6-13. First, a closer look is taken at the current situation as it is at Tebodin. Then the literature techniques are identified, followed by the explanation of the pros and cons of quantitative techniques, ending with a conclusion.

Current situation
The interviews with Tebodin’s PMs showed that quantitative analyses are not extensively used. It is therefore important to take into account the company’s culture, willingness and awareness of the added value to use different methods. Table 6-5 gives an overview of the reasons why quantitative methods are not extensively used. As most interviewees mentioned using the P-I matrix, cost estimates and S-curves as shown in Table 5-2, the focus of quantitative methods in this part of the research is not on these, but on techniques such as EV, Monte Carlo and PERT analyses, where cumulative effects are measured, and probabilistic distributions are simulated.

Table 6-5 Overview why quantitative analyses are not used

<table>
<thead>
<tr>
<th>Interviewee</th>
<th>Quantitative methods used?</th>
<th>Reason not to use quantitative analyses that measure cumulative effects?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>No</td>
<td>Not part of the procedure (TQS).</td>
</tr>
<tr>
<td>2.</td>
<td>No</td>
<td>Not part of the procedure (TQS).</td>
</tr>
<tr>
<td>3.</td>
<td>Monte Carlo</td>
<td>Not all costs were visualized and the scope changed. Not enough knowledge to benefit from added value.</td>
</tr>
<tr>
<td>4.</td>
<td>No</td>
<td>Too small projects.</td>
</tr>
<tr>
<td>5.</td>
<td>Hardly</td>
<td></td>
</tr>
<tr>
<td>6.</td>
<td>Monte Carlo</td>
<td>Time consuming, manipulative direction towards result, subjective tool. Useful to convince the client of budget and time precision.</td>
</tr>
<tr>
<td>7.</td>
<td>No</td>
<td>Not necessary.</td>
</tr>
</tbody>
</table>

Summarized, an aversion can be noticed from the interviewer’s responses, or they have not had any experience using these types of methods.

Literature techniques
The techniques that are analyzed are taken from the conducted literature study from section 4.4. In the conclusion of the analysis in section 5.5 it was explained why the chosen quantitative techniques are included in this research. The research about quantitative analyses is conducted to provide an overview of their added value, but also their limitations, and to explain whether these techniques can become part of a continuous improvement strategy in Tebodin’s procedures. Figure 6-14 shows the quantitative analysis as
part of the conceptual model. The suggested techniques can be used to control time and/or cost.

<table>
<thead>
<tr>
<th>Input</th>
<th>Technique</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decision tree</td>
<td>EV</td>
<td>Chosen option</td>
</tr>
<tr>
<td>Costs of activities</td>
<td>Monte Carlo</td>
<td>Schedule estimate</td>
</tr>
<tr>
<td>Time of activities</td>
<td>Sensitivity analysis</td>
<td>Cost estimate</td>
</tr>
<tr>
<td>Schedule</td>
<td>PERT</td>
<td>Critical path</td>
</tr>
</tbody>
</table>

![Figure 6-14 Quantitative analysis as part of the conceptual model](image)

The focus of this research is to evaluate existing techniques and to identify resources to determine cumulative effects of risks. The difference between deterministic (such as s-curves) and probabilistic models is that with deterministic models outcomes are precisely determined through known relationship without random variation, while probabilistic models use ranges of values for variables in the form of probability distributions (BusinessDictionary, 2014a). With probabilistic models an element of chance is involved, while for deterministic models all data is known beforehand. To integrate quantitative techniques into project management, it is important to define whether it is fit for purpose. First, a description is given of the specified quantitative techniques from Figure 6-14 to elaborate on their added value, and an overview is given which data needs to be available.

**EV**

The expected value, also sometimes referred to as the expected monetary value (EMV), is the product of a risk event probability and the risk event’s monetary value, to help find the EMV a decision tree can be drawn (Schwalbe, 2014). If the risk occurs, the financial or time loss to the project is calculated. It can be used to put aside money in a risk reserve account for potential risks (PMI, 2004). To decide on the EMV, the standard presentation of decision tree analysis is used (Hulett, 2006). The decision tree is a diagramming analysis tool used to help select the best course of action in situations in which future outcomes are uncertain (Schwalbe, 2014). It is used for planning on individual risks instead of planning for the whole project, and takes into account future events to make a decision today, involving mutual exclusivity (PMI, 2004). When certain choices have to be made, a decision tree can be used to compare investment costs for different options and probabilities of the option are placed on the decision tree. Decision tree analysis helps in forming a balanced picture of the risks and rewards associated with each possible course of action (Dey, 2002).

**Monte Carlo and sensitivity analysis**

Simulation uses a representation or model of a system to analyze the expected behavior or performance of the system (Schwalbe, 2014). Monte Carlo analysis simulates model’s outcome many times to provide a statistical distribution of the calculated results (Schwalbe, 2014). It is used to evaluate the impact on the schedule and budget and creates a probability distribution. It determines the probability of completing the project on time and within budget, and takes into account path convergence, which are places in the network diagram where many paths converge into one activity (PMI, 2004). In order to achieve a level of timely completion, mitigation actions can have effect on the duration of the project. The same applies for cost targets.

The sensitivity analysis shows the effects of changing one or more variables on an outcome (Schwalbe, 2014). It is used to determine which risks have the most potential impact to the project and to analyze risk taking scenarios (PMI, 2004). Sensitivity analysis can be efficiently carried out in Monte Carlo simulation and can therefore be combined when estimating project time and cost (Fu & Hu, 1995).
**PERT**

PERT is a methodology for planning many diverse activities regardless of their nature, and is useful in either small or large projects (Cook, 1966). In probabilistic network planning, all the activities of a project are scheduled in order to get an overview which path is going to be the critical path. PERT allows estimated probability distributions for the duration of the activities to be accounted for, by providing three estimates for the duration of an activity (pessimistic, most likely, optimistic) (van Gunsteren, 2011). The critical path forms the necessary route that needs to be taken to complete the projects. Activities from the critical path can start when the activities before are finished. The activities therefore need to be completed in a sequence, and whenever a delay occurs in one activity, this will postpone the completion date of the project. The shortcoming is that PERT only provides information on activities on the critical path that was established using the expected mean times of the activities the project is composed of, while it may be that the critical path is different from the one calculated with the estimated means of the activities (van Gunsteren, 2011). The IPA, who states that merely defining the critical path is not enough for schedule development, confirms this (Merrow, 2011). To remove this shortcoming, one or more paths through the network, that may actually become critical paths as a result of high variability in the duration of activities in those paths, should be established, and a Monte Carlo simulation can be conducted on each of these paths (van Gunsteren, 2011). So if more paths are considered and incorporated in the Monte Carlo simulation, the results show a probability distribution, out of which the probability of completing the project in the associated completion time can be inferred.

**Table 6-6 Necessary data for quantitative analysis**

<table>
<thead>
<tr>
<th>Tools</th>
<th>Data needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>EV</td>
<td>Cost of each decision, scenario probability, monetary impact of values.</td>
</tr>
<tr>
<td>Monte Carlo &amp; Sensitivity analysis</td>
<td>Time of every activity (including most optimistic and most pessimistic), risk of delay, chance of early finish, predecessor, relation between activities, man-hours (cost).</td>
</tr>
<tr>
<td>PERT</td>
<td>Time of every activity (including most optimistic and most pessimistic), relation between activities.</td>
</tr>
</tbody>
</table>

If useful data is found that fits with the quantitative technique as shown in Table 6-6, which is based on the description of the techniques, then the techniques can be used. If no useful data is found, either time should be spent to acquire the required data, estimate, or no use should be made of quantitative analysis. Regarding estimating durations of activities, some subjectivity is involved when no exact data is available from previous projects. It is important that the individual activities on a network be estimated in a random manner to avoid biasing the time estimate of an activity by an estimate given for an activity immediately preceding or succeeding it (Cook, 1966). According to Cook (1966), depending on the uniqueness or newness of the activity, values of the estimates will have a larger or smaller range.

**Pros and cons**

A closer look is taken at what researchers have concluded about whether to use quantitative risk management methods in construction projects. There are pros and cons about the methods, so it is interesting to understand what the added value is and when they can be used. The benefits and limitations of probabilistic distributions are explained by CII (2012), described in Appendix A: Project risk analysis levels. The benefits are that cumulative probability distributions can be simulated, the probability of meeting project targets increases, and project cost or duration is based upon desired level of certainty (CII, 2012). The limitations are that probabilistic distributions require six to fifteen times the amount of time compared to the identification phase, and it is dependent on the validity of information input into the model and complexity of the model (CII, 2012). Opinions differ about the added value of Monte Carlo. According to Merrow (2011), Monte Carlo is worthless, because simulation results have the sense of being true without any of the burden of actually being true, and there is no relationship to success of megaprojects. Is the Monte Carlo only useful to convince the client, as one of the interviewees claimed? For the client it is of great interest to know the probability distribution for the completion of the entire project, while for the PM it is important to know how much attention should be paid to monitoring activities on the various paths, which the result of the Monte Carlo simulation indicates (van Gunsteren, 2011). So for both it is important, but looking at different results of the method.
Quantitative analysis techniques, based on their sophisticated mathematical, statistical and scientific background, promise a detailed and thorough quantification and measurement of risk, which is very important for designing the response to critical situations (Thaleem et al., 2012). Monte Carlo requires a lot of data, and if the scope is not well defined, the central value of every element in the estimate is wrong (Merrow, 2011). Thaleem et al. (2012) reviewed quantitative analysis techniques for construction risk management, and according to them although the quantitative techniques use more resources than the qualitative techniques and are much more complex, the results obtained are also much more detailed and, in terms of risks, these are well analyzed. However, quantitative analysis is highly depended on availability of data and making good assumptions. Insufficient data can limit the accuracy and reliability of the prediction model. Apart from the available data, there are other factors that play a role whether to use quantitative analysis.

A large variety of risk management techniques have made selecting an appropriate solution difficult. De Marco and Thaleem (2014) propose a practical framework methodology to assist construction PMs in choosing a suitable risk analysis technique based on the project drivers: level of challenge, PM responsibility considering the size of the scope of work, the focus on one or more phases of its life-cycle and the level of maturity of the project management processes of the project management organization. Categories of risk analysis techniques are incorporated in a radar diagram, shown in Figure 6-15, which can help PMs to select the appropriate risk analysis technique according to the project’s driver level.

![Figure 6-15 Risk analysis selection for construction projects (Source: (De Marco & Thaleem, 2014))](image)

By defining the four suggested project drivers, the radar diagram gives an indication on what techniques to use. Techniques described to belong to the categories, which are also described in this thesis are:

- Simulation: Monte Carlo
- Quantitative techniques: Decision tree analysis, EMV, sensitivity analysis
- Semi-quantitative: P-I matrix
- Qualitative: Brainstorm, checklist, RBS

De Marco & Thaleem have tested this methodology with two construction projects and concluded that the results and feedback seem promising and call for more exhaustive testing at a broader level. To decide whether quantitative analysis is useful each of De Marco & Thaleem’s project driver is explained concerning Tebodin as a company.

**Challenge**

A project’s level of challenge is defined by the uniqueness of the constructed facility, the innovation of the construction process, the complexity of the system design and the criticality of the time frame (De Marco & Thaleem, 2014). The level of challenge is an important factor because analyzing budget and cost estimates can be useful for more challenging projects. Comments are given on the semi-quantitative P-I matrix that is used. Cox (2008) has examined some mathematical properties of risk matrices and shows that they have
limitations like poor resolution, errors and ambiguous in and outputs. This can be a reason why more developed techniques such as quantitative methods or simulation can be applied. Especially when the criticality of the time frame is considered important at Tebodin, this might be a reason to use quantitative analysis.

**PM responsibility**
The PM’s level of responsibility depends on the scope of the project and number of employees involved with the project. As Tebodin does not make use of an individual risk manager, this means the PM is responsible for managing risks throughout the project. The larger the scope of work, the more difficult it is to retain an overview of the project schedule and budget, so using quantitative or simulation methods to manage project risks can ease this.

**Focus**
To define the project’s focus, the type of project has to be determined and the amount of phases of its life cycle that is concerned. The project size can determine whether to use quantitative tools to estimate cumulative effects for medium and large projects. For small projects, (as confirmed by Tebodin interviewees) the schedule and budget can often be easily overseen, whereas larger projects that cover multiple phases of the project’s life cycle can benefit from the tools because of their accurate estimation.

**Maturity**
It is necessary to understand the company culture and risk maturity to determine what type of analysis is fit for purpose. Large, complex projects involving cutting-edge technologies often require extensive quantitative risk analysis using EV, decision trees, Monte Carlo and sensitivity analysis (Schwalbe, 2014). Depending on the type of projects and how developed risk in Tebodin’s organization is, quantitative methods can be used.

To discover whether cultural change is possible, a culture comparison is made between the Netherlands and Germany, as Tebodin recently has become part of the German engineering and services company Bilfinger. The comparison is based on the cultural dimensions taken from Hofstede’s online comparison tool (G. Hofstede, 2014). The main, and only obvious difference between the countries is their rating in masculinity versus femininity. The Netherlands scores low, which means that the dominant values in society are caring for others and quality of life. Quality of life is the sign of success and standing out from the crowd is not admirable whereas a masculine society, where Germany scores high, is one that is driven by competition, achievement and success (Hofstede, Hofstede, & Minkov, 2010). Another consideration is whether the organization quickly accepts changes in their procedures. From the conducted interviews it was noticed that PMs were open for change, but also prefer their own way of working. A difference was noticed between the years of experience whether PMs were managing according to prescribed documents or through their own experience, which they believe works. Younger PMs appear to be more reliant on existing Tebodin procedures whereas older PMs work according to their self-developed systems.

**Conclusion**
To answer the question: “Are quantitative analyses recommended to continuously improve projects?” quantitative techniques are explained. The advantages are that they can determine cumulative effects of risks, the probability of meeting project targets increases, and project cost or duration is based upon desired level of certainty. The disadvantages are that probabilistic distributions are time consuming and their usefulness is dependent on the validity of information input into the model and complexity of the model. Whether quantitative methods are recommended depends on the type of project, the company culture, and according to availability of data. A strong risk management culture must be developed to benefit from the added value of quantitative tools, which requires more research into a suitable implementation strategy, which is developed in chapter 8.
Summary of in-depth studies
The in-depth studies have led to insight into the valuable tools that can support the techniques and be used to manage risks in construction projects during the risk identification, quantitative analysis and post-project evaluation phase. A comparison of risk-related techniques Tebo isin uses and what is reviewed in literature and benchmarking has been made and an improvement strategy has been presented:

• To improve knowledge transfer between projects and to avoid making the same mistakes twice, a ‘lessons learned’ database is suggested. This can help the company learn from the lessons from previous projects, and facilitates knowledge transfer within the company to. In the database information retrieved from project evaluations can be stored and sent to relevant departments, and checklists in the database can be consulted by PMs when setting up a proposal, business concept and project plan.
• To improve risk identification consulting the database for useful lessons learned and opportunities from previous projects is suggested. Expanding the brainstorm session by using an RBS and consulting a process flowchart enables all project risks (instead of only safety ones) to be evaluated and identifies risk interaction. The PMs should be aware what drives a project, and in consultation with the client, trade-offs need to be made explicit regarding time, cost and quality.
• Whether quantitative methods are recommended depends on the type of project, the company culture, and availability of data. A strong risk management culture must be developed to benefit from the added value of quantitative techniques, which requires more research into a suitable implementation strategy, which is developed in chapter 8.
7 Verification, validity & reliability

The framework is verified by reviewing whether it complies with the preconditions that were set up from interviews and literature study. A validity study is also conducted by interviewing Tebodin management to determine the functionality and the fit of the proposed framework with the company. Finally conclusions are drawn about the reliability.

7.1 Verification

Verification is a process used to demonstrate that the intent of a design is preserved in its implementation (Bergeron, 2003). The preconditions for the risk management framework (Table 5-3) are used to verify the techniques. Table 7-1 shows whether the three described focal points comply with the preconditions.

The aim of setting up preconditions from the interviews was to ensure the correct factors were considered when designing techniques. Table 7-1 shows that with one exception, all preconditions have been met. It can therefore be concluded that the intent of the design is maintained in its application. Each of the focal points in the following paragraphs is explained as to how they comply with the preconditions.

Table 7-1 Meeting the preconditions

<table>
<thead>
<tr>
<th>Preconditions for the risk management framework</th>
<th>Post-project evaluation</th>
<th>Risk identification</th>
<th>Quantitative analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Risk management integration</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Accessible lessons learned</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Incentives for risk management awareness</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Risk management for all project drivers</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Risk identification during FEL</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Communication within the project team</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Unavoidable risk techniques</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Iterative risk management</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Development of quantitative methods</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>• Techniques used in other industries</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Opportunities in risk management</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Post-project evaluation

The awareness that is raised with the post-project evaluation technique is a way of integrating risk management into project management. It recommends reviewing the project by making it part of the TQS, which triggers project team members that their input in project evaluation sessions are of added value to the entire organization. The technique is set up in such a way that it cannot be avoided because the report of the project evaluation session has to be sent to the quality department, and becomes part of the TQS. During the evaluation, lessons learned in both positive and negative aspects of the project are discussed. When a new project has started, it becomes easier to prevent making the same mistakes when identifying risks, because the lessons learned are visible for all in the Active database.

Risk identification

This focal point integrates risk management into construction projects. In addition to risk threats, the suggested techniques also consider opportunities. Using a process flowchart and focusing on the interaction between risk effects is an incentive to create awareness. Taking this into account when assessing risks improves the risk management process, as well as involving the project team such as the CM at an early phase. This focal point suggests consulting checklists in the database (updated with lessons learned) during the FEL phase, brainstorming and using an RBS to include all project risks. As well as considering A-forms or B-forms, it is assumed that risk management starts from beginning of the project, and allows for making trade-offs for project drivers. The identification of risks is a continuous process to improve project control, using the suggested tools minimizes contingencies.
Quantitative analysis
Using quantitative analysis is a way of managing risks and opportunities in a project. The results provide information about project objectives, causing trade-offs between project drivers. Whenever changes occur, these can be implemented in the tool and can be used iteratively during the project depending on scope changes. In order to provide correct data for the quantitative analyses, the client is involved to reach an agreement about the input and to convince the client about project estimation. The results of quantitative analysis are also useful to show trends and detect focal points early in the FEL phase. Although the construction industry lags behind other industries in using quantitative analysis, they can benefit from it when risk maturity is increased.

Summary
The preconditions were set up based on the conducted interviews and substantiated by the literature review. With the exception of risk comparison with other industries, all preconditions were met, and the intent of the design maintained. This does not imply that the proposed framework contains all elements that a risk management framework needs; but that it fits with Tebodin’s current risk maturity and culture. More research is suggested on techniques that are used in other industries that could be transferable to the chemical construction industry.

7.2 Validity & reliability
Klenke (2008) identifies four strategies for design quality, consisting of construct validity, internal validity, external validity and reliability. Validity refers to the objectivity of research (Silverman, 2011), and concerns on how far the results of this research represent reality. Each of the four strategies judge the quality of this research and are, as far as possible, applied and explained:

Construct validity
Construct validity is broadly defined as the extent to which a design measures the concept it is supposed to measure (Bagozzi, Yi, & Phillips, 1991). Yin (1993) suggests using multiple sources of evidence as a way to ensure construct validity. Construct validity can be achieved by developing its constructs through a literature review, use of multiple sources of evidence, establishing a chain of evidence, and having key external informants review draft case study reports (Christie, Rowe, Perry, & Chamard, 2000). This research uses multiple sources of evidence such as interviews, TQS manuals, documents, a literature review and benchmarking with CII and IPA, so can be considered construct valid.

Internal validity
Internal validity is applicable for explanatory or causal studies only and not for descriptive or exploratory studies. It seeks to establish a causal relationship, whereby certain conditions are believed to lead to other conditions, as distinguished from spurious relationships (Kidder & Judd, 1986). Qualitative research does not necessarily deal with cause and effect relationships of independent and dependent variables but rather with establishing a phenomenon in a credible manner (Yin, 1993). In this qualitative research no cause and effect relationship can be detected. Internal validity is therefore not applicable.

External validity
External validity defines the extent to which results of a study can be generalized to and across population, settings, and times (Johnson & Christensen, 2000). To ascertain whether the findings can be applied in the organization, first the choice of this research is explained. There are three main reasons for choosing to modify the current process and not to implement a new method. Firstly, the suggested method complements the current way of working making it accessible to all project members. Secondly, the tools can be integrated into the existing project management systems and procedures; and finally, small adjustments can have a significant impact on the existing system. The alternative would have been to implement a new, separate risk management method with which the company is unfamiliar. This
transformation was considered too drastic when considering the company culture. It is therefore expected that the company’s culture is more likely to accept incremental adjustments to the existing system.

Whether the research findings can be generalized is defined in expert validity interviews, which is divided into two types: validating the framework implementation in Tebodin’s organization, and validating the framework compared to other companies. Seven feedback interviews are held with Tebodin management, shown in Table 7-2 with the purpose to present and explain the framework, receive feedback, gain insight in Tebodin’s perspective, compare with other companies, and conclude the validity of this research. Chapter 8 describes the framework implementation at Tebodin, and takes into account the interview results.

Table 7-2 Expert validity interviews

<table>
<thead>
<tr>
<th>Expert interviewees</th>
<th>Company</th>
<th>Function expert validators</th>
<th>Date</th>
<th>Purpose</th>
<th>Focal points</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Tebodin</td>
<td>Department Coordinator</td>
<td>29-07-2014</td>
<td>Internal validity</td>
<td>1</td>
</tr>
<tr>
<td>2.</td>
<td>Tebodin</td>
<td>Department Manager</td>
<td>31-07-2014</td>
<td>Internal validity</td>
<td>1</td>
</tr>
<tr>
<td>3.</td>
<td>Tebodin</td>
<td>Department Director &amp; Consultant</td>
<td>05-08-2014</td>
<td>Internal validity</td>
<td>1,2,3</td>
</tr>
<tr>
<td>4.</td>
<td>Tebodin</td>
<td>Office Director</td>
<td>05-08-2014</td>
<td>Internal validity</td>
<td>1,2,3</td>
</tr>
<tr>
<td>5.</td>
<td>Tebodin</td>
<td>Department Director</td>
<td>14-08-2014</td>
<td>Internal validity</td>
<td>1,2,3</td>
</tr>
<tr>
<td>6.</td>
<td>Tebodin and other</td>
<td>Department Manager</td>
<td>04-08-2014</td>
<td>External validity</td>
<td>1,2,3</td>
</tr>
<tr>
<td>7.</td>
<td>Tebodin and other</td>
<td>Department Coordinator</td>
<td>14-08-2014</td>
<td>External validity</td>
<td>1,2,3</td>
</tr>
</tbody>
</table>

For validating the framework implementation at Tebodin, a range of experts at director, management and engineer level with extensive Tebodin experience and experience outside the company was selected. It must be noted that the views from directors can differ from for example PMs because their opinion is influenced by their function in the organization. After the interviews, the thesis was revised and the results of the interviews have been incorporated in the risk management framework and organizational implementation chapters (6 and 8).

The seven interviews for the validity of implementing the framework within Tebodin and for the validity by comparing the framework with similar companies are included separately in Appendix G: Validity interviews, and led to some adjustments.

Reflection
As the views from these interviewees can differ from the PM’s view, a reflection is given, which is taken into account in the following chapter, where the implementation of the risk management framework into the organization is described.

To ensure the risk management framework adds value to the entire organization, and not only to the PMs, the techniques mentioned by the directors could be added to the framework. This could be of added value to provide a complete overview of techniques that are also carried out by for example the consultancy department during the FEL of a project.

The framework fits in Tebodin’s culture, but in order to successfully benefit from the added value of risk management tools, the company must realize that the tools only serve as a support, and that the training of individuals and creating awareness requires the most time to change the culture of the organization. The intention of the proposed framework is not to make all the techniques compulsory for projects, but to make these techniques familiar within the organization, in order to improve risk awareness.

Making the project evaluation session compulsory for large projects is not always practical. However, lessons can also be learned in small projects (according to PMs) that can be beneficial to large projects. There is also a chance that small projects develop into larger projects. Tebodin could consider the consequences that when the client asks for more tasks; eventually the project can become a large project without having the obligation to carry out the project evaluation session.


**Reliability**

The objective of reliability is to be sure that, if a later investigator followed the same procedures as described by an earlier investigator and conducted the same case all over again, the later investigator should arrive at the same findings and conclusions (Yin, 2009). Although the interviews were semi-structured, the researcher provided a written summary of the interview to the interviewees and asked for feedback, to ensure that the answers during the interviews are well interpreted. By means of the feedback the interview summaries are adjusted, which makes this research more reliable. If another investigator were to carry out this research at Tebodin, it is likely the same findings were ascertained, however, this could only be the case if a similar representative sample within Tebodin’s staff was approached within the company.
8 Framework implementation in the organization

This chapter explains how to implement the risk management framework in the organization. Complementary to the in-depth studies, an implementation plan is developed for each focal point, which consists of explaining what support the tools and techniques need. This entails which department is involved, who is responsible and how information is transferred. For the company it is described which actions to take on the short and long term.

Through benchmarking with CII and IPA, findings about risk management techniques add to setting up a plan how to implement the techniques into the organization. The CII stresses the importance of project risk analysis, describing the benefits and limitations for risk identification, P-I matrices and probabilistic distributions (CII, 2012). The IPA stresses the importance of the project FEL phase where decisions about costs, schedule, operability and safety are made, and discusses the value of different techniques (Merrow, 2011). Through literature review a gap has been discovered between the theory and practice of risk management. This chapter contributes to filling this gap by describing how the techniques can be implemented in the organization and more importantly, why this implementation plan fits the organization.

8.1 Framework implementation

It is the decision of the company to use the complete or parts of the risk management framework. Parts of the framework can be implemented modularly, as the three focal points are separately described for implementation. This modular setup eases the implementation process, as different departments and responsible persons need to be involved. Based on the results of the conducted experiment, the implementation plan is set up for the post-project evaluation. For the other two focal points, the decision on actual implementation is discussed.

Post-project evaluation

To implement the post-project evaluation part, the results of the experiment are used. The implementation plan consists of three actions, which are separately explained:

1. Inform the QOHSE department about entering lessons learned from the reports in the database
2. Make specific project evaluation sessions compulsory
3. Familiarize PMs with the new procedure and grant them access to the database

This implementation plan can work because it combines the modification of existing tools and information access with raising risk awareness within the organization. If these actions are carried out, the added value of this plan is that all PMs will benefit from each other’s knowledge, and can use the database to improve their projects. A note to take into account is that this tool does not discourage oral communication between PMs about lessons learned. The tool is an example of a means to store information such that everyone has access to it. Awareness from both QOHSE coordinators and PMs is required to make this plan work. A change in behavior and attitude is necessary, which is why training should be given to PMs on how and why a project evaluation session should be carried out. This change requires a small extra effort of the PMs at the end of a project and can lead to great value to the organization and future projects.

Risk identification

It is suggested to change the current way of identifying risks, for which the tools that are discussed in section 6.3.2 can be applied. This plan suggests how to change the mindset within the organization and how integrating additional tools into working procedures can add to that. Risk identification requires a minimal investment of team member’s time to collaborate and create a risk register, and an experienced facilitator capable of identifying risks (CII, 2012). Tebodin complies with these requirements. The results of the in-depth study have led to the following actions:
1. **Introduce project analogy to PMs and facilitators from the consultancy department**
   It is suggested to use the Active database as an additional tool for risk identification, besides brainstorming. The PMs should have access to the database, to easily find lessons learned from previous projects, classified in different topics such as schedule, technical or organizational. The PMs can get access to the database after the test phase of the tool is completed.

2. **Add a process flowchart to identify risk interactions between project tasks**
   The second action of the implementation plan is to enable PMs to use a process flowchart to identify risk interactions between project tasks. To create risk management awareness among the project team, the process flowchart can be used during the brainstorm session. The PM can use the schedule for the project, as the process flowchart consists of the tasks and activities that are described in the planning. Then, as part of the brainstorming, the schedule can be used to identify the types of risk interaction between project tasks (destructive, creative, modifier), which then can be indicated in the PRR.

3. **Add an RBS in the brainstorm session to structure all project risks**
   The third action consists of using an RBS in which project risks are categorized. The goal of subdividing the categories (assuming that the project starts from scratch), is to take all project risks into account, not just the safety. The CM should be involved in this session, to give input on construction, and opportunities should be discussed too. The suggested RBS categories are proposed as a single generic RBS, chosen upon the categories’ mutual exclusivity, and serves as the input for the brainstorm session, shown in Table 8-1. Tebodin may wish to produce a single generic RBS covering all its projects, or there may be different RBSs applying to particular project types. For each topic, more layers can be added.

   **Table 8-1 Suggested risk categories**

<table>
<thead>
<tr>
<th>Categories</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td></td>
<td>Suppliers/subcontractors</td>
</tr>
<tr>
<td>Budget</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td>Legal (procurement/regulatory)</td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Quantitative analysis**

The IPA stresses the importance of a FEL index. FEL is important because it is a prime driver of almost every project outcome: cost, schedule, operability and safety (Merrow, 2011). If the FEL is best, megaproject are not particularly risky from a cost perspective, and the best practically front end loaded projects usually achieved their schedule (Merrow, 2011). In other words, if the schedule and costs are well defined in the FEL, the project is more likely to be successful. Too many megaprojects fail before they ever start execution because the schedule put forward by the sponsor is not achievable (Merrow, 2011). To create awareness among PMs about project risks, no implementation plan is suggested, but a long term perspective on this focal point is given, because risk culture is not something that can be changed overnight:

1. **Analyze which supporting tools for quantitative analysis fit within the company**
   To integrate quantitative analyses in the procedure different software tools exist. These tools can be used to link risk to schedule and cost using quantitative methods. A software tool that Tebodin is familiar with is Crystal ball that can be used to run Monte Carlo simulations. MS-project is already used by PMs and includes a limited version of the PERT analysis, meant to control the project planning. Other software tools that can be suggested to carry out the PERT analysis and that are specifically made for this tool is Primavera, which needs an expert to use it. Tebodin sometimes uses Primavera for larger projects. The disadvantage is that often the contractor's schedule can’t be implemented. For calculating the EV a decision tree is a useful tool.

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23 Interview with Tebodin project manager, see Appendix D: Interview summaries
2. **Develop risk awareness within the company**

A strong risk management culture must be developed to benefit from the added value of quantitative tools. Risk management is an iterative process; as the process is repeated the overall project risk can be tracked and a trend can be determined (PMI, 2004). The PM or the consultancy department can be responsible for the use of the software tool, but the input can be discussed with the client and project team members. To develop risk awareness, PMs should be informed about the techniques that exist and which are relevant to use.

3. **Develop a center of knowledge**

To make use of quantitative techniques, a center of knowledge needs to be developed. It would be useful to invest time in understanding the use of quantitative methods. Whether these techniques can become part of a continuous improvement strategy in Tebodin’s procedures not only depends on the available data, but also as De Marco and Thaleem (2014) concluded, on the company’s maturity, the project’s challenge, focus and the PM’s responsibility. This can be used as a guideline to increase knowledge on deciding which techniques to use.

### 8.2 Quick wins and long term goals

The implementation strategy of the three different focal points has been presented. Different departments are required to be involved, and a change in risk attitude is necessary for the implementation to be successful. For the company it is of added value to understand what the implementation plan on the short and long term should be, and how this fits with the company’s culture. Therefore the quick wins and long term goals are described, taking into account the results of presenting the implementation plan to internal and external validators, which was explained in the section 7.2.

#### Quick wins

A quick win is an implementation step that does not require a large effort and is expected to lead to an improvement. As the interviewees already mentioned something should be done with project evaluation reports in a form of feedback, the post-project evaluation is most likely to be a quick-win alternative. Tebodin is already implementing some initiatives. The database Active already exists, and QOHSE coordinators have had training how to use the software program, and are starting to enter incidents and audit reports into the database. The QOHSE coordinators are given a test phase to adapt to the new software tool, because they want to implement it carefully, as it is a Bilfinger tool that is not yet custom-made for Tebodin. After an evaluation of the tool in September 2014, they should start to include evaluation reports into the database similarly. This change requires a small extra effort for the QOHSE coordinators to implement lessons learned, and for the PMs to organize an evaluation session at the end of a project. This leads to a great value to the organization as everyone can benefit from lessons learned.

Another quick win would be to use the framework as a complete or partial guideline to manage risks during a project. On the short term the PMs should be informed (with for example a workshop) about using tools from the risk management framework. A risk manual could be developed where different risk identification tools are described. Risk-driven projects should brainstorm about all project risks. The additional techniques such as RBS and process flowchart should be explained by informing employees, which can help create risk awareness. This change requires a small extra effort for the project team during risk identification, as a brainstorm session already takes place for safety risks, adding other risk requires a few hours extra, but provides a holistic overview of risks. The CM should be involved earlier in the project, in the RI&E session he can already give input on construction risks. Merrow (2011) identifies the importance of the basis of risk management during the FEL of a project, which this can comply with. The facilitator of the RI&E session could be involved using project analogy (such as looking at cost control reports and checking the database) during the FEL, to identify important risks in previous projects.

Figure 8-1 shows the result of the quick win implementation. The quick wins lead to a small improvement in the risk maturity of the organization. Figure 8-1 is divided into the risk management techniques, the
procedures and the culture in the organization. The procedures and the culture are defined by the preconditions that are set up in section 5.3. The quick wins predominantly advocate the increased use of techniques, while the company’s procedures and culture require more time to change. A true growth in risk maturity can only be identified when the preconditions are complied with.

![Diagram](image)

**Figure 8-1 Risk maturity after implementation quick wins**

### Long term goal

A long term goal applies for an implementation that is expected to lead to an improvement on the long term. Successfully implementing the project evaluation means a change in the procedure and a cultural change. A TQS revision is on going, which is planned to be complete at the end of the year; then the adjusted procedure for project evaluation can be implemented. Once the QOHSE coordinators are adjusted to using the *Active* program, and the Bilfinger tool is custom-made to Tebodin, the next step is to inform the PMs by giving a similar training as the QOHSE coordinators received. This could be the first step of changing the mindset within the organization. The PMs should then be aware of the added value and should be able to access the *Active* database and use it when setting up a proposal, a business concept or a project plan during FEL, or as an additional tool when identifying risks.

To reflect on this, post-project evaluation fits well in the Tebodin organization, as the company wants to close the loop and develop a continuous improvement plan (which was the result of an ISO9001 audit carried out this year). Acceptance and willingness of PMs is needed to successfully integrate lessons learned in the organization. This can lead to a development in risk maturity. Tah and Carr (2001) say that an environment must be created where data can be stored and organized so that individual and teams can access it easily and intuitively. The easy access is explained in the quick win paragraph, but to access the database intuitively requires a change in mindset, which is a long term goal. To reach this, the task for higher management is to embed this in the organization. To create a risk culture, it requires consistent messages to employees that managing risk is a part of their daily responsibilities, and that it is not only valued, but critical to the company’s success and survival (Hoon & Farrell, 2009). To check whether risk

24 Interview with Tebodin consultancy director; results are explained in section 7.2: Validity & reliability
awareness in the organization is improving, performance interviews with PMs are suggested hence higher management is informed about the risk management performance within Tebodin’s projects.

Regarding the discussed quantitative methods, Tebodin’s position needs to be considered compared to peer companies. The construction industry is identified as being slow to realize the potential benefits of risk management, as risk analysis is based on intuition and experience, and it is the least developed industry when it comes to the application of formal risk pricing techniques, compared to the finance and insurance industry (Laryea, 2008). Integrating quantitative analyses as part of risk management could be a way for Tebodin to improve their risk management qualities and to improve their competitive position. The use of quantitative analyses fits with the consultancy department, where some of these analyses are being used. Depending on the client’s demand, a facilitator from the consultancy department who is involved in the RI&E session can for example be involved. To make use of quantitative techniques, a center of knowledge needs to be developed. The project control and cost estimator departments fit well for using Monte Carlo and PERT. The implementation strategy should focus on what techniques fit within Tebodin’s culture, if the company aspires to offer the client a comprehensive risk management portfolio, and to develop a center of knowledge about which techniques fit within the company, and how they should be used.

Figure 8-2 shows the risk maturity after implementation of the long term goals. On the long term, the organization is able to reach a high level of risk maturity by embedding risk management into their procedures and culture. The figure shows that the development of quantitative methods and finding techniques that are used in other industries are developments for the long term that cannot be changed immediately. The reason for this is that these changes require the most time, research and adaptation at both corporate and project level.

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25 Interview with Tebodin consultancy director; results are explained in section 7.2: Validity & reliability
The conclusion consists of chapter 9, which provides answers to the research questions, and describes the scientific and practical contribution. The chapter presents the short term and long term recommendations and future research. The chapter ends with the limitations and a personal reflection on this research.
9 Conclusions and recommendations

The proposed risk management framework has been extensively described and has given an insight into current Tebodin procedures and the incremental adjustments that could be implemented in the organization. This chapter consists of the conclusions, answering the research questions, defining the scientific and practical contribution, and providing short term and long term recommendations for the organization, followed by suggested future research. To conclude, the limitations of this research are described and a personal reflection is given.

9.1 Research questions answered

The research question that is defined in the first part of this thesis was: “How can a risk management framework in the construction industry be developed, and to what extent can this be implemented for EPC and EPCm projects at Tebodin?” The previous chapters have described how the risk management framework can be developed. To answer the main question and draw conclusions about the research, the sub-questions are answered individually.

a) What is the discrepancy between the theory and practice of risk assessment in construction projects?

A thorough analysis of the development of risk management, as well as how risks are managed in the construction industry was conducted. The gap between the theory and practice of risk management is not caused by the techniques or methods but by the individuals who put it into practice. The culture and mindset of a company and the training of individuals appear to be as important as the actual type of assessment. Many researchers identify experience important when assessing risks.

In the construction industry, risk management lags behind compared to other industries, partly due to multiple parties involved with their own risk management perspective, and because practical application to construction projects are limited due to the lack of knowledge and doubts about the suitability of techniques. Many different tools and techniques exist, but there is no specific guideline on how to apply risk management and apply the tools and techniques coherently.

b) What are Tebodin’s risk management procedures in the chemical construction industry and to what extent is this in line with the evolution of risk management?

From the conducted interviews with PMs who have managed construction projects in the chemical industry, the current risk-related techniques have been explored, and these have been compared to the findings of the literature review. Tebodin’s risk management procedures are integrated into project management. Not all PMs use the same techniques. For safety all interviewed PMs make use of safety risk techniques, as a H&S plan has to be set up before the start of construction, but regarding time, cost and quality risks, a difference is noticed. Some PMs consider that lessons learned should be used more actively to improve risk management.

The construction industry lags behind. A commonly identified problem in projects is getting the right people in the project team in the right phase of the project life cycle, which is a key factor for a project’s success. The CM has been identified, through the interviews, as often being involved in the project too late (see Figure 2-1).

c) What does the conceptual model of the risk management framework look like?

The conceptual model of the risk management framework has been designed by including the current risk-related procedures at Tebodin and relevant techniques from literature. The conceptual model has been developed to obtain insight into which techniques and tools can be used to integrate risk management into project management and serves as a guidance to manage risks during the entire project. The design of the framework is shown in Figure 9-1.
The framework consists of three layers that are presented bottom-up:

- **Layer 1**: The bottom layer contains Tebodin risk-related techniques that are placed on a timeline and that are used during the FEL, the project execution, and the operation & evaluation phase. On the vertical axis of the model, the techniques are categorized into project drivers such as quality, safety, time, and cost. Additional techniques from literature are added to this timeline.
- **Layer 2**: The second layer provides a more detailed overview of how the techniques are linked to each other, and to which risk management phase they belong.
- **Layer 3**: In the third layer three focal points are researched in an in-depth study, and are investigated in more detail explaining the input, technique and output.

d) How can a continuous improvement strategy in Tebodin’s EPC or EPCm projects be developed?

With the in-depth studies, three focal points of the conceptual model have been selected and studied in detail, and which can be substantiated on scientific grounds. The three focal points are: *post-project evaluation, risk identification* and *quantitative analysis*, and for each of them an improvement strategy has been developed, by answering to the following three questions:

- **Post-project evaluation**: How can knowledge transfer between EPC or EPCm projects be improved? To improve knowledge transfer between projects and to avoid making the same mistakes twice, a ‘lessons learned’ database is suggested. In the database information retrieved from project evaluations can be stored and sent to relevant departments, and checklists in the database can be consulted by PMs when setting up a proposal, business concept and project plan. This can help learning from lessons from previous projects, and facilitating knowledge transfer within the company.
- **Risk identification**: How can risk identification be improved? To improve risk identification, consulting the database for useful lessons learned and opportunities from previous projects is suggested. Expanding the brainstorm session by using an RBS and consulting a process flowchart enables all project risks (instead of only safety ones) to be evaluated and identifies risk interaction. The PMs should be aware what drives a project, and in consultation with the client, trade-offs need to be made explicit regarding time, cost and quality.
- **Quantitative analysis**: Are quantitative analyses recommended to continuously improve projects? Whether quantitative methods are recommended depends on the type of project, the company culture, and availability of data. A strong risk management culture must be developed to benefit from the added value of quantitative techniques, which requires more research into a suitable implementation strategy, explained in the following sub-question.
e) What recommendations can be given regarding implementing the risk management framework in the organization?

Three focal points have been studied in-depth. Based on the results a modular implementation plan is set up for each of the focal points. The following recommendations for implementation are given:

- **Post-project evaluation:** It is recommended to make the project evaluation sessions compulsory for risk-driven projects. Lessons learned from the report should be implemented in the database, sent to relevant departments, and PMs should be granted access to the database to use information of lessons learned when setting up a proposal, business concept, project plan or during the risk identification phase.

- **Risk identification:** Project analogy should be implemented and brainstorming should be adjusted. To implement project analogy, the database should be consulted before the RI&E session to look up checklists with regard to topics such as technical, budget and procurement. Cost estimates from previous projects should be consulted. A brainstorm session should be organized with the project team including the CM, to brainstorm all project risks, and with the help of a process flowchart, which contains the activities linked to each other, risk interaction in terms of project drivers can be discovered. With the help of an RBS risk events can be categorized and a structure can be used throughout the project to keep track of all risks.

- **Quantitative analysis:** Research showed that it is recommended to use quantitative methods such as EV, Monte Carlo and PERT in the FEL phase of the project, depending on the project’s challenge, PM responsibility, focus and maturity. However, as quantitative methods are not extensively used at Tebodin, a change in risk awareness and development of the risk maturity in the company is recommended.

The suggested techniques fit within the organization because of their practical application, but a limitation is that these do not change the culture of an organization. The successful implementation of risk management is amplified when a fit with the structural and cultural characteristics of an organization can be achieved (Ward, Chapman & Curtis, 1991). In order to benefit from the added value of these techniques cultural change needs to be initiated to embed these techniques in the organization. Therefore a knowledge center, training, and performance interviews are suggested. This is further elaborated on in section 9.3, which describes the short and long term recommendations for Tebodin.

f) Is the framework applicable for risk management in the field of all Tebodin’s construction projects?

The framework has been designed based on information about EPC and EPCm projects in the chemical construction industry, as these are the types of projects the interviewed PMs from Tebodin carry out. The entire framework as designed could be applied to other types of projects at Tebodin, because the techniques that are integrated are not project specific. The framework can be used for traditional contracts too, for example for commercial construction, by taking parts of the framework that are relevant.

### 9.2 Scientific and practical contribution

In this section, the scientific and practical contribution of this research is discussed. The underlying thought of this research was Tebodin’s need of increased professionalization of construction management services and communication flows. The research subject of this thesis has been demarcated to analyzing current procedures of risk management practices at Tebodin, and developing an improvement strategy. From an academic perspective, the challenge was to identify the gap between what literature reveals about risk management in construction projects, and how this is applied at Tebodin in practice, and furthermore to design a risk management framework that can be used during the lifecycle of EPC and EPCm projects. The following summarizes why this research has contributed to science:

- **This research uses a unique approach to analyzing risk management in construction projects. Comparing *theory* from a literature review with the *reality* acquired through interviews with PMs from Tebodin were used to set up preconditions that must be met for a successful application of a risk management framework.**
This research exposes the gap between risk management theory and practice and concludes that the culture and mindset of a company and the training of individuals appear to be as important as the actual techniques that are used.

A connection is made between the theory and practice. The proposed risk management framework not only focuses on the procedure and the detailed techniques that are used, but also includes the culture at Tebodin, which altogether provides input for the suggested implementation strategy. The strategy focuses on how risk management practices should be integrated with project management.

A risk management framework has been developed with a potential for use in the construction industry.

Regarding the practical contribution for Tebodin, this research has provided a detailed analysis of the current performance at Tebodin. Combining the collected information about the current risk procedures at Tebodin with the literature review has led to insights into existing and new risk management techniques, and has shown that several incremental adjustments can help Tebodin achieve a continuous improvement strategy in integrating risk management. The introduction of this report described Tebodin’s risk maturity and the extent to which the company was aware of its own current performance and possible improvements. This research project has contributed to substantially increasing knowledge and awareness, and thereby increasing risk maturity within the organization.

9.3 Recommendations for Tebodin

9.4 Recommendations for future research

This research has looked at introducing incremental adjustments to manage risks in construction projects. It would be useful as a next step to also look at the response, monitor and control phases of risk management. A research could be conducted on how risk response strategies and monitoring and control can be integrated in the risk management process too, which is left out of the scope of this research, but which can be of added value to fully integrate risk management techniques as part of project management.

In this research, only risk management techniques used in the construction industry are described. A valuable study that is recommended is to investigate is the way quantitative risk management techniques from other industries could lead to improvement in risk performance in the construction industry.

9.5 Limitations and personal reflection

During this research several choices have been made regarding the type of research and the approach and method. To reflect on this, the limitations on this research method and results are discussed. A personal reflection on this research is described.

Limitations of in-depth studies

The in-depth studies focused on the identification, analysis and evaluation phase of project risks. The identification and analysis phases were chosen because chronologically these are the first two phases of risk management, and shortcomings were noticed with the current way of managing risks. For risk identification only the brainstorming technique was used while many more valuable techniques are described in literature. For risk analysis limited use was made of quantitative analysis while in literature the added value (positive and negative) is extensively discussed. The most improvement can be expected during the evaluation phase. This means no focus was put on the risk response and monitor phase, even though these phases require research too.

Limitations to the approach and method

The seven PMs that were interviewed all had affinity with the chemical construction industry. Most of them are carrying out a project for one particular client organization, a company that has its own project management procedures that are followed by Tebodin, besides Tebodin’s own procedures. The results are

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26 In this public version the recommendation are intentionally left out as it contains information sensitive to Tebodin
based on these interviews, which means there is a limitation to generalize the research, as it would require an assumption that PMs who have different clients use the same procedures. The described procedure has been validated externally, so this statement can be assumed. It was noticed that during the FEL phase, more techniques are used to manage safety and quality risks by the consultancy department, however the PM is not directly involved so this is left outside the scope of the framework. The framework could be extended with these techniques to make it practical for other departments, besides the project management department, leading to fully integrated risk processes in the company.

**Limitations on the results**
The results of this research are applicable to Tebodin, as their current procedures form the baseline of the risk management framework. If other companies want to integrate risk management as part of their project management procedures, the framework has to be adjusted to the current way risks are managed at that company. Then the company needs to analyze whether the same shortcomings are found and if the same solutions to improve this can be applied.

**Personal reflection**
Finally, a reflection is given on this research process, to provide recommendations for students who are about to start writing their thesis. At the end of this research, I found out that multiple sources of information were very valuable to validate this research. Only relying on the theoretical literature or the company’s culture and procedures is not enough. By combining several sources and benchmarking with organizations such as CII and IPA, this research has established substantial value. I would recommend to any graduating student to take this into account at the start of their research.
References


References


Towards a better modelling and assessment of construction risk: Insights from a literature review. 


Appendix A: Project risk analysis levels

The Construction Industry Institute (CII) is a learning organization with a wealth of knowledge and information for the engineer-procure-construct process that provides guidance on best practices discovered through research.

<table>
<thead>
<tr>
<th>LEVEL 1: IDENTIFICATION</th>
<th>LEVEL 2: DETERMINISTIC</th>
<th>LEVEL 3: PROBABILISTIC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk</strong></td>
<td><strong>Probability</strong></td>
<td><strong>Impact</strong></td>
</tr>
<tr>
<td>Poor soil conditions may require deep foundations, resulting in cost increase.</td>
<td>Cost</td>
<td>SHEET</td>
</tr>
<tr>
<td>Utility relocation delay could result in longer schedule.</td>
<td>Schedule</td>
<td>Impact</td>
</tr>
</tbody>
</table>

**What’s the Risk?**

- **LEVEL 1: IDENTIFICATION**
  - **Definition**: Identify risks and opportunities.
  - **Benefits**: Generates list of project risks and opportunities.
  - **Results**: Identify, allocate, and manage risks. Communicate potential risks to project stakeholders. Transfer organizational knowledge to projects.
  - **Limitations**: Does not quantify the impact or probability of occurrence of risk events. Cannot assess the impact of risk events on the project.
  - **Requirements**: Permissions minimal investment of team members’ time to collaborate and create risk register. Requires experienced facilitator, capable of identifying risks.

- **LEVEL 2: DETERMINISTIC**
  - **Definition**: Analyze risk through single-point estimates of potential impacts.
  - **Benefits**: Provides probability x impact matrix. Generates prioritized list of risks. Calculates expected value for contingency allocation of time or cost.
  - **Results**: Make Go/No-go decisions based upon expected value. Prioritize risks to manage. Communicate risks intuitively and visually. Allocate resources to mitigate and manage the most significant risks.
  - **Limitations**: One-point estimate does not include uncertainty inherent in the risk. Is unable to communicate the collective impact of risks to achieve project targets.
  - **Requirements**: Requires further investment of time (6-15x Level 1 investment) for in-house or outsourced expert to perform and analyze qualitative simulation. Requires experienced facilitator who can elicit multi-point estimates of probabilities and impacts of risks.

- **LEVEL 3: PROBABILISTIC**
  - **Definition**: Analyze risk through cumulative probability distribution estimates of potential impacts.
  - **Benefits**: Provides cumulative probability distribution. Increases probability of meeting project targets. Project cost or duration is based upon desired level of certainty.
  - **Results**: Clearly communicate project cost or schedule uncertainty. Determine impacts of risk events on project performance. Determine likelihood of achieving project outcomes.
  - **Limitations**: Is dependent on validity of information input into the model and complexity of model.
  - **Requirements**: Requires further investment of time (6-15x Level 1 investment) for in-house or outsourced expert to perform and analyze quantitative simulation. Requires experienced facilitator who can elicit multi-point estimates of probabilities and impacts of risks.

Figure A-1 Project risk analysis levels (Source: (CII, 2012))

Figure A-1 shows the three levels that are distinguished for project risk analysis. The first level consists of risk identification, which generates list of project risks and opportunities, but which has the limitations of not quantifying the impact or probability of occurrence of risk events.

In the second level risks are deterministic analyzed and placed in a probability-impact matrix. A prioritized list is generated. The limitation is that the collective impact of risks to achieve project targets is not defined.

In the third level risks are analyzed through probability distribution estimates of potential impacts. Project cost or schedule uncertainty is clearly communicated, and the likelihood of achieving project outcomes is determined. Although the limitations of the first two layers do not occur with probabilistic analysis, this layer has the limitation that it is dependent on validity of information input into the model and complexity of the model. Also, it requires much more time than only generating a probability-impact matrix, and an experienced facilitator is required who can elicit multi-point estimates of probabilities and impacts of risks.
Appendix B: Risk management methods


The risk management process that is illustrated by the Project Management Institute in Figure B-1 consists of six phases. Before identification a risk management planning phase is added. Furthermore after risk monitoring another phase is added: risk review.

![Figure B-1 PMI’s Risk management process](image)


The risk management process consists of the four initial phases that are mentioned in section 4.1. Figure B-2 shows that risk identification, risk assessment, risk response development and risk response control have to be carried out as an iterative process.

![Figure B-2 Gray & Larson’s Risk management process](image)
3. ATOM (Hillson & Simon, 2012)

Figure B-3 illustrates the active threat & opportunity method, which is a method developed to actively manage threats and opportunities in a project containing an extra phase, post-project review.

4. RISMAN (van Well-Stam et al., 2013)

Since 1995 a risk analysis method is available, the RISMAN-method, which is an instrument to carry out risk analysis and risk management for infrastructure projects shown in Figure B-4. This method is developed in a partnership between Rijkswaterstaat, ProRail, Twynstra Gudde, Technical University of Delft and Gemeentewerken Rotterdam. The steps can be compared with the discussed approach in section 4.1.
Appendix C: Interview structure

At the start of the interview, an introduction of the author is given, followed by an explanation of this research and the goal of the interview. The interviewee is asked if the interview can be recorded and is told that all the information retrieved from the interview is treated confidentially. The interviewee is told that during the interview, a number of subjects are discussed, depending on the interview’s progress. The interview approximately lasts one hour. An overview is given of the main interview subjects that form the guideline for the interview.

<table>
<thead>
<tr>
<th>Interview subjects</th>
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</thead>
<tbody>
<tr>
<td><strong>1. Personal background</strong></td>
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<tr>
<td>• Education &amp; working experience</td>
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<td>• Current function and types of project that have been managed</td>
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<tr>
<td><strong>2. Risk management methods chemical industry</strong></td>
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<tr>
<td>• Risk culture in the company (part of project management)</td>
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<tr>
<td>• What methods and tools are used</td>
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<td>• Use of risk registers, RBS, R&amp;E, quantitative methods (theory vs. practice)</td>
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<tr>
<td>• Phases where methods are applied: Initiation - planning - design &amp; engineering – construction - maintenance</td>
</tr>
<tr>
<td>• Risk documentation conforming company standards</td>
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<tr>
<td>• Risk opportunities and threats (positive &amp; negative risk - perception)</td>
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<tr>
<td><strong>3. Awareness</strong></td>
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<tr>
<td>• Use and added value of risk management</td>
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<td>• Optimistic/pessimistic about current risk management approach</td>
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<tr>
<td><strong>4. Project drivers</strong></td>
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<tr>
<td>• Similar drivers (time, cost, quality, scope, safety) for each chemical project</td>
</tr>
<tr>
<td>• Prioritizing in general project drivers (ranking 1-5)</td>
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<tr>
<td>• How to deal with scope &amp; time changes compared to safety &amp; quality changes</td>
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<tr>
<td><strong>5. Information transfer</strong></td>
</tr>
<tr>
<td>• Transfer: Client -&gt; Front end engineering design (FEED) responsibility (internal / external transfer) -&gt; Tebodin</td>
</tr>
<tr>
<td>• Risk management information transfer from client to EPC or EPCm contractor per project promise (time, cost, quality, scope, safety)</td>
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<tr>
<td><strong>6. Risk liability</strong></td>
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<tr>
<td>• Contractual risk allocation</td>
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<tr>
<td>• Adjustment of responsibilities during project</td>
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<tr>
<td><strong>7. Safety link to risk management</strong></td>
</tr>
<tr>
<td>• How safety risks are managed</td>
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<tr>
<td>• Importance of safety versus other project risks</td>
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<tr>
<td>• Project risks with a safety effect versus safety for operation &amp; construction</td>
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<tr>
<td>• Extending safety risk management (H&amp;S) with all project risks</td>
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<tr>
<td><strong>8. Risk management practice</strong></td>
</tr>
<tr>
<td>• Responsibility of risk actions</td>
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<tr>
<td>• Responsibility of updating risk register (or other tools)</td>
</tr>
<tr>
<td>• Risk communication in the organization (is there a risk manager)</td>
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<tr>
<td>• Post-project review and using a company level database to save information</td>
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<tr>
<td>• Risk cycle phases considered most important/most time spent:</td>
</tr>
<tr>
<td>• Risk identification (brainstorming)</td>
</tr>
<tr>
<td>• Risk analysis/assessment (probability-impact matrix)</td>
</tr>
<tr>
<td>• Risk response (reduce-accept-transfer-avoid)</td>
</tr>
<tr>
<td>• Risk monitoring and control (continuous check if change is made)</td>
</tr>
<tr>
<td><strong>9. Quantitative and qualitative risk management methods</strong></td>
</tr>
<tr>
<td>• Use of quantitative methods such as:</td>
</tr>
<tr>
<td>• Monte Carlo to simulate time and cost expectation</td>
</tr>
<tr>
<td>• Primavera to integrate cost &amp; project schedule risk management</td>
</tr>
<tr>
<td>• Availability of data to use quantitative methods</td>
</tr>
<tr>
<td><strong>10. Comparing industries</strong></td>
</tr>
<tr>
<td>• Performance of chemical industry compared with other industrial projects</td>
</tr>
<tr>
<td>• Differences/similarities between industries</td>
</tr>
<tr>
<td>• Possibility of integrating tools of one industry with another industry</td>
</tr>
</tbody>
</table>

With respect to the company and the interviewee’s privacy a public and a non-public version of this thesis is made. In the public version, unless permission is given, no names are mentioned and the interview responses are not linked to anyone. Only in the non-public version the summary of the interviews is included in the appendix.
Appendix D: Interview summaries
In this public version the interview summaries are intentionally left out as it contains information sensitive to Tebodin.
Appendix E: Experiment
In this public version the experiment is intentionally left out as it contains information sensitive to Tebodin.
Appendix F: Risk breakdown structure

A risk breakdown structure (RBS) is a hierarchy of potential risk categories for a project (Hillson, 2002). It is similar to a work breakdown structure but used to identify and categorize risks. A comparison is made between dividing risks into categories from both literature as topics used by Tebodin. An RBS should be distinguished from the categories that are used to evaluate the project. From literature RBS’s are looked at and at Tebodin both RBS’s and project evaluation topics are consulted. From these lists a list of categories is designed to use as an RBS and a list is designed for a project evaluation.

Literature

An overview is given on the many theories on how to categorize risks. The first three examples separate internal and external risks. Researchers, focusing on the construction industry, suggest different categories.

Table F-1 Risk Breakdown Structure (Source: (Tah & Carr, 2001))

<table>
<thead>
<tr>
<th>Local Risk</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labor</td>
<td>Client</td>
<td>Financial</td>
</tr>
<tr>
<td>Materials</td>
<td>Construction</td>
<td>Location</td>
</tr>
<tr>
<td>Plant</td>
<td>Contractual</td>
<td>Management</td>
</tr>
<tr>
<td>Site</td>
<td>Design</td>
<td>Pre-contract</td>
</tr>
<tr>
<td>Sub-contractor</td>
<td>Environmental</td>
<td>Timeframe</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Economic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Physical</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Political</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Technological Change</td>
</tr>
</tbody>
</table>

Table F-2 Risk Breakdown Structure (Source: (Pipattanapiwong, 2004))

<table>
<thead>
<tr>
<th>Activity</th>
<th>Internal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Project</td>
</tr>
<tr>
<td></td>
<td>Project</td>
</tr>
<tr>
<td>Labor</td>
<td>Procurement process</td>
</tr>
<tr>
<td>Equipment</td>
<td>Contractor</td>
</tr>
<tr>
<td>Sub-contractor &amp; supplier</td>
<td>Contract</td>
</tr>
<tr>
<td>Material</td>
<td>Lender &amp; bank</td>
</tr>
<tr>
<td>Site</td>
<td>Design &amp; specification</td>
</tr>
<tr>
<td>Work</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Economic</td>
</tr>
<tr>
<td></td>
<td>Legal</td>
</tr>
<tr>
<td></td>
<td>Political</td>
</tr>
<tr>
<td></td>
<td>Nature (weather)</td>
</tr>
</tbody>
</table>

Table F-3 Hierarchy structure of the project risks (Source: (Hsueh, Perng, Yan, & Lee, 2007))

<table>
<thead>
<tr>
<th>Overall Assessment</th>
<th>Internal</th>
<th>Project-Specific</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Relationship with</td>
<td>Background of</td>
<td>Project Characteristics</td>
</tr>
<tr>
<td>Agreement</td>
<td>Partner</td>
<td>Engineer</td>
<td>Engineering Contract</td>
</tr>
<tr>
<td>Renegotiation</td>
<td>Current Work</td>
<td>Duration</td>
<td>Technical Skills</td>
</tr>
<tr>
<td>Good Relationship</td>
<td>Historic Profits</td>
<td>Cash Flow Requirement</td>
<td>Machines/Tools Available</td>
</tr>
<tr>
<td>Regulations/Law</td>
<td>Complexity</td>
<td>Project Allocation</td>
<td>Public Facilities</td>
</tr>
<tr>
<td>Bank Credibility</td>
<td>Project Type</td>
<td>Employment</td>
<td></td>
</tr>
</tbody>
</table>

The examples in Table F-1, Table F-2 and Table F-3 are extensive, and contain many subcategories. From literature three smaller examples are discovered of how to categorize risks, shown in Table F-4, Table F-5 and Table F-6.

Table F-4 Risk breakdown structure (Source: (Schwalbe, 2014))

<table>
<thead>
<tr>
<th>IT Project</th>
<th>Business</th>
<th>Technical</th>
<th>Organizational</th>
<th>Project Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitors</td>
<td>Hardware</td>
<td>Executive support</td>
<td>Estimates</td>
<td></td>
</tr>
<tr>
<td>Suppliers</td>
<td>Software</td>
<td>User support</td>
<td>Communication</td>
<td></td>
</tr>
<tr>
<td>Cash flow</td>
<td>Network</td>
<td>Team support</td>
<td>Resources</td>
<td></td>
</tr>
</tbody>
</table>
Table F-5 Risk identification categories (Source: (Tennant, 2010))

<table>
<thead>
<tr>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Legal</td>
<td>Suppliers</td>
</tr>
<tr>
<td>Technical</td>
<td>Regulatory</td>
</tr>
<tr>
<td>Procurement</td>
<td>Customer</td>
</tr>
<tr>
<td>Organization</td>
<td>Community</td>
</tr>
<tr>
<td>Resources</td>
<td>Publicity</td>
</tr>
</tbody>
</table>

Table F-6 Risk categories (Source: (El-Naggar, 2012))

<table>
<thead>
<tr>
<th>Project</th>
<th>Technical</th>
<th>Organizational</th>
<th>Project Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Requirements</td>
<td>Requirements</td>
<td>Project Dependencies</td>
<td>Estimating</td>
</tr>
<tr>
<td>Technology</td>
<td>Technology</td>
<td>Resources</td>
<td>Planning</td>
</tr>
<tr>
<td>Complexity and Interfaces</td>
<td>Complexity</td>
<td>Funding</td>
<td>Controlling</td>
</tr>
<tr>
<td>Performances and Reliability</td>
<td>Performances</td>
<td>Prioritization</td>
<td>Communication</td>
</tr>
<tr>
<td>Quality</td>
<td>Quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Risk Breakdown Structure (RBS) lists the categories and sub-categories within which risks may arise for a typical project (El-Naggar, 2012). Different RBSs will be appropriate for different types of projects and different types of organizations. One benefit of this approach is to remind participants in a risk identification exercise of the many sources from which project risk may arise.

Table F-7 Risk analysis perspectives (Source: (van Well-Stam et al., 2013))

<table>
<thead>
<tr>
<th>RISMAN Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>Political/governance</td>
</tr>
<tr>
<td>Financial/economical</td>
</tr>
<tr>
<td>Legal</td>
</tr>
<tr>
<td>Technical</td>
</tr>
<tr>
<td>Organizational</td>
</tr>
<tr>
<td>Geographical/spatial</td>
</tr>
<tr>
<td>Social</td>
</tr>
</tbody>
</table>

Another way to organize to categorize risk is by the suggested RISMANbrillen from Rijkswaterstaat. Every contractor that carries out a project for Rijkswaterstaat is obliged to focus on risk management during the project (van Well-Stam et al., 2013). Therefore in collaboration with other contractors RISMAN suggests the categories as shown in Table F-7.

**Tebodin**

Tebodin uses different categories for their risk registers and for their lessons learned document per project. From the different categories an overview is made in Table F-8 to define the differences and similarities between the project categories.

Table F-8 Overview of Tebodin’s used categories

<table>
<thead>
<tr>
<th>Categories</th>
<th>Project manager</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Document type</td>
<td>Client</td>
<td>P</td>
<td>A</td>
<td>Q</td>
<td>R</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Budget</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>General/miscellaneous</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Objectives/scope/design</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organization</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Procurement</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction/commissioning</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permit</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
All risk registers and the lessons learned session use some categories, such as safety, budget and schedule, other categories depend on the project. From the overview, a selection is made of categories that are useful to be used for a lessons learned document, as well as for the risk identification phase and for the risk assessment at the beginning of a new project.

**Suggested categories**

From all the possibilities one list with categories is made as a suggestion to be used when identifying risks, when assessing them and when reviewing risk in a project evaluation session. The categories should be comprehensive, but conservative, which means that not too many categories should be included to obtain a clear overview that can be used both in the risk identification phase and in the assessment phase. The categories cover the ones that are already used by Tebodin, but distinguish internal risks from external. Budget, schedule and safety are categories that are used by all PMs. The categories should also be mutually exclusive; to prevent it is unclear in which category to place risks an event should fit in one category. Therefore some suggested categories are combined. When it is unclear in which category to place the risk, one should look at the source of the risk, instead of the consequence. Table F-9 presents suggested project evaluation categories and Table F-10 presents suggested RBS categories.

### Table F-9 Suggested project evaluation categories

<table>
<thead>
<tr>
<th>Categories</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>Suppliers/subcontractors</td>
<td>Suppliers/subcontractors</td>
</tr>
<tr>
<td>Budget</td>
<td>Legal (procurement/regulatory)</td>
<td>Legal (procurement/regulatory)</td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scope</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organizational</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table F-10 Suggested RBS categories

<table>
<thead>
<tr>
<th>Categories</th>
<th>Internal</th>
<th>External</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>Suppliers/subcontractors</td>
<td>Suppliers/subcontractors</td>
</tr>
<tr>
<td>Budget</td>
<td>Legal (procurement/regulatory)</td>
<td>Legal (procurement/regulatory)</td>
</tr>
<tr>
<td>Schedule</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix G: Validity interviews
In this public version the interview summaries are intentionally left out as it contains information sensitive to Tebodin.