Master Thesis report

Enhancing the risk management process in the tender phase of infrastructure projects

T. (Timo) Rodink
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Preface

Before you lies the Master Thesis: “Enhancing the risk management process in the tender phase of infrastructure projects”. It has been written to fulfil the graduation requirements of the Master Construction Management and Engineering at the University of Twente and has been conducted on behalf of Heijmans Infra B.V.

The writing of this Master Thesis took me from January 2017 to April 2019. The reason for this long period is the fact that I accepted a job offer from Heijmans while I was still working on my thesis. Due to the fact it was harder to combine working and finishing my thesis as expected, and several personal issues I am glad to finish my thesis in the end.

I would like to thank my supervisors Prof. dr. ir. J.I.M. (Joop) Halman and Dr. S.H.S. (Saad) Al-Jibouri for their guidance and support during this long process. Besides Prof. dr. ir. J.I.M. (Joop) Halman and Dr. S.H.S. Al-Jibouri I would like to thank Drs. Ing. J. (Hans) Boes for assessing my thesis, because Mr. Al-Jibouri has retired from the University of Twente.

Besides my supervisors of the University of Twente I would like to thank Joris van der Meer and William Cornuyt, my supervisors from Heijmans, for their trust, help and feedback. I also would like to thank all my other colleagues at Heijmans Infra who provided me with information by means of documents or interviews.

Specials thanks to my partner Anouk Aaldering for her constant faith and patience in me during my Thesis.

I hope you enjoy reading my thesis.

Timo Rodink

Velp, May 09, 2019

Management Summary

The profit margins in the Dutch infrastructure market are low compared to for example the ICT or automotive sector. While the profit margins are low the risks for the contractor can be very high. When risks occur, it can lead to significant budget overruns. Which in the worst case can result in bankruptcy for the contractors. In recent years almost all big infrastructure contractors made the headlines in the newspapers with large budget overruns as a result of risks which occurred during their projects. Therefore it is extremely important to identify the risks early and manage them effectively. In order to do so it is important to share and maintain the knowledge about risk management within the organisation. Heijmans infra faces a problem in sharing and maintaining the knowledge about risk management.

One of the possible solutions to overcome this problem is the development of a risk database. The desirability of developing a risk database is investigated in a preliminary research. This is done by interviewing tender and risk managers within the organisation of Heijmans Infra. The interviews led to the following conclusions. There is no explicit exchange of knowledge about risks within the organisation. For example each tender starts with a blank risk register. Also at the end of the project there is no evaluation, to compare the initial tender process, with the development of the risks over the lifecycle of the project. It is concluded that a risk database can be a useful tool to store and maintain knowledge about risks in a practical way. Despite the fact that developing a risk database can be useful in the development of risk management a more urgent problem came forward during the preliminary research.

According to the Risk and Tender managers the risk management process in the tender phase of infrastructure projects is not structured. As a result risks are not identified in the tender phase, risks are not managed effectively and risks lead to budget overruns during the lifecycle of a project. This lead to the following research problem:

The risk management process currently applied by Heijmans Infra in the tender phase is unstructured and of insufficient quality to identify, analyse and manage potential project risks.

This research problem resulted in the following main research question of this research:

What are the reasons for the unstructured, incomplete and inefficient risk management process, in the tender phase of Heijmans Infra, and how can these problems be overcome?

To answer this research question a theoretical and empirical research has been executed. A literature review, based on scientific literature, is held to determine how the risk management process can be structured to be complete and reliable in construction tendering. At first the terms *risk* and *project risk* have been investigated to determine a baseline for this research. Thereafter risk categorizing and risk management are extensively investigated. This resulted in the following process steps to come to a complete and reliable risk management process:

1. Risk management planning: deciding how to approach and plan the risk management activities
2. Risk identification: determining which risks might affect the project and documenting their characteristics.
3. Qualitative risks analysis to prioritize the effects on project objectives
4. Quantitative risk analysis: measuring the probability and consequences of risks and estimating their implications for project objectives

5. Risk response planning: developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives.
6. Risk monitoring and control: monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project lifecycle.

The empirical research consisting of case studies and interviews gave an answer to the question why the current risk management process is unstructured, incomplete and inefficient. In the case studies five projects were analysed. These case studies gave more understanding in the result of the risk management process during the tender. Based on the analysis the following conclusion have been made:

1. Risks are missed during the risk identification in the tender phase.
2. The risk management analysis is not complete because control measures are missing.
3. On average only 50% percent of the risks is financially quantified in the tender phase
4. The risk budget from the tender phase coffers on average only 22% of the top-10 financial budget overruns.

The tender and project managers explained the results of the case studies during interviews. This led to the following conclusions why the risk management process is unstructured, incomplete and inefficient.

1. The role of the risk manager during the tender phase is not explicit enough
2. The tender team is not the same from the start of the tender until the end, which makes it difficult to instruct the tender team.
3. The format of the risk register used in the tender phase is not suited to quantify the risk effectively and not suited to register the control measures.
4. The main reason for de incompleteness of the risk register is related to the period of economic crisis, in which Heijmans was desperate for work. As a result, risks were deleted from the risk register, which resulted in a lower risk budget. Which resulted in the construction phase that when risks occurred there was no budget for the corrective control measures which resulted in the cost overruns.

Based on the literature review and the conclusions from the case studies, a process plan for risk management in construction tendering is developed to make the risk management process in the tender phase better structured, complete and reliable. This process plan is validated during a validation session with the risk managers from Heijmans Infra. It is the product resulting form this Master Thesis.

Management Samenvatting

De winstmarges in de Nederlandse zijn laag vergeleken met bijvoorbeeld de ICT sector of de auto-industrie. De winstmarges zijn laag maar de risico's voor de aannemers kunnen heel hoog zijn. Wanneer risico's optreden kan dit leiden tot significante kostenoverschrijdingen. In het ergste geval kan dit leiden tot het faillissement van de aannemer. In de afgelopen jaren hebben de grotere aannemers in de Nederlandse infrasector de voorpagina's van de kranten gehaald doordat projecten vele malen duurder werden als gevolg van het optreden van risico's. Het is daarom heel erg belangrijk dat risico's in een zo vroeg mogelijk stadium worden geïdentificeerd en effectief worden gecontroleerd. Hiervoor is het belangrijk om kennis over risico management te delen en te borgen binnen de organisatie. Heijmans Infra heeft een probleem in het delen en het borgen van de kennis over risicomanagement binnen de organisatie.

Een van de mogelijke oplossingen voor dit probleem is het ontwikkelen van een risicodatabase. De wens om een risicodatabase te ontwikkelen is onderzocht in een voorbereidend onderzoek. Dit is gedaan middels interviews met tendermanagers en risicomanager werkzaam binnen Heijmans Infra. Deze interviews hebben geleid tot de volgende conclusies. De kennis over risico's en risicomanagement wordt onvoldoende gedeeld en geborgd binnen de organisatie. Een bijbehorend voorbeeld is dat elke tender begint met een leeg risicoregister, waarbij de enige inbreng de kennis is van het betreffende tenderteam. Ook is er aan het eind van het project geen evaluatie over hoe de risico's zich hebben ontwikkeld gedurende de looptijd van het project. Uit de interviews is geconcludeerd dat het ontwikkelen van een risicodatabase een nuttige bijdragen kan leveren bij de ontwikkeling van het risicomanagement proces. Echter is er tijdens het voorbereidende onderzoek een meer urgent probleem naar voren gekomen.

Volgens de tender- en risicomanagers is het risicomanagementproces in de tenderfase van infrastructuur projecten onvoldoende gestructureerd. Het gevolg hiervan is dat risico's niet in de tenderfase worden geïdentificeerd en risico's onvoldoende worden gemanaged wat leidt tot kostenoverschrijdingen op de projecten. Dit heeft geleid tot de volgende probleembeschrijving voor dit onderzoek:

Het huidige risicomanagementproces wat momenteel door Heijmans Infra wordt toegepast is niet gestructureerd en van onvoldoende kwaliteit om de mogelijke project risico's te identificeren, te analyseren en te controleren.

Deze probleembeschrijving heeft geleid tot de volgende onderzoekvraag voor dit onderzoek:

Wat zijn de redenen dat het risicomanagement proces, in de tenderfase van Heijmans infra, niet gestructureerd, compleet en efficiënt is en hoe kunnen deze problemen worden verholpen?

Om deze onderzoeksvraag te beantwoorden is een onderzoek uitgevoerd bestaande uit een theoretisch en een empirisch gedeelte. Een literatuur studie, gebaseerd op wetenschappelijke literatuur, is uitgevoerd om te bepalen hoe het risicomanagementproces gestructureerd kan worden om te komen tot een zo volledig en betrouwbaar mogelijk risicodossier tijdens de tenderfase. Hiervoor zijn eerst de begrippen *risico* en *projectrisico* onderzocht. Hierna zijn de onderdelen risico categorisering en risicomanagement uitgebreid onderzocht op basis van de wetenschappelijke literatuur. Dat heeft geresulteerd in de volgende proces stappen om te komen tot een zo compleet mogelijk en betrouwbaar risicomanagement proces.

1. Plan van aanpak risicomanagement: het bepalen hoe het risicomanagement proces wordt aangevlogen gedurende de tender en de rest van het project.

2. Risico identificatie: bepalen welke risico's een effect kunnen hebben op het project en daarbij het vastleggen van de kenmerken van de risico's.
3. Kwalitatieve risicoanalyse om de gevolgen van de risico's te bepalen
4. Kwantitatieve risicoanalyse om te kans van optreden en de mogelijke gevolgen van de risico's te bepalen.
5. Risicobeheersing: bepalen hoe de risico's beheerst kunnen worden gerelateerd aan de projectdoelstellingen.
6. Het blijven monitoren van de ontwikkeling van de risico's en het doorvoeren van beheersmaatregelen en uiteindelijk het evalueren van de ontwikkeling van de risico's gedurende het project.

Het empirische onderzoek, bestaande uit case studies en interviews heeft geleid tot een antwoord op de vraag waarom het huidige risicomanagementproces niet gestructureerd, compleet en efficiënt is. In de case studies zijn 5 projecten geanalyseerd. Hierin is gekeken naar de risicodossiers uit de tenderfase, de realisatiefase en de relatie tussen de risico's en de kostenoverschrijdingen op de projecten gerelateerd aan de risico's. Dit heeft geleid tot een beter inzicht in de resultaten van het risicomanagementproces tijdens de tenderfase. Op basis van de case studies zijn onder ander de volgende conclusies getrokken:

1. De risico identificatie tijdens de tenderfase is onvolledig.
2. The beoordeling en classificering van de risico's in onvolledig, bijvoorbeeld de beheersmaatregelen ontbreken.
3. Gemiddeld wordt slechts 50% van de risico's financieel gekwantificeerd in de tenderfase.
4. Het risicobudget dat in de tenderfase word vastgesteld dekt gemiddeld slechts 22% van de top-10 kostenoverschrijdingen aan het eind van het project.

Op basis van de resultaten uit de case studies zijn de tender en projectmanagers van de betreffende projecten geïnterviewd om een nadere onderbouwing te geven bij de resultaten uit de case studies en een antwoord te geven waarom het huidige risicomanagement proces in de tenderfase niet gestructureerd, compleet en volledig is. Dat heeft geleid tot de volgende conclusies.

1. De rol van risicomanager is vaak 1 van de taken van een van de tenderteamleden, hierdoor ontbreekt er onvoldoende stuur op het risicomanagementproces.
2. Tevens is het tenderteam niet gelijk vanaf het begin van de tender tot het eind van de tender. Hierdoor is het lastig om het team op één lijn te krijgen betreffende het risicomanagementproces.
3. Het huidige format voor het risicodossier wat gebruikt wordt in de tenderfase bied onvoldoende mogelijkheden om de risico's en de beheersmaatregelen goed vast te leggen en (financieel) te kwantificeren.
4. Een van de hoofoorzaken genoemd door de tender en project managers van de betreffende projecten is dat alle projecten zijn aangenomen ten tijde van de economische crisis. In deze tijd had Heijmans projecten nodig om zijn medewerkers aan het werk te houden. Als gevolg hiervan zijn risico's in de tenderfase uit het risicodossier geschrapt of onderkent. Dit heeft geleid tot een laag risicobudget en aanneemsom, waardoor de projecten wel zijn aangenomen. Maar door het optreden van risico's heeft dit uiteindelijk gezorgd voor flinke kostenoverschrijdingen.

Op basis van de uitkomsten uit het literatuuronderzoek, de case studies en bijbehorende interviews is een procesplan ontwikkeld als leidraad voor het risicomanagement proces tijdens de tenderfase voor infra projecten. Dit procesplan is in een validatiesessie met de risicomanagers van Heijmans gevalideerd. Het procesplan is het eindproduct volgend uit deze Master Thesis.

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1. Introduction

1.1. Motive for research

The reason for the instigation of this research lies in the Heijmans Risk management year plan 2016 (Ebskamp & van der Meer, 2016). Investigating the desirability of developing a risk database for Heijmans infra is part of this plan. According to the department of process- and environment management, knowledge about risks within the organization is not sufficiently shared and maintained. As a consequence of this, the risk management process within the organisation becomes inefficient and many of the risks of projects will be difficult to identify early in the process. This could have negative impacts on achieving the project objectives.

1.2. Heijmans Infra

This section describes the background of this research and its context within Heijmans' organisational structure. Heijmans was founded in 1923 by Jan Heijmans and is considered now as one of the largest contractors in the Netherlands. Originally the company was specialised in road pavement works using bitumen. The post-war reconstruction period provided plenty of opportunities for the organisation to grow through repairs and laying of roadways and airfields. In 1993, Heijmans was listed on the Amsterdam Exchange. This made further growth possible. The organizational structure of Heijmans is visualised in Figure 1.

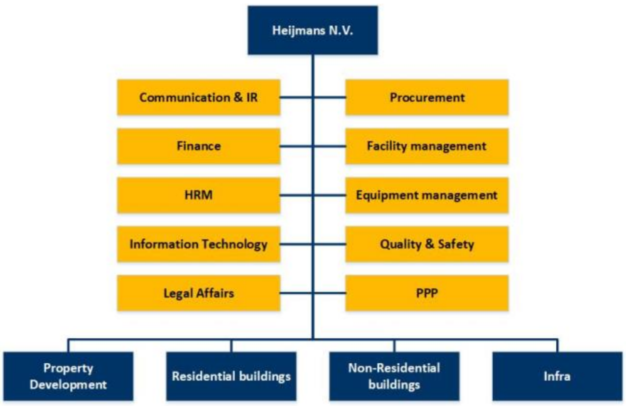


Figure 1: Organizational structure Heijmans N.V. (Heijmans)

At present Heijmans is operating in four main fields of work; property development, residential and non-residential buildings, as well as in Infrastructures. This research is instigated by Heijmans Infra. Heijmans infra is responsible for all infrastructure projects within the company. The infra business unit was created through the merger of the two business units, Heijmans roads and Heijmans Civil. Heijmans Infra has its own managing board, who is responsible for 3 main disciplines; Specialists; Regional Projects and Central Projects. These 3 disciplines are further subdivided into 26 departments. The organizational chart of Heijmans Infra is depicted in Figure 2.

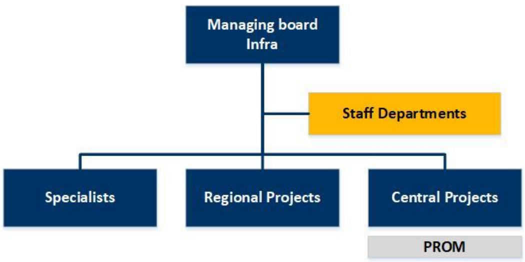


Figure 2: Organizational Structure Heijmans Infra, (Heijmans)

This research work is carried out within the department of Process- and Environment management which will be referred to in the rest of the thesis as PROM. PROM is a department of the discipline Central projects, as shown in Figure 2. The organizational chart of the department PROM is shown in Figure 3. The focus of this research is on the application of risk management in the tender phase. Risk management is one of the processes within PROM. The other processes include systems engineering, planning and process management. The next section will explain how the topic of this research is tied to the rest of the organizational structure.

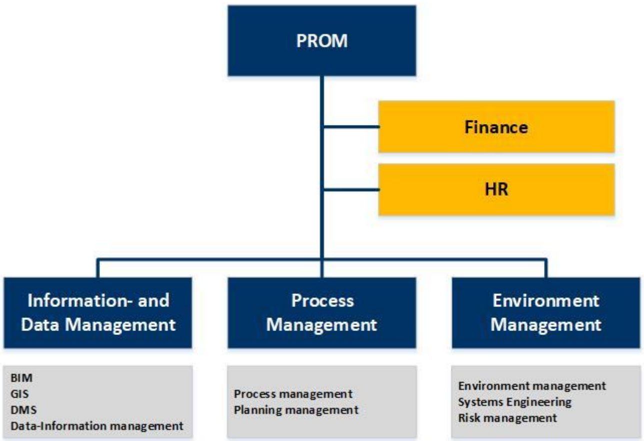


Figure 3: Organizational Structure Heijmans Infra: PROM (Heijmans)

The tender phase and project acquisition are, like PROM, a department of the discipline Central projects. Project tendering takes place in the acquisition department and when the project is awarded to Heijmans the project is executed by the realisation department.

As mentioned earlier, this master thesis focuses on risk management in the tender phase and hence it is carried out within PROM. However, the work is also related to two other departments within Heijmans Infra, Project Acquisition and Realisation.

1.3. Risk management in the tender phase

The following section describes how risk management is implemented in the tender phase (Acquisition) of projects at Heijmans Infra. This is currently carried out according to the business process system (BPS) of Heijmans. BPS describes how various processes, including risk management, should be carried out with links to norms and guidelines. Standard documents, manuals and instructions can also be found on the BPS as shown in Figure 4.

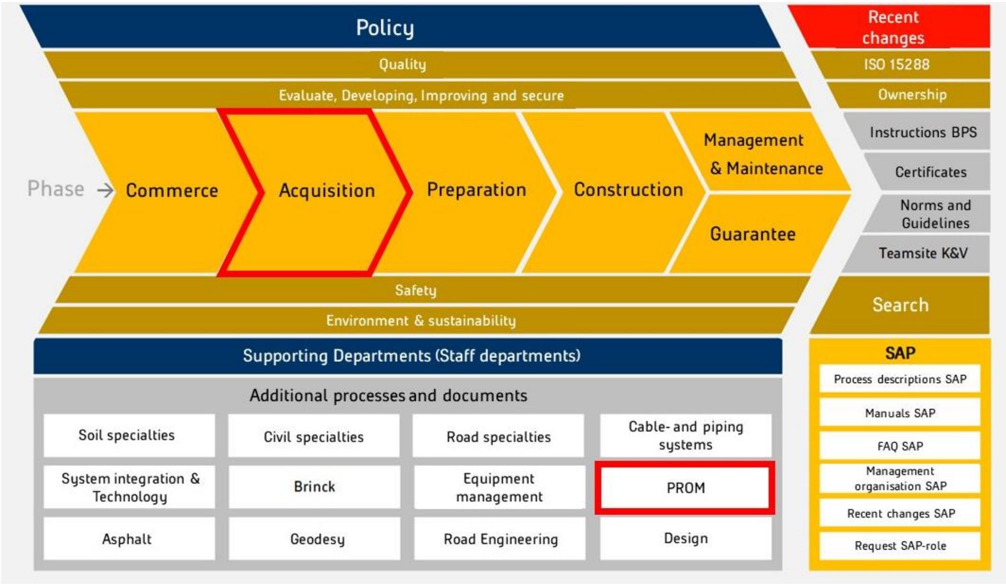


Figure 4: BPS Heijmans Infra, (Heijmans BPS)

Project acquisition is one of the main processes included in the BPS Infra. The main process is subdivided into several sub-processes as indicated in Figure 5. These sub-processes are divided by Go/No Go milestones. At these stages it is determined if the tender can go through the next sub-process.

Figure 5: sub-Processes of the main process project acquisition, (Heijmans BPS)

The inputs or outputs of some of the steps in the various sub-processes are linked to the document "Kansen en Risicodossier" (Translated: The Opportunity and Risk register) which contains a collection of risks and opportunities. The document "Kansen en Risicodossier" is a standard risk management format used in the tender phase. In this document, the risks and opportunities are assigned to their risk owners. The risk owner is responsible for defining the control measures required, and for quantifying the risk. Having risks and opportunities stored in a "Kansen en Risicodossier" document is only mandatory for projects/tenders of values more than €100.000. In the tender phase, it is mandatory for category 2 (projects between €5-20 million, not RAW contracts) and category 3 (projects above €20million) to be analysed using a Monte Carlo simulation. A Monte Carlo simulation simulates the project by choosing at random the values for each of the variables and then uses them to calculate the outcome of the project. This is repeated many times to produce a distribution of the possible outcomes of the project (Al-Jibouri, 2016). In the BPS, the document "Kansen en Risicodossier" is also linked to a check list of generalised risks which are common in many projects.

2. Research design and methodology

2.1. Problem description:

The problem description is the outcome of sequential steps to define the research problem. The first step describes the motive for this research. Secondly the purpose and outcome of the preliminary research is discussed. The third part further investigates the outcome of the preliminary research, which results in the problem definition for this research.

As mentioned earlier the motive for this research originates from the Heijmans risk management year plan 2016 (Ebskamp & van der Meer, 2016). Investigating the usefulness or necessity for developing a risk database for Heijmans infra, as part of sharing risk knowledge, is part of this plan. According to an investigation carried out by the department of process- and environment management (PROM) knowledge related to risks is not sufficiently shared or maintained within the organization. In this work, a preliminary research has been executed to verify these observations by PROM as well as to investigate the need and necessity for developing a risk database for Heijmans Infra.

The preliminary research findings seem to concur with the observations by PROM. For instance, the orientation study shows that there is no explicit exchange of knowledge about risk within the organisation. In practice, the risk management process for each tender starts with a blank sheet and the only input used is the risk knowledge of the project team members. Also at the end of the project there is no evaluation, to compare the initial tender process, with the development of the risks over the lifecycle of the project. A risk database could be a useful tool to store and maintain the risk knowledge in a practical way. However, the structure, input and output of the database is yet required to be developed. It is believed that by not sharing and retaining the acquired risk knowledge, many of the risks will not be identified which leads to budget and duration overruns in many projects.

A second cause of the missed risks and budget overruns of projects came forward during the preliminary research. The way risk management is incorporated in the tender phase is described in section 1.3. However, the risk management itself is not structured in the tender phase. For example, not in all tenders a risk session is organised, or the risk sheet is filled at the end of the tender. This unstructured risk management process includes that, risks are missed, risks are not already controlled in the tender, and risks lead to budget overruns during the life cycle of a project.

The current risk management process and its problems have been identified by interviewing tender managers and risk managers, who are responsible for the risk management process in the tender. The risk management process and its problems are visualised in Figure 6.

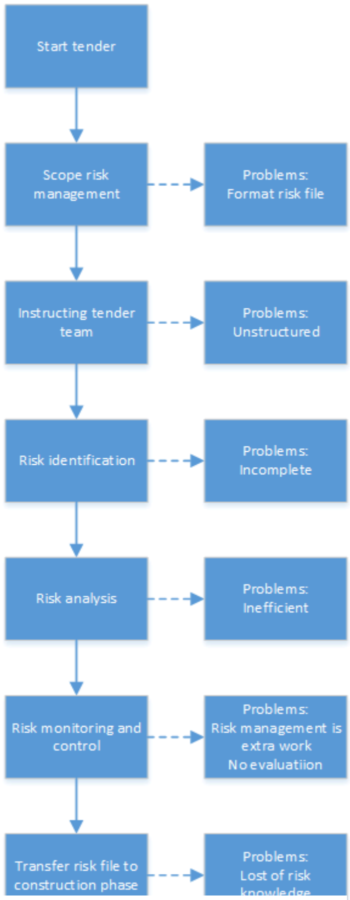


Figure 6: Risk management process and problems

The first step in the risk management process is defining the *scope of risk management* in the tender. In this step, the risk management process for the tender is defined. The main problem in this step is the use of the mandatory risk register. The format risk register does not provide sufficient depth to control the risk management process.

The second step is *instructing the tender* team about risk management. There is no guideline how to instruct the tender team about the risk management process, this is the main problem in this step. This is related to the fact that employees join the tender at different moments in time.

Risk identification is the third step in the current risk management process. Previous research concluded that on average only 2 of the top 10 risks at the end of a project, were identified in the tender phase. This means that risk identification in the tender phase is incomplete. Knowledge from previous projects and from the construction phase is barely used in the risk identification phase.

The *risk analysis* step includes quantifying the risks and defining the control measures. The first problem about the quantification is consistent with the problem in the first step. In the construction phase risk register it is only possible to use a quantification of 1, 2 or 3, this is perceived as insufficient depth in the quantification of the risks. The second problem is determining the probability of occurrence. The tender managers find it hard to see a difference in a probability ration from 1% to 15%.

There are several problems with defining the control measures. The first problem is defining the control measures SMART. To control the risk efficiently the control measures should be SMART formulated, but the current process often lacks a SMART formulation. A second problem related to the control measures is the check if the cost related to the measures are included in the budget, this check is not always done. A third problem is the lack of knowledge about the effectiveness of the control measures.

The fifth step is the *risk monitoring and control*. The main problem related to this step is that the employees in the tender team often see risk management as extra work in addition to their own work. As a result, the tender/risk manager needs to encourage the employees to identify and analyse the risks as an iterative process. A second problem related to the step monitoring and control is the evaluation of the development of the risks during the project. There is no evaluation of the risks which is used in new tender projects.

The last step in the current risk management process is the *transfer of the risk register to the construction phase*. The main problem related to this step is whether the risk manager, or every member of the tender team, proceed in the construction phase. When this is not the case, project specific risk knowledge is lost.

To summarise, the current risk management process in the tender phase seems to be unstructured and no lessons learned are used or documented. The results are that many projects encounter a variety of unidentified risks that lead to budget and duration overruns. The research problem can be formulated as follows:

The risk management process currently applied by Heijmans infra in the tender phase is unstructured and of insufficient quality to identify, analyse and manage potential project risks.

2.2. Research goal

From Heijmans' perspective the goal of this research is to:

Increasing the successful completion of projects for Heijmans Infra by enhancing the risk management process in the tender phase.

The goal within this research is to:

Structure the risk management process in the tender phase and the procedure to maintain, share and use of existing risk knowledge and information during the process.

2.3. Research Question

Main research question:

What are the reasons for the unstructured, incomplete and inefficient risk management process, in the tender phase of Heijmans Infra, and how can these problems be overcome?

Research questions:

1. *How can the risk management process be structured to be complete and reliable in construction tendering?*
   1.1. How can the risk identification be carried out?
   1.2. How can the risk analysis be performed?
   1.3. How can the risk register be monitored and evaluated?
   1.4. How can risk knowledge be retained within the organisation?

2. *Why is the current risk management process, in the tender phase at Heijmans Infra, unstructured, incomplete and inefficient?*
   2.1. Why is the risk management process in the tender phase unstructured?
   2.2. Why is the current risk identification incomplete?
   2.3. Why is the risk analysis inefficient?

3. *What changes can be made to make the risk management process in the tender phase better structured, complete and reliable?*

2.4. Research scope

- The research is carried out within Heijmans Infra in the departments, process- and environment management and acquisition.
- The research involves only the risk management process during the tender phase. This means from the start of the tender up until the transfer of the risk files to the construction phase. In this work, the term risk management process is used to refer to the risk management process in the tender phase.
- The risk documents that are used in this research are those submitted at the end of the tender and at the end of the project.
- This research focuses on the project specific risks, opportunities and control measures, that fall outside the normal processes. For example, mistakes in the design process is not a risk. This is a problem that must be overcome in the standard work processes.

2.5. Research Methodology

The research strategy and data collection required to address the different parts of the research are described in this section. The section includes descriptions of how each research question will be answered. The research process framework is shown in Figure 7 and 8.

2.5.1. Answering research question 1

How can the risk management process be structured to be complete and reliable in construction tendering?

This research question will be answered based on a study of the literature and available techniques. The literature study addresses the different topics related to the sub-questions derived from this first main research question. Scientific literature is gathered using the "platform risicomanagement", a platform for sharing information about risk management between (old) students and professors. Other scientific literature is gathered using scientific search engines, mainly Scopus. In addition to this books and corporate documents provided by Heijmans will be used.

2.5.2. Answering research question 2

Why is the current risk management process, in the tender phase at Heijmans Infra, unstructured, incomplete and inefficient?

The second research question and its sub questions are answered using document studies, case studies and interviews. In the case studies, five projects will be investigated. The risk register from the tender phase will be compared to the top 10 risks at the end of the project. Based on the differences in the risk registers the tender and risks managers will be interviewed to identify why the problems arises in the current risk management process. The interviews will also be used to gather information on how the problems can be overcome.

2.5.3. Answering research question 3

What changes can be made to make the risk management process in the tender phase better structured, complete and reliable?

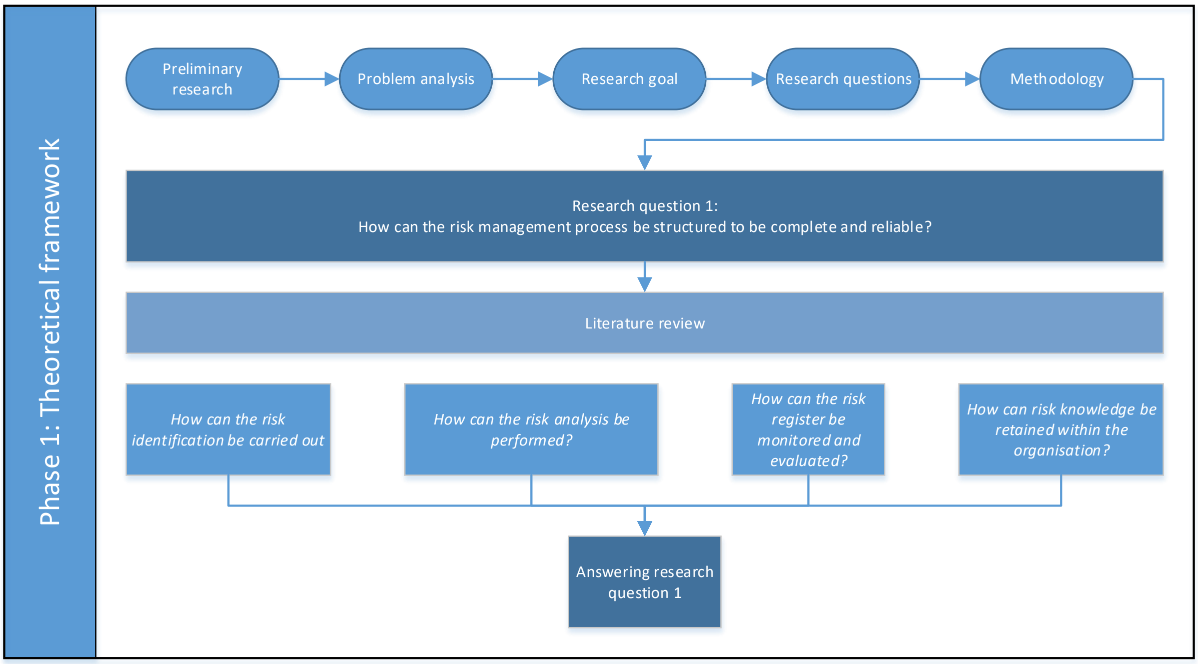
A modified process for the risk management in the tender phase will be developed based on the findings in the two previous phases. The modified process will then be validated by experts. The results of the validation will be processed to produce the final proposed process to be used for the risk management in de tender phase.

2.5.4. Answering main research question

What are the reasons for the unstructured, incomplete and inefficient risk management process, in the tender phase of Heijmans Infra, and how can these problems be overcome?

The main research question, stated above, will be answered when all three research questions are answered. In short, the main research question will be answered using literature review followed by analysis of the current risk management process to produce a modified and verified process plan for the risk management in construction tendering. This will represent the proposed final risk management process to be used for the tender phase of infrastructure projects by Heijmans Infra.

2.6. Research Process Framework



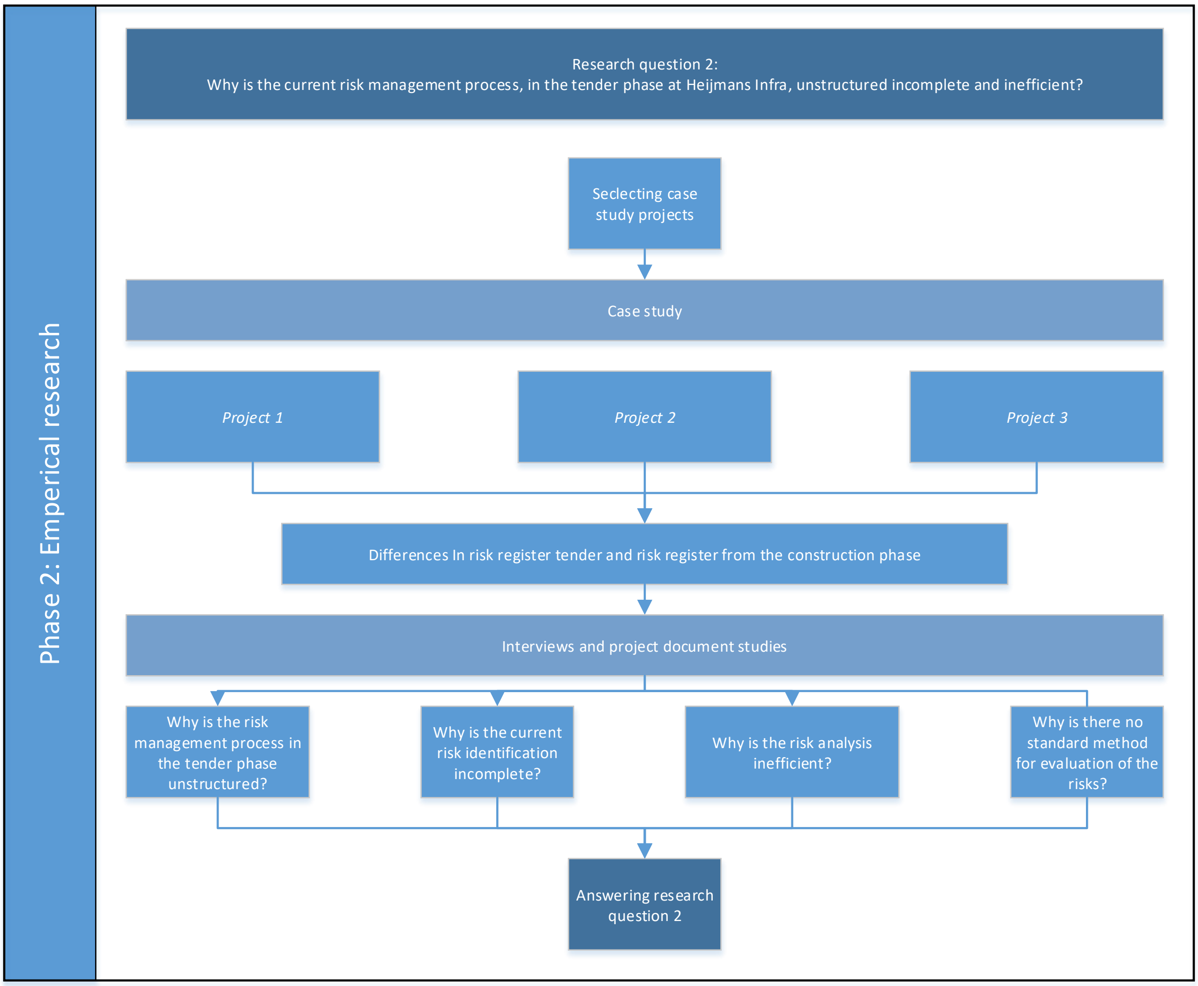


Figure 7: Research Process framework part 1

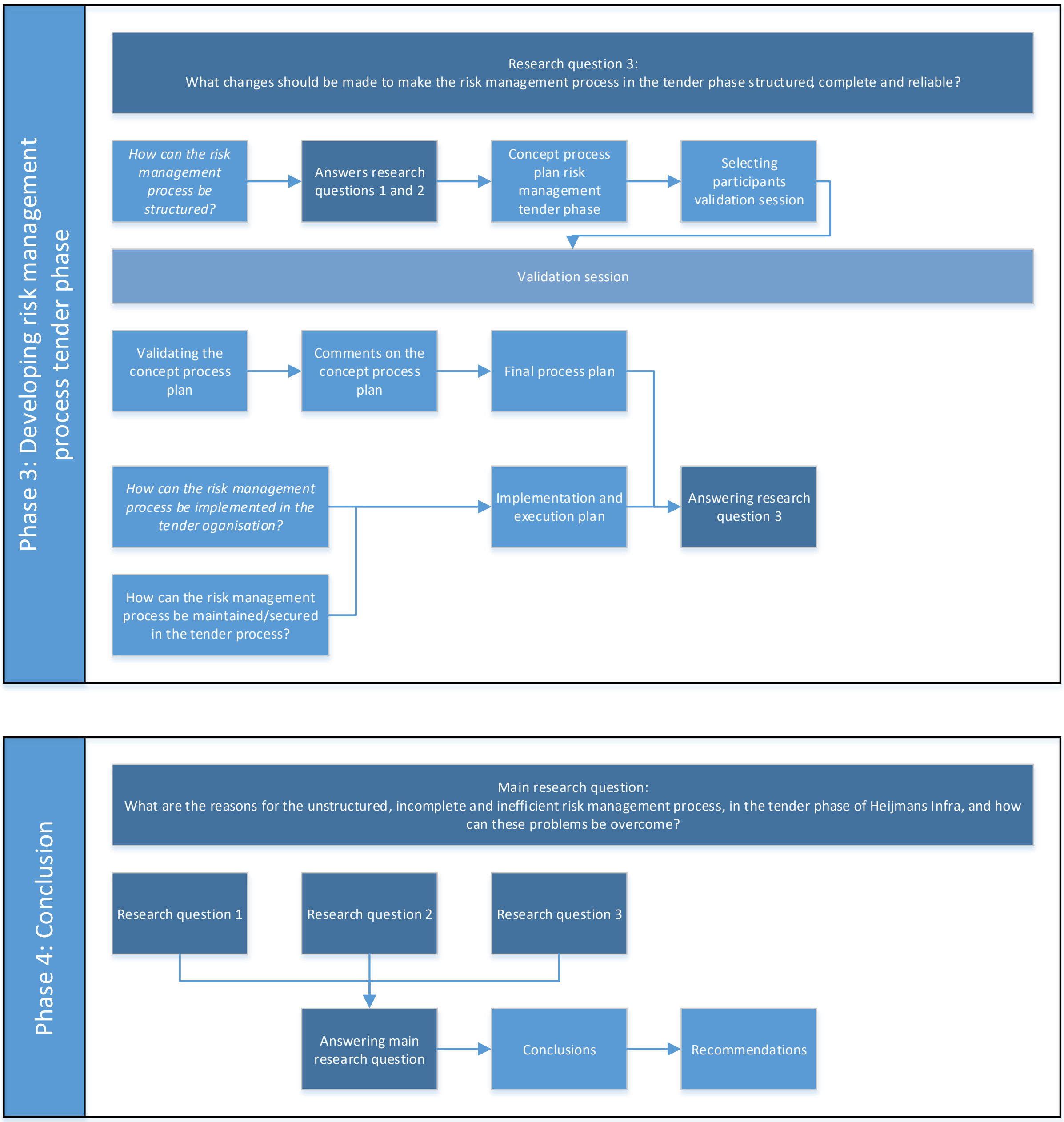


Figure 8: Research Process Framework part 2

3. Theoretical framework

The theoretical framework describes the background of the identified problems based on scientific literature. It also aims to answer the first research questions and its sub questions.

- How can the risk management process be structured to be complete and reliable?
    - How can the risk identification be carried out?
    - How can the risk analysis be performed?
    - How can the risk register be monitored and evaluated?
    - How can risk knowledge be retained within the organisation?

3.1. Methodology

Scientific literature related to this research is gathered in two steps. The first step is the use of the "Platform Risicomanagement", which is a digital platform, from the University of Twente, for sharing information about risk management between (old) students, professors and experts from the field of work. The platform contains bachelor and master thesis reports about risk management, a folder with strongly advised scientific literature about risk management and a folder with dissertations in the field of risk management.

The second step in gathering scientific literature is the use of the university library. The university library is used to access the different online databases which offer access to all digital scientific literature available. The mainly used database is Scopus to gather scientific literature, however also ScienceDirect and GoogleScholar are used.

The master thesis report "Best practices in risico-inventarisatie" by van der Meer (2015) is the result of the research by Joris van der Meer at Heijmans Integrated Projects. The report answers his main question: "What input, heuristics, and organizational assets of Heijmans Integrated Projects deliver the best results relating to risk management and how can this be used to improve the risk management in the future?". This report is the starting point of this literature review.

The folder with strongly advised scientific literature, from the "platform Risicomanagement", is used to form a scientific substantiation for the terms risk and risk management. Thereafter the literature review elaborates on the identified problems in the current risk management process of Heijmans Infra. To gather the scientific literature the following key words are used, in combination and apart from each other: risk, risk management, risk identification, risk analysis, risk register, risk repository, knowledge management, construction, infrastructure, tendering, process.

The used papers are selected based on several criteria. At first the papers which have the most interfaces with this research have been looked at. A second selection criterion is the number of citations of the papers, the more the paper is cited in other papers, the higher the acceptance is in scientific research. When a paper is found which is relevant for this research, there is also looked at the papers which quote the relevant paper to find more current information on the topic.

Based on the gathered scientific literature, the following sections investigate the terms risk, project risk, risk categorizing, risk management.

3.2. Risk

The origin of the word risk is thoroughly investigated by Althaus (2005). Early notations of the word risk are often related to the maritime context, this also applies to the origin of the word risk according to Bernstein (1996). According to Bernstein (1996) the word risk derives from the Italian word *risicare*, which means to dare. It was used by sailors to warn the helmsman that rocks might be near (Aven, 2012).

In contemporary scientific literature, risk is defined in many ways. It is even impossible to present and discuss all the risk concepts suggested in scientific research. This might relate to the fact that there is no agreed definition of the concept of risk (Aven, 2012).

Although there is no agreed definition of risk, the concept of risk can be explained by its characteristics. The terms events, consequences and probabilities are included in the definition of risk, by for example Kaplan & Garrick (1981), Kaplan (1991) and Lowrance (1976). A risk consists of an event, which has a consequence and is associated by probabilities. The use of the term probability in the definition of risk has been discussed by several authors, probabilities are used as a tool to express uncertainties (Aven, 2010).

The term uncertainty is also used in the definition of risk according to the ISO 31000 and the ISO guide 73 on risk terminology (ISO, 2009a) (ISO, 2009b). In the ISO guide the following definitions are given for risk, probability and uncertainty:

> *Risk*: Risk is the effect of uncertainty on objectives.
>
> *Probability*: Probability is defined as a measure of the chance of occurrence expressed as a number between 0 and 1.
>
> *Uncertainty*: Uncertainty is considered the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequences or likelihood

These definitions are discussed by Aven (2011) and other definitions are suggested:

> *Risk*: Uncertainty about and severity of the consequences of an activity or the two-dimensional combination of consequences (of the activity studied) and associated uncertainties (what will the consequences of the activity be). (These consequences could be more or less severe, and defined in relation to expected values, objectives or other reverences).
>
> *Probability*: A measure for representing or expressing uncertainty, following the rules of probability criteria.
>
> *Uncertainty*: Uncertainty means that we do not know what the consequences of the activity will be or the value of unknown quantities.

Al-Jibouri (2016) defines uncertainty as “an event whose outcome cannot be accurately predicted”. The outcome of an event cannot be accurately predicted, however it is possible to assess the outcomes of the event. Based on the nature of the consequences, uncertainty has two possible outcomes. The outcome is a risk or an opportunity.

Risk: The possibility that an uncertain event, whose consequence is damaging, will occur

Opportunity: The possibility that an uncertain event, whose consequence is beneficial, will occur.

Halman (1994) describes risk as a process chain, including cause, exposure and a harmful effect which are all related to each other and all are affected by uncertainty.

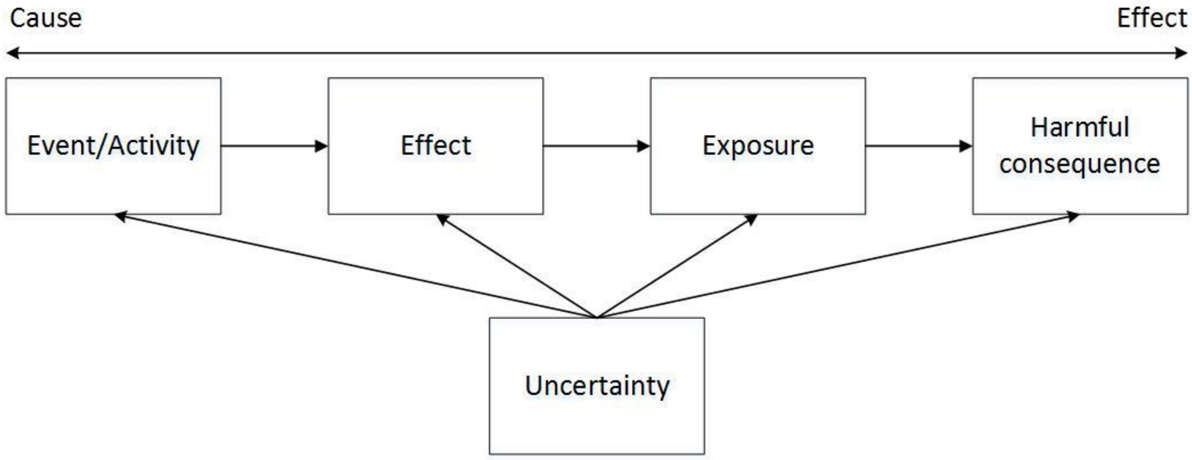


Figure 9: Risk as a process chain, based on Halman 1994 & Van der Meer 2015

Based on the scientific literature above, risk is defined for this research as:

- Risk is an event that has an effect and exposure which result in a harmful consequence.
- Risk is the uncertainty of an event and the uncertainty about the consequence.
- Uncertainty is measured by probability.

3.3. Project Risk

In the above section the concept of risk is discussed. Project risks will be discussed in more detail in this section. The Project Management Body of Knowledge (PMBOK) (Project Management Insititute, 2000) defines risk as "An uncertain event or condition that, if it occurs, has a positive or negative effect on an objective". This definition is used by Karimiazari, Mousavi, Mousavi, & Hosseini (2011),Zayed, Amer, & Pan (2008) and El-Sayegh (2008). In this section, a definition is given for the term project risk and the focus is on the effect on project objectives and the categorization of the risk.

Risk event is considered to be any fact or event whose occurrence can have some impact/consequence on at least one of the project objectives: time, final costs and performance of the project (Mehdizadeh, Taillandier, & Breysse, 2012). The definition of a project risk is given by Breysse et al. (2013), project risk can be defined as the possibility that a project does not run as expected in time, in cost and in quality. Time, cost and quality are common project objectives, as can be seen in table 1.

Table 1: Project objectives

	Time	Cost	Quality	Safety	Environmental sustainability	Function
Akintoye & MacLeod (1997)	v	v	V			
Zou, Zhang, & Wang (2007)	v	v	v	v	V	
Baloi & Price (2003)	v	v	v			V
Zhao, Hwang, & Phng (2014)	v	v	v			
Ebrahimnejad, Mousavi, &	v	v	v	v	v	

Seyrafianpour (2010)						
Eybpoosh, Dikmen, & Birgonul (2011)	v	v	v	v		
Chapman (2001)	v	V	v			

3.4. Risk categorizing

Mehdizadeh et al. (2012):
Risk Breakdown Structure (RBS) is a hierarchically organised depiction of the identified project risks arranged by risk category and subcategory that identifies the various areas and causes of potential risks.
However, RBS suffers several drawbacks such as lack of consensus on how to develop an RBS for a new project, lack of clarity and inconsistencies in definition of risk categories and lack of rules enabling transfer of qualitative/quantitative information of risks across the tree.

Many different classifications of risk have been developed over the years, however, most of these have considered the source criteria as the most important. Following these criteria, a broad classification of construction project risks could be: technical, construction, legal, natural, logistic, social, economic, financial, commercial and political. However, apart from the source criteria, there have been other forms of classifying risks, which take different perspectives. A classification considering the location of the impact of risks in the elements of the project was suggested by Tah. It is also usual to categorise risks into dynamic/static, corporate/individual, internal/external, positive/negative, acceptable/unacceptable and insurable/non-insurable. (Baloi & Price, 2003).

Risk that may affect the project for better or worse can be identified and organized into risk categories. Risk categories should be well defined and should reflect common sources of risk for the industry or application area (Project Management Institute Inc, 2000). Categories include the following:

- Technical, quality, or performance risks
- Project-management risks
- Organizational risks
- External risks

Construction risks can be categorized in several ways based on the source of risk, impact of risk or by project phase. project risks are divided into two groups, according to their source, into internal and external (El-Sayegh, 2008). Internal risks are initiated inside the project while external risks originate due to the project environment (El-Sayegh, 2008). In risk identification step all internal and external risks must be identified. After the establishment of a list of risk events that had actually occurred in the process of project performance, these risks must be assessed. (Karimiazari et al., 2011)

3.5. Risk Management

Risk management is the systematic process of identifying, analysing, and responding to project risk. It includes maximizing the probability and consequences of positive events and minimizing the probability and consequences of adverse events to project objectives (Project Management Institute Inc, 2000).

Risk management is nowadays a critical factor to successful project management, as projects tend to be more complex and competition increasingly tougher. There is a direct relationship between effective risk management and project success since risks are assessed by their potential effect on the objectives of the project.

Project risk management aims to identify possible causes of threat and opportunity that may affect the project objectives (cost, time, quality), to analyse risks qualitatively and quantitively, and to propose a plan of action and monitoring indicators of risks considered critical (Breysse et al., 2013).

The risk management process aims to identify and assess risks in order to enable the risks to be understood clearly and managed effectively (Hillson, 2002).

To be successful, the organization must be committed to addressing risk management throughout the project. One measure of the organizational commitment is its dedication to gathering high-quality data on project risks and their characteristics (Project Management Institute Inc, 2000).

The risk management process is thoroughly described in scientific literature. The content of the information available is very similar, the difference is the level at which risk management is described. Risk management is commonly described as a three-step process of risk identification, risk assessment and risk mitigation (Zayed et al., 2008)(Karimiazari et al., 2011)(Zou et al., 2007). The project risks management process by Project Management Institute Inc (2000) is used in this research, the risk management process is divided in six major processes:

- Risk management planning – deciding how to approach and plan the risk management activities for a project.
- Risk identification – determining which risks might affect the project and documenting their characteristics.
- Qualitative risk analysis – performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.
- Quantitative risk analysis – measuring the probability and consequences of risks and estimating their implications for project objectives.
- Risk response planning – developing procedures and techniques to enhance opportunities and reduce threats to the project’s objectives.
- Risk monitoring and control – monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle.

The processes are in line with the main steps of risk management defined by Baloi & Price (2003): risk management planning, risk identification, risk assessment, risk analysis, risk response, risk monitoring and risk communication.

Risk management planning:
"*Risk management planning is the process of deciding how to approach and plan the risk management activities for a project. It is important to plan for the risk management processes that follow to ensure that the level, type, and visibility of risk management are commensurate with both the risk and importance of the project to the organization*." (Project Management Institute Inc, 2000).

Risk identification:
"*Risk identification involves determining which risks might affect the project and documenting their characteristics. Risk identification is an iterative process. Often simple and effective risk responses can be developed and even implemented as soon as the risk is identified*."(Project Management Institute Inc, 2000).

The risk identification stage is considered the most important and perhaps the most difficult stage. It is important because it defines the aspects of the problem to be studied. It is difficult as all projects, which risk management is commonly applied to, are prototypes. Risk identification is of great importance as the following stages are of little use if the uncertainties were not correctly identified (Al-Jibouri, 2016).

Many researchers suggest a categorised system of classification to aid in the identification process. This categorisation is based on the nature of uncertainties and can be shown as a hierarchy of uncertainty (Al-Jibouri, 2016).

Standard checklist like tables are suggested as a means of documenting the uncertainties identified as it is thought this helps to focus the mind. This is intended to identify those uncertainties which would otherwise be ignored in the unformalized system (Al-Jibouri, 2016).

Qualitative risk analysis:
"*Qualitative risk analysis is the process of assessing the impact and likelihood of identified risks. This process prioritizes risks according to their potential effect on project objectives. Qualitative risk analysis is one way to determine the importance of addressing specific risks and guiding risk responses. Qualitative risk analysis requires that the probability and consequences of the risks be evaluated using established qualitative-analysis methods and tools. Qualitative risk analysis should be revisited during the project's life cycle to stay current with changes in the project risks*."(Project Management Institute Inc, 2000).

Quantitative risk analysis:
"*The quantitative risk analysis process aims to analysis process aims to analyse numerically the probability of each risk and its consequence on project objectives, as well as the extent of overall project risk. This process uses techniques such as Monte Carlo simulation and decision analysis to:*

- *Determine the probability of achieving a specific project objective.*
- *Quantify the risk exposure for the project, and determine the size of cost and schedule contingency reserves that may be needed*
- *Identify risks requiring the most attention by quantifying their relative contribution to project risk.*
- *Identify realistic and achievable cost, schedule, or scope targets.*

Quantitative risk analysis generally follows qualitative risk analysis, it requires risk identification. The qualitative and quantitative risk analysis processes can be used separately or together."(Project Management Institute Inc, 2000).

Risk response planning:
"*Risk response planning is the process of developing options and determining actions to enhance opportunities and reduce threats to the project's objectives. The effectiveness of response planning will directly determine whether risk increases or decreases for the project. Risk response planning must be appropriate to the severity of the risk, cost effective in meeting the challenge, timely to be successful, realistic within the project context, agreed upon by all parties involved, and owned by a responsible person*."(Project Management Institute Inc, 2000).

Four prerequisites defined by Hillson (1999) should be in place before effort is spent on risk response development:

- List of identified and assessed risks, screened to ensure that only genuine risks remain, assessed for probability and impacts, and categorised by source of risk and area affected. Where time for response planning is limited, it will be helpful to prioritise the list of risks, so that available time can be spent on the most significant risks first.
- List of potential responses (if previously identified during the risk identification stage), to be reviewed and confirmed.
- List of project stakeholders, able to act as owners of risk responses.
- Agreed risk threshold for the project, to define the "acceptable" level of risk as a target for risk responses to meet.

If any of these prerequisites are missing, the effectiveness of response development is likely to be compromised (Hillson, 1999).

To be effective, risk responses must meet a number of important criteria, all responses must be (Hillson, 1999):

- *Appropriate* – the correct level of response must be determined, based on the "size" of the risk. This ranges from a crisis response where the project cannot proceed without the risk being addressed, through to a "do nothing" response for minor risks. It is important not to spend inordinate amounts of time or effort developing inappropriate responses for minor risks, but also not to spend too little time considering how to respond to key risks.
- *Affordable* – the cost-effectiveness of responses must be determined, so that the amount of time, effort and money spent on addressing the risk does not exceed the available budget or the degree of risk exposure. Each risk response should have an agreed budget.
- *Actionable* – an action window should be determined, defining the time within which responses need to be completed to address the risk. Some risks require immediate action, while others can safely be left until later.
- *Achievable* – there is no point in describing responses which are not realistically achievable or feasible, either technically or within the scope of the respondent's capability and responsibility.
- *Assessed* – all proposed responses must work! The effectiveness of a response is best determined by making a "post-response risk assessment" of the size of the risk assuming effective implementation of the response.
- *Agreed* – the consensus and commitment of stakeholders should be obtained before agreeing responses.
- *Allocated & Accepted* – each response should be owned and accepted to ensure a single point of responsibility and accountability for implementing the response.

Each proposed response should be tested against these seven criteria before it is accepted.

Four key risk response strategies are described in scientific literature, for example by Akintoye & MacLeod (1997); Hillson (1999); Project Management Institute Inc. (2000); Zou et al. (2007):

- *Risk avoidance*. Risk avoidance is changing the project plan to eliminate the risk or condition or to protect the project objectives from its impact. Although the project team can never eliminate all risk events, some specific risks may be avoided. (Project Management Institute Inc, 2000).

- *Risk Transference*. Risk transfer is seeking to shift the consequence of a risk to a third party together with ownership of the response. Transferring the risk simply gives another party responsibility for its management; it does not eliminate it(Project Management Institute Inc, 2000).
- *Risk mitigation/reduction*. Mitigation seeks to reduce the probability and/or consequences of an adverse risk event to an acceptable threshold. Taking early action to reduce the probability of a risk occurring or its impact on the project is more effective than trying to repair the consequences after it has occurred. Mitigation costs should be appropriate, given the likely probability of the risk and its consequences(Project Management Institute Inc, 2000).
- *Risk acceptance/retention*. Risk acceptance indicates that the project team has decided not to change the project plan to deal with a risk or is unable to identify any other suitable response strategy. Active acceptance may include developing a contingency plan to execute, should a risk occur. Passive acceptance requires no action, leaving the project team to deal with the risks as they occur(Project Management Institute Inc, 2000).

Risk monitoring and control:
"Risk monitoring and control is the process of keeping track of the identified risks, monitoring residual risks and identifying new risks, ensuring the execution of risk plans, and evaluating their effectiveness in reducing risk. Risk monitoring and control is an ongoing process for the life of the project. The risks change as the project matures, new risks develop, or anticipated risks disappear. Good risk monitoring and control processes provide information that assists with making effective decisions in advance of the risk's occurring. Communication to all project stakeholders is needed to assess periodically the acceptability of the level of risk on the project."(Project Management Institute Inc, 2000).

Karimiazari et al. (2011) presents numerous methods that can be used for risk assessment. These methods can be divided in quantitative methods and fuzzy risk assessment methods.
Quantitative methods:

- Monte Carlo Simulation
- Sensitivity Analysis
- Critical path method
- Fault tree analysis
- Event tree analysis
- Failure mode, effects and criticality analysis

Fuzzy risk assessment methods as explained by the following authors:

- Mustafa and Al-Bahar (1991)
- Mohammad & Al-Bahar (1991)
- Halman & Keizer (1994)
- Sadiq and Husain (2005)
- Carr and Tah (2001)
- Cho, Choi, and Kim (2002)
- Choi, Cho, and Seo (2004)
- Zeng et al. (2007)
- Zayed et al. (2008)

The risk assessment method used at Heijmans ins the RISMAN method. This method is described by Well-Stam et al., (2004).

These methods differ in a variety of ways and they have their own advantages and disadvantages. So an ideal risk assessment method which would suit all organizations does not exist, as each of the organizations and projects possesses its own unique characteristics (Lichtenstein, 1996), so, an organization and project management team need to select the most appropriate methodology on its specific (Karimiazari et al., 2011).

3.6. Knowledge Management

The term knowledge management and the application in the construction industry, specifically risk management, are explained by Malhotra (1998) and Tah & Carr (2001).
I explain Knowledge management by caters to the critical issues of organisational adaption, survival, and competence in face of increasingly discontinuous environmental change. Essentially, it embodies organisational processes that seek synergistic combination of data and information processing capacity of information technologies, and the creative and innovative capacity of human beings" (Malhotra, 1998).
The increasing complexity and dynamism of major construction projects can decrease a project manager's ability to identify and manage risks effectively. Project managers cannot afford to inadvertently repeat past mistakes because they were unaware of successful risk management strategies applied elsewhere or on previous projects. A smart use of information technology designed to capture risk management experience lets project managers learn form and share with others by readily tapping into a centralised or distributed corporate knowledge repository using emerging knowledge management techniques (Tah & Carr, 2001).

To incorporate risk and knowledge management successfully it has to meet several requirements, Tah & Carr (2001) listed the following requirements. An environment must be created where data can be stored and organised so that individuals and teams can:

- Access it easily and intuitively
- Evaluate it using intelligent systems and tools
- Share that analysis with colleagues
- Act upon those findings effortlessly

Such an environment would be integrated and built on a scalable infrastructure necessary to allow distributed knowledge-enabled software components to thrive and grow across the entire enterprise. The biggest challenge to realise such an environment is to gather all pertinent data that flows through an enterprise, and transforming information technology systems from mere databanks into true institutional memory (Tah & Carr, 2001).

Lessons learnt and experiences from the past are essential to support risk identification and management. Therefore, there is need to manage risks by retaining and maintaining knowledge about past project risks in the form of informal or formal databases which then could be used in the future (Karningsih, Kayis, & Kara, 2010).

3.7. Conclusion

Scientific literature is used to answer the first research question: "*How can the risk management process be structured to be complete and reliable in construction tendering?*".

The literature review resulted in the following process steps to come to complete and reliable risk management process in construction tendering:

- Risk management planning – deciding how to approach and plan the risk management activities for a project.
- Risk identification – determining which risks might affect the project and documenting their characteristics.

- Qualitative risk analysis – performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.
- Quantitative risk analysis – measuring the probability and consequences of risks and estimating their implications for project objectives.
- Risk response planning – developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives.
- Risk monitoring and control – monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle.

These process steps form the scientific basis for the risk management process plan in chapter 5.

4. Case Study

The case study is the follow-up of the interviews which leads to the problem analysis and the literature research. The first research question answered how the risk management process can be structured to be complete and reliable. The case study research methodology is used to answer the second research question and its sub questions:

- ***Why is the current risk management process, in the tender phase at Heijmans Infra, unstructured, incomplete and inefficient?***
    - *Why is the risk management process in the tender phase unstructured?*
    - *Why is the current risk identification incomplete?*
    - *Why is the risk analysis inefficient?*

This chapter starts with the goal of the case study and the methodology on how the research questions are answered. After the methodology a description is given about risk assessment at Heijmans and how the risks are financially controlled by the project controller.

4.1. Goal case studies

The goal with the case studies is to investigate if the perceived problems in the problem analysis are consistent with the actual project data. The second goal of the case study research is to identify the reasons why the current risk management process, in the tender phase at Heijmans Infra, is unstructured, incomplete and inefficient.

4.2. Research method

In the case study five different projects are analysed. These are all Heijmans infrastructural projects which have been completed in recent years or are almost complete. At first the required documents have been requested from the risk managers and project controllers, as explained below. After gathering the documents, the risk registers from the tender and the construction phase risk register have been analysed to determine the completeness of the risk identification during the tender phase. The third step is the analysis of the top-10 cost overruns of the respective project. Thereafter the relations between the cost overruns and the risks from the risk register tender phase are discussed. The outcome of the analysis is discussed in an interview with the project manager to determine why the risk/cost overrun occurred. Subsequently the tender manager of the project is interviewed to determine why he could not have foreseen the risk, and how the risk/cost overrun could be avoided in the future. Finally, a conclusion is given which serves as input for the risk management process in the tender phase.

After selecting the projects, three documents have been requested, from the risk managers and project controllers, for each project:

- **Risk register tender**: This document contains all the risks and opportunities that have been identified and quantified during the tender phase. This document contains the probability of occurrence and the expected costs when the risk occurs, for every risk and opportunity in the risk register. This information is the input for the Monte Carlo analysis to determine the risk budget for the project.
- **The construction phase risk register**: This document contains all the risks that have been identified and updated during the lifecycle of the project. Generally, this document should include all the identified risks, because the risks are not deleted from the register when they are controlled, occurred or expired. Besides the initial quantification a quantification is given about the current state of the risk. The content of the risk register is described in the section "Risk registers at Heijmans".

- **Top 10 with the budget overruns on the project**: The top-10 budget overruns are requested because they had the most impact on the financial outcome of the project. In the analysis will be determined if the risk related to the cost overrun was identified and if so why the quantification is incorrect. The cost overrun is not linked to every risk individually, so it is not possible to immediately select the top 10 risks with the biggest cost overrun. The project controllers record the cost overruns per activity, this is further explained in the section "Project control in relation to risk management". For the case study analysis, the top 10 activities with the biggest cost overruns have been requested from the project controllers for each project.

The quality and consistency of the received documents differs between the projects. The risk register from the tender phase differs with the construction phase risk register, for example in the used format. The risk register from the tender phase is commonly documented in Excel, however the construction phase risk register is commonly documented in Relatics. Also, the types of information recorded in the risk register per risk differ between the tender and construction phase risk register. This also differs between the projects.

4.3. Risk registers at Heijmans

This analysis uses two different risk registers. First the risk register which is made in the tender phase of the project. The second risk register is the construction phase risk register, this register is extracted from the Relatics environment of the project. Relatics is a web-based environment where risks can be registered and monitored. The Relatics environment is also used for the verification and validation of the contract requirements. The following sections elaborate on the content of the different risk registers.

4.3.1. Risk register tender phase

Currently a standard format risk register is used for all tenders at Heijmans. The risk register is documented in Excel, as shown in Figure 10. This format is not only used within the business unit infra, but also within the business areas property development, residential building and non-residential. The format contains the following aspects:

- Identification number
- Name of the initiator
- Opportunity or Risk
- Category → choice between: client, environment, technical, financial, planning, safety and organisation
- Topic, this is a description of the risk/opportunity in one word
- Description, this includes a description of the risk/opportunity, the cause and the effect.
- Classification, this indicates the importance of the risk/opportunity → choice between 1,2 and 3
- Description control measure, both a description of the preventive control measure and the corrective control measure
- Name of the person responsible for the fulfilment of the control measure
- Costs of the preventive control measure
- New classification, classification of the risk/opportunity after fulfilment of the preventive control measure → choice between 1,2 and 3
- The cost of the risk/opportunity if it occurs, after fulfilment of the preventive control measure.
- The probability of occurrence of the risk/opportunity in percentage
- The financial expectation of the risk/opportunity, this is the cost multiplied with probability of occurrence

There are several aspects that can be added to the format, which are:

- Business area or business unit
- WBS (Work Breakdown Structure) or SBS (System Breakdown Structure) code
- Residual risk, including a description, name of the person responsible for the fulfilment and a new classification
- Monte Carlo, by using this function a minimum and maximum are added for the probability of occurrence and the cost of the risk/opportunity. As well as the name of the board member who must approve the input for the Monte Carlo simulation
- Comments can be added to the risks/opportunities

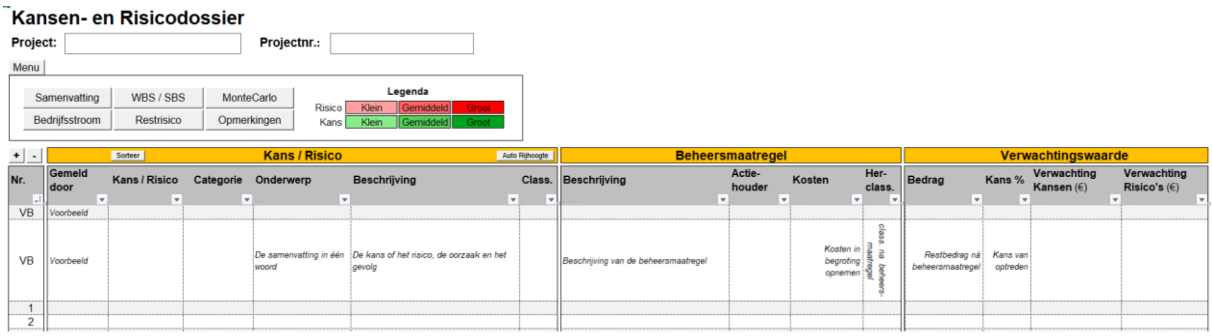


Figure 10: Format opportunity and risk register

4.3.2. Construction phase risk register

In the execution phase of the project the risks and opportunities are registered in a risk register in Relatics. The risk registers differ in output, because the Relatics template has changed by the years and not all aspects where mandatory. In the current Relatics template the following aspects can be documented:

- Risk Identification number
- Risk identification number for client
- Risk/Opportunity grouping
- Title
- Description
- Aspect
- Date drafted
- Date occurred
- Date discharged
- Risk/opportunity type (intern/extern)
- Status
- Risk carrier
- Risk owner
- Board member
- Agreed with allocation
- Comment if not agreed
- Urgency
- Incorporate in quarterly figures
- Cause
- Effect
- Preventive control measure
- Preventive control measure status
- Preventive control measure actionee
- Preventive control measure date accomplished
- Corrective control measure
- Corrective control measure status
- Corrective control measure actionee
- Corrective control measure date accomplished
- Quantification initial, actual and rest according to the RISMAN method, which will be explained below.
- Requirement ID
- Requirement
- ID
- Object
- ID
- Work package
- ID
- Work package activity
- Comment
- Actual in project stage

Heijmans is using the RISMAN method (Well-Stam et al., 2004) to quantify risks and opportunities. This is a qualitative method which multiplies the probability of occurrence with the sum of the effects to rank the risks and opportunities in the risk register. The effects are categorized in the following categories: money, time, quality, safety and environment. The risk owner assigns a score from 0 to 5 to the probability and all effect categories. The categories money and time should be adjusted for every project specifically. This is visualised in Table 2.

Table 2: Risman table

Score	Probability	Effect money	Effect time	Effect quality	Effect safety	Effect environment
0	Does not apply	None	None	None	None	None
1	0 – 1% (rarely occurs)	< €50.000	< 1 day	More/less reparable deviations	Increased / reduced sense of safety	Noticed in the area
2	1 – 5% (unlikely)	€50.000 – €100.00	1 day – 1 week	Significant increase / decrease residual points	More / less expected injuries	More / less complaints
3	5 – 10% (chance exist, not big)	€100.00 - €250.000	1 week – 1 month	Reduced / increased client satisfaction	More / less expected accidents with default	More / less protests licenses
4	10 – 25% (there is a real chance)	€250.000 - €500.000	1 month – 3 months	Failure to fulfil a requirement / Addition of a wish	More / less expected serious accidents	Negative / positive publicity
5	> 25% (big chance)	> €500.000	> 3 months	Not meeting functional demand / delivery of additional functionality	More / less expected very serious accidents	Image damage / Image improvement

The importance of the risk and its possible impact can be determined by multiplying the score for probability with the sum of the scores for the effects. Table 3 gives an example of the calculation of the Risman score for a specific risk or opportunity.

Table 3: Example RISMAN calculation

Probability	Effect money	Effect time	Effect quality	Effect safety	Effect environment	RISMAN score
4	3	4	2	1	5	**4*(3+4+2+1+5) = 60**

After identifying and quantifying the risk/opportunity the RISMAN score forms the initial risk. Control measures are recorded which reduce the initial risk to an acceptable level when the measures are fulfilled. Based on the control measures a new RISMAN calculation is made. The output of this RISMAN calculation is called the residual risk. An example is given in Table 4 and 5.

Table 4: Example initial risk

Risk	Cause	Effect	Probability	Money	Time	Quality	Safety	Environment	Initial risk
Damage cables and pipes due to applying sheet / foundation piles	Vibration cause sag of the subsurface or sheet pile hits cables or pipes	Repairs Delays Not able to remove sheet piles	4	3	4	2	1	0	**40**

Table 5: Example residual risk

Control measures	Status control measures	Probability	Money	Time	Quality	Safety	Environment	Rest risk
1. communicate with stakeholders 2. investigate different design options 3. Check with 3D model 4. Monitoring during execution 5. Levelling the cables and pipes	1. Expired 2. Executed 3. Accepted 4. Expired 5. Executed	3	2	4	2	1	0	**27**

4.4. Project control in relation to risk management

This section describes the function of a project controller and the relation to risk management. The function of the project controller can be described as: providing and monitoring financial project reports and information. This includes advising the project management on financial aspects including risk management of the project.

In the tender phase, a Monte Carlo simulation is used to determine the expected risk budget for the project. The risk budget is divided among the different work packages. The project controllers monitor the financial status of a project by updating an opportunities and threats document. In this document, a prognosis is made about the expected profit or loss per work package or work package activity. However, the document with the opportunities and threats which is monitored by the project controller is not the same as the risks and opportunities in the risk register which is controlled by the risk manager. Since the project controller monitors the opportunities and threats using the work packages and work package activities, it is not possible to determine the financial impact of a specific risk, from the risk register, directly.

The goal of the case studies is to investigate if the perceived problems in the problem analysis are consistent with the actual project data. The risks with the biggest budget overruns are the risks with the biggest consequences and are not identified or quantified insufficiently. However, due to the fact that the financial consequences are monitored per work package it is not possible to select the 10 risks with the biggest cost overruns.

In the case studies, the top 10 activities with the biggest cost overruns are requested from the project controllers. The activities are compared with the risk register from the tender to determine if the risks related to the activities have been identified in the tender and the quantification of the risks is investigated. Based on the analysis the project manager has been interviewed to explain the budget overruns in relation to the identified risks. After these interviews, the tender managers have been interviewed to determine if the risks could have been identified in the tender and how the cost overruns can be prevented in the future.

4.5. Case studies

This section describes the cross-case analysis of the five projects that have been analysed. This section starts with a brief description of the projects that have been analysed. The project descriptions are followed by a cross-case analysis of the risk register from the tender phase and of the construction phase risk register. Followed by a cross-case analysis of the 10 largest cost overruns of the projects. An analysis is done based on the relation between the risks and the cost overruns. This section ends with the conclusion about the risk management process in the tender phase.

4.5.1. Projects

This section provides a short description of the five projects that have been analysed.

Project 1: A1 Apeldoorn – Beekbergen
This project is carried out on the route between the A1 Apeldoorn South and the Beekbergen highway junction. The project includes a new connecting road from Deventer to Arnhem with a new viaduct across the A1 highway and widening of the A1. This project will ensure improved traffic flow and accessibility of the region.
Contract: The project was put out to tender in line with the principles of Best Value Procurement.
Time: 2016-2018
Budget: €20.000.000
Client: Rijkswaterstaat (Directorate-General of public works and water management)

Project 2: Parallelstructuur A12
This project consists of two trajectories: The Extra Gouwe Crossing, parallel to the A12 between Gouda and the Gouda West exit and the Moordrechtboog as the connection between the A12 and the A20. The project includes the construction of 2x2 lanes throughout the entire trajectories, including traffic control systems, bridge and shipping installations, lighting, nature facilities, noise—proofing measures and eight civil structures including an underpass under the A12. The biggest civil structure is the construction of the bridge for crossing the Gouwe on the north side of the Gouwe aqueduct. This bridge will be 500 meters long and has a moveable part of about 25 meters.
Contract: Design and Construct with 10 years of maintenance
Time: 2014-2016
Budget: €65.000.000
Client: Province of Zuid-Holland

Project 3: A12 Veenendaal – Ede – Grijsoord (A12 VEG)
The A12 is an important east-west connection in the Netherlands. This highway will be widened from 2x2 to 2x3 lanes over an 11-km stretch between Ede and Grijsoord. This project will significantly improve traffic flow and safety on the A12. This route runs partly through the Veluwe nature reserve, which requires special attention. The ecological embedding of the A12 is part of the total approach of Heijmans.
Contract: Public Private Partnership, Heijmans is responsible for the entire project from design to maintenance (16 years, till the end of 2032), including financing.
Time: 2014 -2032
Budget: €80.000.000
Client: Rijkswaterstaat (Directorate-General of public works and water management)

Project 4: Bio Science Park Leiden
To improve the traffic flow on the Plesmanlaan and the accessibility of the Bio Science Park (OBSP) Leiden, an uneven intersection will be constructed on the intersection of the Plesmanlaan and the Haagse Schouwweg. The project also includes the restructuring of connecting roads and the nearby intersections to and from the A44. The construction of this project is an important condition for starting the area development at the Bio Science Park.
Contract: Design and Construct, including 1 year of maintenance
Time: 2015-2016
Budget: €25.000.000
Client: Municipality of Leiden

Project 5: Bypass Reeuwijk
The new 3,4km long bypass around Reeuwijk-Brug will reduce the traffic intensity in the village centre. In addition to the construction of the bypass, the project consists of the construction of two new roundabout, several sound barriers, the provision of three crossings for crossing cables and pipes, partial replacement of sewerage and various flora and fauna facilities.
Contract: Design and Construct
Time: 2014-2015
Client: Municipality of Bodegraven-Reeuwijk

4.5.2. Cross-case analysis tender and construction phase risk register

Number of risks and opportunities
The next table shows the number of risks and opportunities that have been identified in the risk register from the tender phase and in the construction phase risk register. The last two columns show the difference between the number of risks and opportunities, this is measured by how many times the construction phase risk register is bigger than the risk register from the tender and the absolute difference.

Table 6: Number of identified risks and opportunities

Number of identified risks and opportunities				
Projects	**Tender**	**Construction**	**Difference**	**Absolut**
A1 Apeldoorn - Beekbergen	149	225	1.51	76
Parallelstructuur A12	155	188	1.21	33
A12 VEG	114	227	1.99	113
OBSP Leiden	65	175	2.69	110
Randweg Reeuwijk	8	68	8.50	60

From Table 6 it can be concluded that the project Parallelstructuur A12 has the smallest difference (1.21) between the number of identified risks and opportunities and the project Randweg Reeuwijk has the largest difference (8.50). Based on this comparison it is concluded that the risk identification process in the tender phase is not complete for all five projects, because the number of identified risks in the construction phase risk register is larger than the number of the identified risks during the tender phase. The difference of 1.21 indicates that the risk identification has been almost complete for the project Parallelstructuur A12. The difference of 8.50 and the number of identified risks and opportunities in de tender (8) of the project Randweg Reeuwijk indicate that the identification process is far from complete. Also, the absolute numbers show a big difference.

Ratio between risks and opportunities

Table 7 shows the ratio between the identified risks and opportunities in the risk registers from the tender. The construction phase risk register is not considered, because only the construction phase risk register of the project Randweg Reeuwijk contains risks and opportunities. The other risk registers only contain risks.

Table 7: Ration between identified risk and opportunities

Ratio between identified risks and opportunities				
Projects	**Number of risks and opportunities**	**Risk**	**Opportunity**	**Point of attention**
A1 Apeldoorn - Beekbergen	149	62%	29%	9%
Parallelstructuur A12	155	62%	38%	0%
A12 VEG	114	80%	20%	0%
OBSP Leiden	65	83%	17%	0%
Randweg Reeuwijk	8	50%	50%	0%

Table 7 indicates that during the identification process the focus was mainly on identifying risks for the projects A12 VEG and OBSP Leiden, in which 80% and 83% of the risk register consist of risks. The risk percentage for the project Parallelstructuur A12 equals the risk percentage for the project A1 Apeldoorn – Beekbergen, however 9% of this risk register consist of points of attention besides the risks and opportunities. The risk register of the project Randweg Reeuwijk equals the number of identified risks and opportunities.

Control measures

Table 8 shows the percentage of the risks and opportunities in the risk registers for which one or more control measures have been identified. The project OBSP Leiden is the only project which make a difference between preventive and corrective control measures in the risk register during the tender phase. That is why no difference is made between preventive/corrective control measure in the tender phase. For the project OBSP Leiden the percentage of the preventive control measure is used in the table below. For the construction phase risk register a difference is made between the identified preventive and corrective control measures.

Table 8: Control measures identified

Control measures identified			
Projects	**Tender phase preventive**	**Construction phase preventive**	**Construction phase corrective**
A1 Apeldoorn - Beekbergen	89%	92%	13%
Parallelstructuur A12	72%	95%	16%
A12 VEG	69%	90%	60%
OBSP Leiden	94%	90%	43%
Randweg Reeuwijk	25%	76%	71%

Table 8 shows differences between the percentages for which a (preventive/corrective) control measure is identified. Ideally every risk should be reduced by means of a preventive control measures, this means that the percentage for the preventive control measure should be near 100%. In the tender, the projects OBSP Leiden and A1 Apeldoorn – Beekbergen have the highest percentage, 94% and 89%) of risks and opportunities wherefore a control measure is identified. This percentage is lower for the projects Parallelstructuur A12 (72%) and A12 VEG (69%), which indicate that less effort is done to identify control measures during the tender phase. The project Randweg Reeuwijk has the lowest percentage, 25%, of risks and opportunities wherefore a control measure has been identified. In the construction phase risk registers the percentages of risks wherefore a preventive control measure has been identified lies for all projects, except the project Randweg Reeuwijk, on 90% or above. The percentage for the project Randweg Reeuwijk is 76%, this is less than the other projects but considerably higher than the percentage of identified control measures in the tender phase. There is a big difference in the percentage of risks for which a corrective control measure has been identified. Surprisingly the project Randweg Reeuwijk has the highest percentage of identified corrective control measures with 71%. This is considerably more than the 60% for the project A12 VEG and the 43% for the project OBSP Leiden. The percentage for the projects A1 Apeldoorn – Beekbergen and Parallelstructuur A12 are just 13% and 16%. Overall is concluded that the identification of control measures can be better during the tender, this percentage should be 100%. The identification of preventive control measures is almost complete, however improving is still possible. More attention should be put in place to define corrective control measures. This is also important for the calculation of the costs when a risk does occur.

Financially quantified in the risk register.

Table 9 shows the percentage of risks and opportunities for which a financial consequence is quantified. This means that the probability of occurrence times the financial consequence does not equal €0. This is only done for the risk register from the tender phase, because the probability of occurrence and the financial consequence are not part of the construction phase risk registers, for 3 out of the 5 projects.

Table 9: financial consequence quantified

Financial consequence quantified				
Projects	**Number of risks and opportunities**	**Risks & Opportunities**	**Risks**	**Opportunities**
A1 Apeldoorn - Beekbergen	149	19%	21%	23%
Parallelstructuur A12	155	46%	34%	66%
A12 VEG	114	38%	31%	65%
OBSP Leiden	65	51%	50%	55%
Randweg Reeuwijk	8	88%	75%	100%

Table 9 shows multiple differences in the percentages of the risks and opportunities for which a financial consequence is quantified. The project A1 Apeldoorn – Beekbergen has the lowest percentage (19%) of risks & opportunities that have been financially quantified, while the project Randweg Reeuwijk has the highest percentage (88%). Based on the table above is concluded that a larger percentage of the opportunities is financially quantified compared to the risks. This is logical, because an opportunity has a positive effect on the project goals. Which result normally is less costs.

Effectiveness of control measures

Based on the difference between the Risman score before the control measure and after, conclusions can be drawn on the effectiveness of the control measure. When there is no reduction in the Risman score, it can be concluded that the control measure was not effective. (This statement is open to discussion because the value for the consequence can remain the same, however the effect drops with for example €200.000). Table 10 shows the percentage of the risks wherefore the control measure did not lead to a reduction of the Risman score. The risks wherefore the initial Risman score is 0, are excluded in this analysis. The table is based on the data from the construction phase risk registers, because the Risman method was only used in two risks registers from the tender. In the construction phase risk registers the Risman method is used to quantify the risks, except for the project Randweg Reeuwijk.

Table 10: Effectiveness of control measures

Effectiveness of control measures					
Projects	**Number of risks**	**Number of risks (with the initial Risman score "0" excluded)**	**Number of risks with no reduction of the Risman score after control measure**	**Percentage of risks with no reduction of the Risman score after control measure**	**Difference in Risman score between**
A1 Apeldoorn - Beekbergen	225	129	11	8%	Initial - Actual
Parallelstructuur A12	188	152	96	63%	Actual - Rest
A12 VEG	227	201	14	7%	Initial - Rest
OBSP Leiden	175	158	11	7%	Actual - Rest
Randweg Reeuwijk	-	-	-	-	

The following conclusions can be drawn based on Table 10. At first, all the projects have risks where the initial quantification has the Risman score "0". Especially the project A1 Apeldoorn – Beekbergen has 96 (225-119=96) risks who do not have an initial Risman quantification. The question that arises based on this difference is: if a risk has an initial Risman score of 0 is it a risk or not?

Another percentage that stands out is the 63% of risks with no reduction of the Risman score after the control measure. This indicates that most of the control measures are not effective, because the Risman score is not reduced. However, the results can be discussed because all the risk registers differ in the data that is recorded. For the project Parallelstructuur A12 the actual and the rest Risman scores are recorded. Therefore, it is not possible to draw conclusions, because the initial Risman score is unknown. Table 10 gives an indication about the effectivity of the control measures, but further research is needed to give more insight in the quality and effectiveness of the control measures.

Top-10 financial budget overruns

Table 11 shows the aspects that caused the highest budget overruns on the projects. The table is called a top-10 with financial budget overruns, however for the project A1 Apeldoorn – Beekbergen only 5 aspects have been identified and the project controller identified a top-11 for the project OBSP Leiden. A top-10 was not given for the project Parallelstructuur A12, the analysis for this project is based on the financial budget overruns larger then €100.000. This resulted in 32 overruns, which are summarised in the top 10 in Table 11.

Table 11: Top-10 financial budget overruns

Top-10 financial budget overruns	A1 Apeldoorn - Beekbergen	Parallelstructuur A12	A12 VEG	OBSP Leiden	Randweg Reeuwijk
1	UTA costs	Design	UTA costs	UTA costs	Ground and foundation works
2	Maintenance	UTA costs	Traffic control measures	Construction (earthworks, electrical, tarmac, paving)	Civil structures related to water systems
3	Milling	Civil structures	Supplying sand/ground	Design	UTA costs
4	Temporary lighting	Equipment	Earthworks	Sheet piles temporary construction pit	Foundation piles
5	Preliminary investigations	Groundworks	Asphalt coating + research	Cable & pipes works	Design
6	-	Technical installations	Temporary lighting	Anker construction	General construction site costs
7	-	Dimensioning	Civil beams	Requirement related to water level	Asphalt
8	-	Optimisations	Cable & pipes works	Foundation piles	Civil foundation works
9	-	Items that were forgotten	Remediate	Sewer system	Traffic control measures
10	-	Licenses	Asphalt	Income of removed sand	Dimensioning
11	-	-	-	Traffic control measures	-

Based on the table above it is concluded that the UTA costs, which are the staff and labour costs of the personnel which not directly build the project, are the most common and have the biggest budget overrun. The UTA costs are the highest in three of the five projects and for the other two projects, the UTA costs are in the top 3 of financial budget overruns. Financial budget overruns on the aspect design are identified in three of the five projects. Other financial budget overrun aspects that have been identified multiple times are, traffic control measures, dimensioning, ground and foundation works, temporary lighting and asphalt.

Risks related to budget overruns
In section 4.4, about the relation between project control and risk management, it has already been explained that it is not possible to determine the financial impact of a specific risk, because the costs are not controlled based on the risks but on the work packages.

The way in which the relation between the risk and the budget overruns is investigated, is explained in this section. The top-10 financial budget overruns and the risk register from the tender forms the basis for this analysis. The risk registers from the tender are analysed to determine if the risks have an impact on the one of the top-10 financial budget overruns.

- The first column in Table 12 includes the five projects that have been analysed.
- The second column shows the number of risks and opportunities that have been identified in the tender risk register.
- The third column shows the number of risks and opportunities from the tender risk register that are related to the top-10 financial budget overruns.
- This number is expressed as a percentage of the number of risks and opportunities, in the fourth column.
- The fifth column shows the number of risks and opportunities related to the top-10 financial budget overruns, which are financially quantified in the tender risk register.
- The sixth column shows the percentage of risks and opportunities related to the top-10 financial budget overruns which are financially quantified in the tender risk register with respect to the number of risks and opportunities related to the top-10 financial budget overruns.
- A comparison is made between the sum of the probability of occurrence times the financial impact for the risks and opportunities from the tender risk register which are related to the top-10 financial budget overruns, and the sum of the top-10 financial budget overruns. The amount from the tender is expressed as a percentage from the top-10 financial budget overruns, this percentage is presented in the seventh column.
- This is also done in the eight column, however the probability of occurrence is excluded. The amount used in the comparison is the amount when all the risks and opportunities, which are related to the top-10 financial budget overruns do occur.

As explained in the previous section, the project Parallelstructuur A12 does not have a specific top-10. In the analysis of this project all the financial budget overruns lager then €100.000 have been investigated. The project data table 12 below is based on this project analysis.

Table 12: Overview of results from the case studies

1	2	3	4	5	6	7	8
Projects	**Number of risks and opportunities in tender risk register**	**Number of risks and opportunities related to the top-10 financial budget overruns**	**Percentage of risks and opportunities related to the top-10 financial budget overruns**	**Number of risks and opportunities related to the top-10 financial budget overruns which are financially quantified in the tender risk register**	**Percentage of risks and opportunities related to the top-10 financial budget overruns and which are financially quantified in the tender risk register**	**Expected costs risks and opportunities from tender risk register expressed in percentage of the top-10 financial budget overruns**	**Maximum costs risks and opportunities from tender risk register expressed in percentage of the top-10 financial budget overruns**
A1 Apeldoorn - Beekbergen	149	21	14%	4	19%	22%	120%
Parallelstructuur A12	155	43	28%	20	47%	2%	20%
A12 VEG	114	30	26%	7	23%	8%	22%
OBSP Leiden	65	33	51%	25	76%	2%	38%
Randweg Reeuwijk	8	1	13%	1	100%	0.1%	38%

Multiple conclusions can be made on table 12.

- The second till fourth column show the number and percentage of risks and opportunities, from the tender risk register, which are related to the top-10 financial budget overruns. About the half of the risks and opportunities from the project OBSP Leiden are related to the top 10 financial budget overruns. For the projects Parallelstructuur A12 and A12 VEG about a quarter of the risks and opportunities are related to the top-10 financial budget overruns and for the projects A1 Apeldoorn – Beekbergen and Randweg Reeuwijk it is 14% and 13%. Based on the 51% for the project for the project OBSP Leiden is concluded that the risks are not controlled effectively.
- The fifth column shows the number of risks and opportunities which are related to the top-10 financial budget overruns, which are also financially quantified in the tender. This difference is made because not all the identified risks and opportunities are financially quantified in the tender.
- The sixth column shows the percentage of the risks and opportunities which are also financially quantified in the tender, compared to the number in the third column. The outcome of the analysis is a wide range of percentages from 19% for the project A1 Apeldoorn – Beekbergen to 100% for the project Randweg Reeuwijk. For example, the 19% for the project A1 Apeldoorn – Beekbergen means that 4 of the 21 risks from the tender risk register which are related to the top-10 financial budget overruns, are also financially quantified in the tender.
- Based on the data is concluded that only a small percentage of the identified risks and opportunities, related to the top-10 financial budget overruns, is financially quantified in the tender.

- In the seventh and eight columns form the outcome of the financial analysis. The seventh column shows the sum of the probability of occurrence times the expected costs, expressed in a percentage in relation to the financial sum of the top-10 financial budget overruns. The 22% for the project A1 Apeldoorn – Beekbergen indicates that for 22% of the top-10 financial budget overruns, an amount of money is calculated for the risks. The percentage for the project Randweg Reeuwijk is 0.1%, from which is concluded that hardly and money is reserved for risks related to the top-10 financial budget overruns.
- The eight column does the same as the seventh column, however here the sum of the expected costs is used, and the probability of occurrence is excluded. The 120% for the project A1 Apeldoorn – Beekbergen shows that the financial quantification was good, because when the risks would occur the expected cost would be enough compared to the top-10 financial budget overruns. However, the quantification of the probability of occurrence was not good because the final risk budget only covers 22% of the top-10 financial budget overruns. The other projects are in the range between 20-40%, which lead to the conclusion that both the quantification of the probability of occurrence as the expected costs was not sufficient.

4.6. Interviews

The case studies provided proof of the incompleteness and ineffectiveness of the risk management process in the tender phase. Based on the case study, the tender managers and project managers are asked what led to incompleteness and ineffectiveness and how the risk management process should be improved in the future to overcome the budget overruns related to the risks.

The results of the interviews are summarized based on the sub questions of the research question: *Why is the current risk management process, in the tender phase at Heijmans Infra, unstructured, incomplete and inefficient?*

Why is the risk management process in the tender phase unstructured?
The main reasons mentioned by the tender managers is the role of the risk manager. This role is commonly not the main task for someone in the tender team. And the tender team is not the same from start to finish, different people start at different moments during the tender. So, it is hard to form one line of thought between the tender team. Another reason for the unstructured process is the Risk Register. The format of the risk register used in the tender phase is not suited to quantify the risk effectively and not suited to register the control measures.

Why is the current risk identification incomplete?
The main reason for de incompleteness of the risk register is related to the period of economic crisis, in which Heijmans was desperate for work. As a result, risks were deleted from the risk register, which resulted in a low risk budget. Which resulted in the construction phase that when risks occurred there was no budget for the corrective control measures which resulted in the cost overruns.

Why is the risk analysis inefficient?
The main conclusion from the tender managers was the fact that the risk register used in the tender phase was insufficient to quantify the risks. Besides the risk register also the subjective quantification of the consequences and probability of occurrence led to problems in the risk analysis.

4.7. Conclusions case studies

This section summarises the outcomes of the project analysis and the interviews with the tender manager and project manager gives insight in the incompleteness and ineffectiveness of the risk management process in the tender phase.

At first an introduction is given about the risk management process at Heijmans and about the financial project control in relation to risk management. Thereafter a cross-case analysis is made to compare the project analysis of the five projects. The analysis started with a comparison between the tender and the current risks register, thereafter the financial budget overruns have been analysed. Finally, the relation between the risks from the tender and the financial budget overruns have been analysed. The following paragraphs give the conclusions per subject.

From the comparison of the number of identified risks and opportunities in the tender and construction phase risk register is concluded that the identification process is not complete during the tender. However, based on the data and information from the tender and project managers it is not known which percentage of the risks that were added in the construction phase risk register could have been identified in the tender.

The ratio between the identified risks and opportunities is analysed. The analysis concludes that most of the risk register consist of risks and a small part of the register consists of opportunities. This suggest that the focus is mainly on identifying risks and less focus is on identifying opportunities.

The control measures are analysed to determine the completeness of the quantification. The analysis shows that the amount of risks and opportunities for which a control measure is identified in the tender lies in the range between 25-94%. Based on this analysis is concluded that the identification of control measures in the tender is not complete. The identification of preventive control measures in the construction phase risk register is on average 90%. This percentage can be 100% to have a complete risk register. The analysis also showed that there is less attention for identifying corrective control measures. The range for which a corrective control measures has been identified lies between 13-71%. The fact that a control measure is identified does not say anything about the quality or effectiveness of the control measure.

The analysis showed that not all the risks and opportunities which are identified in the tender, and included in the risk register, are financially quantified in the tender. The range of risks and opportunities which are financially quantified lies between 19-88%, on average this percentage is around 50%. The percentage of financially quantified opportunities is higher than the percentage of the financially quantified risks.

The effectiveness of the control measures is measured based on the Risman scores for the risks in the construction phase risk registers. Based on the analysis is concluded that about 8% of the identified control measures is not effective, because it did not result in a reduction of the Risman score. However, it is not known if the risks are reduced, because the quantification is based on perception of the influence of the control measures.

The analysis of the top-10 financial budget overruns shows that the budget related to UTA cost, personnel and staff costs, is exceeded in all five projects and is the biggest overrun in three of the five projects. Other aspects of which the budget is exceeded in multiple projects are design, traffic control measures, dimensioning, ground and foundation works, temporary lighting and tarmac. Based on this analysis is concluded that more attention should be paid to control these aspects, this can be done by identifying risks related to these aspects.

The last analysis, in which the relation between the identified risks from the tender risk register and the top-10 financial budget overruns have been analysed, concludes that about a quarter to half of risks and opportunities in de tender risk register is related to the top-10 financial budget overruns. However, the percentage of the risks and opportunities which is also financially quantified in the tender is significantly lower. The analysis showed that the amount following out of the sum of the probability of occurrence times the expected cost was 22% of the sum of the top-10 financial budget overruns, this was the highest percentage of the five projects. The analysis showed that it is not just the probability of occurrence but also the quantification of the costs which led to the difference between the sum of the risks and the sum of the top-10 financial budget overruns.

Another conclusion, which is also a recommendation, is the fact that it is not possible to reflect objectively on the data from the risk register and the financial budget overruns. This is because the costs related to the specific risks are not recorded for every risk individually. To give a good reflection about the risk management process, including the financial quantification, changed need to be made in the way the project controllers keep track of the project progress and risks.

5. Process plan risk management tender phase

The process plan risk management tender phase is developed based on the information from the literature review, the case study and the consecutive interviews. It combines the results from chapter 3 and 4 and forms a product for Heijmans Infra to come to a more structured risk management process for the tender phase. It gives an answer to the third research question:

What changes can be made to make the risk management process in the tender phase better structured, complete and reliable?

The process contains the following eight steps:

1. Determine risk strategy
2. Risk management plan
3. Project introduction of risk management
4. Identifying risks
5. Quantifying the risks
6. Setting control measures
7. Monte Carlo Analysis
8. Transfer of the risk register to execution phase

The eight steps are visualised in Figure 11. Each step is described by:

- The context of the process step;
- How the process step should be executed;
- The input necessary for the execution of the process step;
- The output of the process step;
- Who is responsible for the execution of the process step.

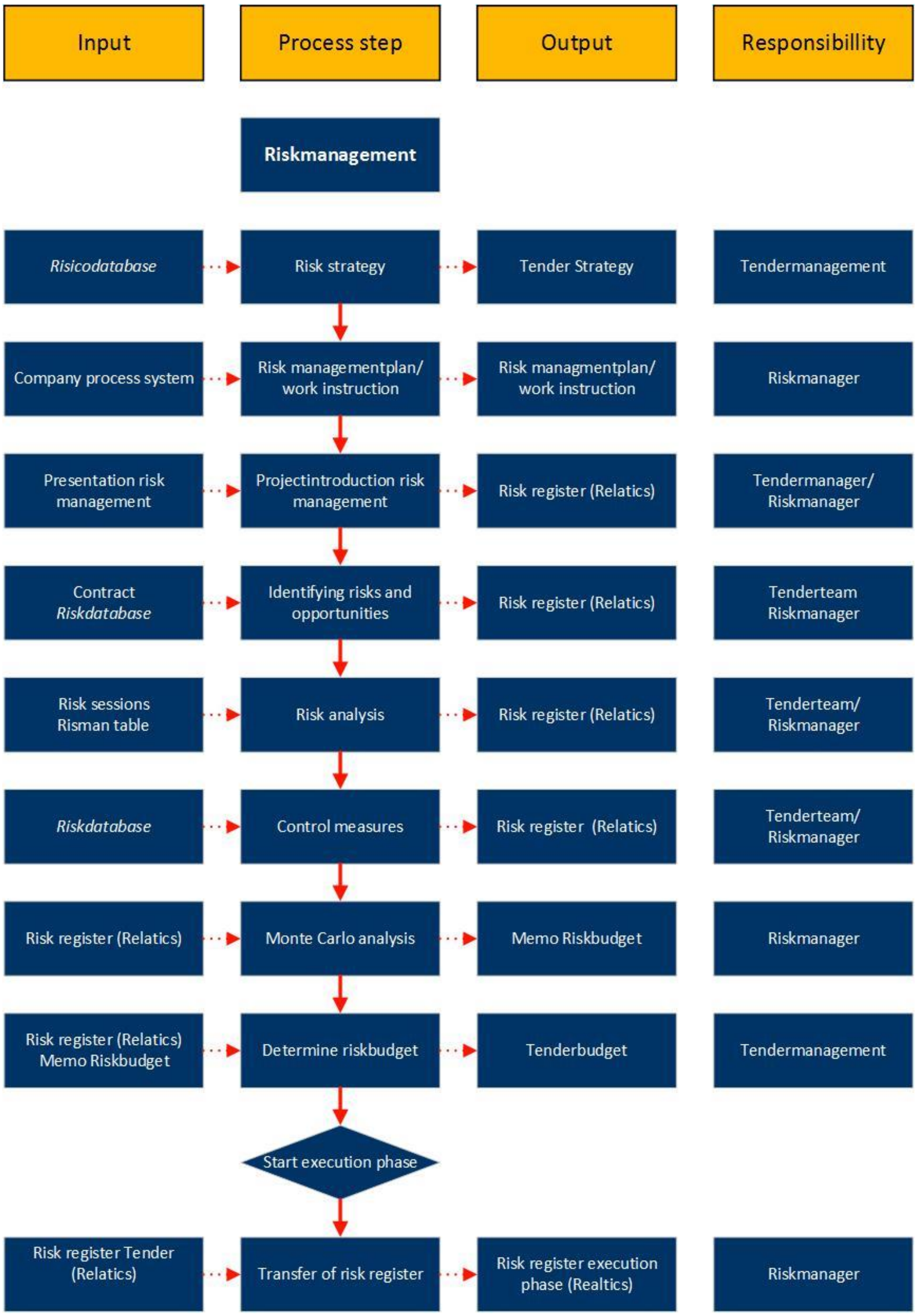


Figure 11: Process plan risk management during the Tender Phase

Table 13: Step 1 Determine Risk Strategy

Step 1: Determine Risk Strategy	
Context	Determining the risk strategy is the first step in the risk management phase during the tender phase. The project specific agreements are made between the Tendermanager and the Riskmanager
How	The Tendermanager and the Riskmanager need to discuss the following points: ➢ The project goals, because the project specific risks influence the project goals; ➢ The division of roles between the tender manager and the risk manager for the execution of risk management during the tender; ➢ The risk management process in relation to the time aspect, which steps need to be taken on a certain time during the tender; ➢ The format in which the risks will be registered.
Input	The following information can be used as input do determine the risk strategy: ➢ Contract documents; ➢ Quick scan; ➢ Risk database, for past experiences with comparable projects.
Output	The output of this process step is a risk management strategy, which is also part of the tender strategy. In
Responsibility	Tendermanager & Riskmanager

Table 14: Step 2: Risk Management Plan

Step 2: Risk Management Plan	
Context	Setting up a risk management plan is the second step in the risk management process. A risk management plan describes the following points: ➢ The goals of using risk management; ➢ The risk strategy ➢ An explanation of the project specific process ➢ The tasks and responsibilities
How	The company format for a risk management plan, which is an output document of the company process system. This document will be made project specific by the Riskmanager.
Input	The following information can be used as input for the risk management plan: ➢ The risk strategy (from step 1) ➢ The company process system ➢ Format Risk management plan

Output	A risk management plan for the tender phase
Responsibility	Riskmanager

Table 15: Step 3: Project introduction of Risk Management

Step 3: Project introduction of Risk Management	
Context	A project introduction of risk management to the tender team is the third step in the risk management process. This is a very important step in the process. When the tender team understands the importance of risk management it will be easier to execute the risk management process efficiently.
How	A project introduction can be given to the tenderteam in the form of a presentation or individually. When the presentation is given the following points are important to be discussed: ➢ The goal of the risk management process; ➢ The scope of the risk management process; ➢ The benefits of a good execution of the risk management process; ➢ A timeline for the activities within the risk management process; ➢ An explanation of the steps that need to be followed; ➢ An explanation of what is expected from the tender team; ➢ An explanation of the output (risk register); ➢ Definition of the terms probability, impact and risk; ➢ Using a probability/ impact matrix; ➢ Risk ownership; ➢ How to define control measures.
Input	The following activities contribute to an active contribution of the tender team to the risk management process: ➢ Presentation about the risk management process; ➢ An instruction on documenting risks; ➢ An award for the persons that are risk mature.
Output	Risk register
Responsibility	Tendermanager & Risk manager

Table 16: Step 4: Identifying Risks and Opportunities

Step 4: Identifying Risks and Opportunities	
Context	Identifying risks and opportunities is the fourth step in the risk management process. Documenting the risks and opportunities need to be done as early in the process as possible, however this is an iterative process. In this stage it is not important to have a SMART description or that the risk register is complete. Documenting the risks and opportunities is most important. The earlier the risks are documented, the earlier the risks can be controlled. Risks should be made SMART as soon as possible and the risks should be allocated to a risk owner who is responsible for controlling the risk.
How	There are multiple ways to identify risks: ➢ The knowledge of the tenderteam; ➢ Risk sessions, group sessions in general or a specific theme; ➢ Bilateral sessions with risk owners; ➢ Risk database, with risks from past projects; ➢ Project evaluations.
Input	The following information can serve as input for this step: ➢ Contract documents ➢ Risk identification methods (presentations)
Output	A risk register which include: ➢ SMART description of the risks, its cause and effect ➢ An allocation of a risk owner to the risk
Responsibility	Riskmanager and tenderteam

Table 17: Step 5: Risk analysis

Step 5: Risk analysis	
Context	The goal of this step is quantifying the risks to come to a financial budget reservation. The risk analysis contains three important aspects: the classification of the risk, the probability of occurrence and the financial consequences when the risk occurs. The classification is important to prioritize the risks. The probability of occurrence directly influences the financial budget reservation. The financial consequences are the financial consequences when a risk occurs. The risk analysis is a irritative process, this means that the risk register should be an iterative product.
How	The Risman-method is used to quantify the risks. Paragraph 3.3.2 describes how the Risman-method works. The Riskmanager is responsible to make the Risman table project specific. A rule of thumb is that a score of 5 for the costs is 5% of the project costs and a score of 5 for time is 20% of the duration of the project. The risk owner is responsible for the calculation of the financial consequences when a risk occurs.

Input	Contract Risk sessions Risman table
Output	Risk register, including financial consequences.
Responsibility	Risk manager

Table 18: Step 6: Control measures

Step 6: Control measures	
Context	Risks can be mitigated by setting control measures. "to prevent is better than to cure" is part of the risk strategy of Heijmans. This means that the intention is to prevent a risk from occurring by setting preventive control measures. When the preventive control measures are not enough the focus is also on the corrective control measures.
How	The Risk owner is responsible for setting control measures, both preventive as corrective measures. The measures in time and money should always be lower than the reduction of the risk (financially). The risk owner is responsible for allocating a actionee for the execution of the control measure. The execution of a control measure leads to a renewal of the quantification of the risk. The control measures should be described as SMART as possible.
Input	Risk database Risk knowledge from execution phase Risk register
Output	Risk register, with a SMART description of the preventive and corrective control measures.
Responsibility	Risk owner(s)

Table 19: Step 7: Monte Carlo Analysis

Step 7: Monte Carlo Analysis	
Context	The Monte Carlo Analysis is a simulation technique in which a process is simulated at least 5000 times, with different starting conditions. The result of the analysis is a collection of the results which present a range of possible outcomes. The expected value of p85 is used for the budget calculation. p85 means that in 85% of the time the corresponding budget is enough to cover the costs of the occurring of risks during the project.
How	The risk register is the input for the Monte Carlo Analysis. The expected probability of occurrence is needed with a bandwidth as well as the expected costs of the risk with a bandwidth. This is done for every risk. The programme runs the calculation with 5000 iterations, with different starting conditions within the bandwidth of the probability and costs.
Input	The risks register is used as input for the Monte Carlo Analysis.
Output	A memo about the risk budget that should be part of the total budget. This memo describes the possible effect of the financial consequence related to the risks.
Responsibility	Risk Manager

Table 20: Step 8: Detremine Risk budget

Step 8: Determine Risk budget	
Context	The risk budget is based on the outcome of the Monte Carlo Analysis. In the commercial offer of the tender the final risk budget is determined.
How	The final risk budget is determined in the commercial closure of the tender, this is done in compliance with the board.
Input	Memo Monte Carlo Analysis
Output	Final Risk budget as part of the overall budget.

Responsibility	Tender manager & Board

Table 21: Step 9: Transfer of Risk Register

Step 9: Transfer of Risk Register	
Context	Transferring the risk register from the tender phase to the construction phase is the last step in the risk management process of the tender phase. This step describes how the knowledge and the risk register should be transferred to the next phase of the project.
How	The risk register is part of the main documents that is transferred to the execution phase. The transfer should be as soon as possible, but at the latest within five days after the project is awarded to the company. This gives the project team enough time to read through the documents. The most important risks are presented during the transfer presentation. The risk should be discussed in detail by the former and the new risk owners.
Input	Risk register Presentation of the transferring documents
Output	Risk register for the execution phase
Responsibility	Risk manager & tender manager.

5.1. Validation of the process plan

The process plan is validated in a session with eight risk managers of Heijmans Infra. This paragraph presents the comments and recommendations for the process plan. This is done based on every step of the risk management process. The conclusion from this validation session was that the proposed Process plan gives more structure to the risk management process during the tender phase.

Determine Risk strategy:

- Make a distinction between internal and external goals;
- Make sure the tender management is committed;
- Define the responsibilities by using the RASCI-model;
- Include the risk appetite in the risk strategy.

Risk management plan:

- Include the EMVI criteria in the plan as input;
- Define the products from the risk management plan;
- Include the new risk classification (category 4);
- Relatics as starting point increases the followability.

Project introduction of Risk Management:

- During the introduction the expectation should be clear, in both ways. What does the Riskmanager expect from the tender team and what does the tender team expect from the Riskmanager;
- A clear definition of a risk, and when it is included in the risk register

Identifying Risks and opportunities:

- Document screening is also input for this step;
- Identification based on several themes to be complete;
- The usage of Relatics depends on the classification of the project;
- Adding a report risk button on the Relatics application makes it easier to add a risk to the register.

Risk analysis

- Link the analysis with the frequency of occurrence.

Control measures:

- Include in the risk strategy also a strategy how to deal with the control measures, a risk control strategy;
- Calculate the corrective costs and the resulting risk in the calculation.
- Monitoring and documenting the status of the control measures

Monte Carlo analysis:

- In the risk strategy it can be decided to assign different risk budgets for different disciplines of the organisation.
- Run a Monte Carlo analysis with the risks and opportunities combined and separated from each other to get a better insight in the consequences.

General comments:

- Make clear in the risk register which risks are defined during the tender phase;
- Make a presentation about the working of the Monte Carlo Analysis;
- Attention for incorporating external risks.

6. Conclusions & Discussion

The motive for this research originated from the Heijmans Risk management year plan of 2016, which recommended to investigate the usefulness or necessity for developing a risk database for Heijmans infra. According to PROM the knowledge related to risks was not sufficiently shared, a risk database could help to overcome this problem. The preliminary research, which consists of interviewing 9 tender managers and risk managers, resulted in the following findings:

- The exchange of knowledge about risk within the organisation is insufficient;
- There is no evaluation about the risk register over the lifecycle of the project;
- A risk database could be a useful tool to store and maintain the risk knowledge;
- It is believed that by not sharing and retaining the acquired risk knowledge, many of the risks will not be identified which leads to budget and duration overruns in many projects.;
- The risk management process in the tender phase is not structured;
- The risk management process in the tender phase is incomplete;
- The risk management process in the tender phase is inefficient.

The preliminary research resulted in the following main research question of this master thesis:

"What are the reasons for the unstructured, incomplete and inefficient risk management process, in the tender phase of Heijmans Infra, and how can these problems be overcome?"

The literature review resulted in the following process steps to come to complete and reliable risk management process in construction tendering:

- Risk management planning – deciding how to approach and plan the risk management activities for a project.
- Risk identification – determining which risks might affect the project and documenting their characteristics.
- Qualitative risk analysis – performing a qualitative analysis of risks and conditions to prioritize their effects on project objectives.
- Quantitative risk analysis – measuring the probability and consequences of risks and estimating their implications for project objectives.
- Risk response planning – developing procedures and techniques to enhance opportunities and reduce threats to the project's objectives.
- Risk monitoring and control – monitoring residual risks, identifying new risks, executing risk reduction plans, and evaluating their effectiveness throughout the project life cycle.

The case study, followed by the interviews with the tender and project managers resulted in the following conclusions about why the current risk management process, in the tender phase at Heijmans Infra is unstructured, incomplete and inefficient.

- The most important conclusion came forward during the interviews with the tender and project managers. Al the projects analysed in the case study where adopted during the economic crisis. Heijmans needed projects to keep the personal working. This resulted in projects with risks that could not be controlled effectively and risks that would could cost a lot of money if the risks occurred.
- This first conclusion is also one of the reasons for the difference in the number of identified risks during the tender and construction phase. Risks where eliminated from the tender risk register to reduce the risk budget. But also, the risk identification process was unstructured and inefficient which led to an incomplete risk register. The standard risk register format used in the tender is inefficient to analyse the risks effectively.

- From the analysis of the identified preventive and corrective control measures is concluded that the risk analysis was unstructured, because it resulted in risks with no control measures. This led to an incomplete risk register.
- The analysis showed that on average 50% of the risks in the tender phase was financially quantified.
- Based on the Risman scores it is concluded that 8% of the control measures don't result in a reduction of the risk. From which can be concluded that the risk analysis is not effective on this point. However, this is open for discussion because the quantification is based on perception.
- The analysis of the top-10 financial budget overruns shows that the budget related to UTA cost, personnel and staff costs, is exceeded in all five projects and is the biggest overrun in three of the five projects. The project managers can explain this, because a delay in planning result in more labour, which affect the UTA costs directly.
- Risks related to the other aspects with budget overruns could be better controlled by more attention in the risk identification process, for example by the help of a risk register.
- The case studies showed that a quarter to half of the risks in the tender risk register is related to the top-10 financial budget overruns. This means that risks are missed in the identification process.
- The top-10 budget overruns related to the identified, and financially quantified, risks identified in the tender phase show that on average only 8% of the costs is taken in to account during the tender phase.
- The last conclusion, which is also a recommendation, is the fact that it is not possible to reflect objectively on the data from the risk register and the financial budget overruns. This is because the costs related to the specific risks are not recorded for every risk individually. To give a good reflection about the risk management process, including the financial quantification, changed need to be made in the way the project controllers keep track of the project progress and risks.

The validated process plan risk management tender phase is developed based on the information from the literature review, the case study and the consecutive interviews. It describes the steps to come to a more structured, complete and reliable risk management process for the tender phase of construction projects at Heijmans Infra.

7. Bibliography

Akintoye, A. S., & MacLeod, M. J. (1997). Risk analysis and management in construction. *International Journal of Project Management*, *15*(1), 31–38. https://doi.org/http://dx.doi.org/10.1016/S0263-7863(96)00035-X

Al-Jibouri, S. S. H. (2016). *Planning & control of construction projects*____. Enschede.

Althaus, C. E. (2005). A disciplinary perspective on the epistemological status of risk. *Risk Analysis*, *25*(3), 567–588. https://doi.org/10.1111/j.1539-6924.2005.00625.x

Aven, T. (2010). On how to define, understand and describe risk. *Reliability Engineering and System Safety*, *95*(6), 623–631. https://doi.org/10.1016/j.ress.2010.01.011

Aven, T. (2011). On the new ISO guide on risk management terminology. *Reliability Engineering and System Safety*, *96*(7), 719–726. https://doi.org/10.1016/j.ress.2010.12.020

Aven, T. (2012). The risk concept-historical and recent development trends. *Reliability Engineering and System Safety*, *99*(951), 33–44. https://doi.org/10.1016/j.ress.2011.11.006

Baloi, D., & Price, A. D. F. (2003). Modelling global risk factors affecting construction cost performance. *International Journal of Project Management*, *21*(4), 261–269. https://doi.org/10.1016/S0263-7863(02)00017-0

Bernstein. (1996). *Against the Gods: The Remarkable Story of Risk*. New York: John Wiley & Sons.

Breysse, Tepeli, Khartabil, Taillandier, Mehdizadeh, & Morand. (2013). Project risk management in construction projects: Developing modelling tools to favour a multidisciplinary approach. In *Safety , Reliability, Risk and Life-Cycle Performance of Strucutres and Infrastructures* (pp. 173–180).

Chapman, R. J. (2001). The controlling influences on effective risk identification and assessment for construction design management. *International Journal of Project Management*, *19*(3), 147–160. https://doi.org/10.1016/S0263-7863(99)00070-8

Ebrahimnejad, S., Mousavi, S. M., & Seyrafianpour, H. (2010). Risk identification and assessment for build-operate-transfer projects: A fuzzy multi attribute decision making model. *Expert Systems with Applications*, *37*(1), 575–586. https://doi.org/10.1016/j.eswa.2009.05.037

Ebskamp, M., & van der Meer, J. (2016). *Heijmans Risicomanagement Jaarplan 2016*.

El-Sayegh, S. M. (2008). Risk assessment and allocation in the UAE construction industry. *International Journal of Project Management*, *26*(4), 431–438. https://doi.org/10.1016/j.ijproman.2007.07.004

Eybpoosh, M., Dikmen, I., & Birgonul, M. T. (2011). Identification of risk paths in international construction projects using structural equation modeling. *Journal of Construction …*, *137*(12), 1164–1175. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000382.

Halman, J.I.M. & Keizer, J.A, (1994). Diagnosing risks in product-innovation projects. International Journal of Project Management.

Hillson, D. (1999). Developing effective risk responses. *Proceedings of the 30th Annual Project Management …*. Retrieved from http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Developing+Effective+Risk+Responses#0

Hillson, D. (2002). Use a Risk Breakdown Structure (RBS) to Understand Your Risks. *Proceedings of the Project Management Institute Annual Seminars & Symposium*, (3–10), 1–5.

ISO. (2009a). *Guide 73: Risk management - vocabulary*.

ISO. (2009b). *ISO 31000. Risk management - principles and guidelines*.

Kaplan. (1991). In risk management: expanding horizons in nuclear power and other industries. In *Risk assessment and risk management-basic concepts and terminology* (pp. 11–28). Boston: Hemishphere Publ. Corp.

Kaplan, & Garrick. (1981). On the quantitative definition of risk. *Risk Analysis*, *1*(1), 11–27.

Karimiazari, A., Mousavi, N., Mousavi, S. F., & Hosseini, S. (2011). Risk assessment model selection in construction industry. *Expert Systems with Applications*, *38*(8), 9105–9111. https://doi.org/10.1016/j.eswa.2010.12.110

Karningsih, P. D., Kayis, B., & Kara, S. (2010). Development of SCRIS A Knowledge Based System Tool for Assisting Organizations in managing Supply Chain Risks. https://doi.org/10.1109/WAINA.2010.191

Lowrance. (1976). *Of Acceptable Risk: Science and the Determination of Safety*. Los Altos: William Kaufmann Inc. https://doi.org/10.1149/1.2132690

Malhotra, Y. (1998). Tools@work: Deciphering the knowledge management hype. *The Journal for Quality and Participation*, *21*(4), 58–60. Retrieved from http://www.brint.org/JQP.pdf

Mehdizadeh, R., Taillandier, F., & Breysse, D. (2012). Methodology and tools for risk evaluation in construction projects using Risk Breakdown Structure. *European Journal of Environmental and Civil Engineering*, *16*(sup1), s78–s98. https://doi.org/10.1080/19648189.2012.681959

Project Management Insititute. (2000). *A guide to the project management body of knowledge*.

Project Management Institute Inc. (2000). *A guide to the project management body of knowledge (PMBOK® guide)*. *Book*. https://doi.org/10.5860/CHOICE.34-1636

Tah, J. H. M., & Carr, V. (2001). Towards a framework for project risk knowledge management in the construction supply chain. *Advances in Engineering Software*, *32*(10–11), 835–846. https://doi.org/10.1016/S0965-9978(01)00035-7

van der Meer, J. (2015). *Best practices in risico-inventarisatie*.

Well-Stam, D., Lindenaar, F., Kinderen, S., Van Den Bunt, B. (2004). Project Risk Management. An essential tool for managing and controlling projects. London: Kogan Page.

Zayed, T., Amer, M., & Pan, J. (2008). Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, *26*(4), 408–419. https://doi.org/10.1016/j.ijproman.2007.05.012

Zhao, X., Hwang, B. G., & Phng, W. (2014). Construction project risk management in Singapore: Resources, effectiveness, impact, and understanding. *KSCE Journal of Civil Engineering*, *18*(1), 27–36. https://doi.org/10.1007/s12205-014-0045-x

Zou, P. X. W., Zhang, G., & Wang, J. (2007). Understanding the key risks in construction projects in China. *International Journal of Project Management*, *25*(6), 601–614. https://doi.org/10.1016/j.ijproman.2007.03.001