Improving Risk Management Through Knowledge and Experience Sharing

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Figure on cover page:

Prologue

This paper represents the completion of the program Construction Management & Engineering at TU Delft. Having spent two years in a foreign country, pursuing my dream of a master’s degree has been an incredible experience and definitely something I would recommend to all. Everybody I have contacted during my time in Delft has had an effect on my life here, some obviously more than others, and all deserve a thank you – some even a big hug.

There are few individuals I would like to thank specially as they helped me during my work for this thesis by contributing valuable insights and information in times of need. On the top of the list is Fokke Huisman from BAM Infraconsult who was available day and night and showed incredible interest and enthusiasm for my work. My committee who gave their time to guide me also deserve a special praise. Grettir, Fritz, Rodrigo, Han, Bart, Charlotte and Ewine who contributed more than they can imagine and held my hand at crucial times. Furthermore I would like to thank BAM Infraconsult for their amazing hospitality to their non-Dutch speaking graduate student and all my interviewees who shared their time and experiences with me.

My family should also be mentioned as their continued support has kept me studying over the years, and my husband who went above and beyond my expectations.
Summary
The problem explored in this thesis is how to reduce the amount of unknown knowns in relation to risks in the construction sector. An organization is affected by the unknown knowns when it fails to learn from previous experiences and need to “re-invent the wheel” every time a risk event happens. This leads to unnecessary waste of time, money and effort of employees as the project team is unaware of the knowledge residing within the organization. The objective of this thesis was thus to develop an easy-to-use conceptual model which facilitates an improved risk management process of a construction company.

The risk management process is split in two parts: risk analysis and risk management. The research conducted, in collaboration with BAM Infraconsult, for this thesis indicates that the risk analysis part is sufficiently executed. The risk management, however, leaves room for improvements. Therefore, this thesis proposes a solution that will improve the risk management part of the process where simplicity and low-cost are the keywords.

Theory and practice were used to find the solution space. The main source of the problem is identified as the low profit margin in the construction sector which leaves little to be reinvested in process improvements. The industry’s habit of not sharing information in a systematic manner also contributes to the problem. Two different methods for risk analysis and management are introduced. The first one, based on Project management body of knowledge (PMBoK) which is mainly used in the US and the second one being RISMAN, predominantly a Dutch method. Post-project review, which is described as the last step of the risk management process by some experts, i.e. closing the learning loop, is named as the first part of the possible solution of the problem at hand. This is due to the review requiring the project team to document the lessons learned. If conducted for each major risk fired, the project actors can receive feedback and a foundation for knowledge sharing is established.

The main contents of a successful, i.e. established, solution is based on the theory behind knowledge sharing within organizations. The theory identifies four steps individuals, groups, and organizations need to go through for individual tacit information to become organizational tacit information, which is important to keep in mind while the solution is designed. The codification strategy of knowledge management is chosen as the preferred strategy over personalization as it is more applicable for sharing knowledge of re-occurring problems which is often the case in construction. Codification of knowledge can help organizations to identify reference class projects and to measure project outputs in order to compare it to other, similar projects. The awareness of both knowledge sharing and codification serves as the foundation for the second part of the proposed solution, a database, which can facilitate organizational learning if given time. Apart from using the literature, experts are interviewed for further insights into the current processes and habits at BAM Infraconsult and to help set the parameters for the solution.

Post-risk review is one of the two elements of the solution. It is founded upon the post-project review and is required to be made in a structured way at regular intervals. The review should be coupled to meetings already taking place such as risk update sessions to limit the added workload on staff. The database uses the client requirements, the risk registers and the post-risk
reviews of projects. With that input the database produces a list of the most common risks, provides feedback, introduces a search option, and allows for comparison between projects, for example. Risk teams can, for instance, use the output as an input in brainstorming sessions, as a check list to see if all important areas are covered, as a tool to find the economically best mitigation strategy, and to see the average cost and standard deviation of risks and mitigations. In short, if the method proposed here were to be applied, the reviews should improve the risk management process as experiences of the individuals are now documented and shared with other risk teams, making discovery of knowledge easier.

Adding and applying post-risk reviews in the risk process can take time to become a natural part of the procedure in the minds of project personnel. Therefore, the process should not be hurried and only applied in big projects on a predetermined number of risks, at least to begin with. While actors are getting used to the new procedure, imperfections in the process and the standardized form are smoothened out. The benefits of the new process, however, should come to light once a few forms are filled out. Project actors get accustomed to reviewing, and critiquing their own work, and consequentially apply the lessons learned while the project is still ongoing. The risk database, which uses the reviews and makes them easily accessible for project teams, takes longer than the post-risk reviews to become useful as it is directly linked to the quantity of reviews stored. Therefore the benefits of the knowledge repository take longer to be materialized. Although these process changes take time, they can be used to help the organization to improve the standardization of the risk process. The database can serve as a data collection mechanism as well as an instrument to monitor the risk process, making it a valuable tool for organizations striving for improved quality. Moreover, these process refinements are one of the attributes needed to reach improvements according to the ISO/IEC 15504-6 (2008) standard and thus should be considered an important step towards an improved process maturity.
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PART 1

This first part of the thesis introduces the problem; establishes the objective and the research questions; looks at the current risk processes and the possible solution space.
1 Introduction

The construction industry is known for being conservative. Modern construction companies are trying to change the actuality of new tools or processes seldom being realized in an industry where the main way of learning is still very much through verbal interaction (Styhre, Josephson, & Knauseder, 2004). To survive, in this business or any other, a company’s product must be of value to the customer and of more value than the competitors product. Value, as defined by the customer, can range from monetary value to aesthetic value and everything in between. What these different types of value have in common, however, is the quality. Quality is “the goodness of fit” meaning giving the customer the product that fits his requirements the best. One of the factors affecting quality is risk and risk management. Managing risk properly and preventing negative risks and increasing the possibility of a positive risk is has become a standard in large construction projects. Theoretically, risk management can play an influential part in increasing the quality of the product and lowering the cost of execution, increasing the total benefit for the client and the contractor as a better product is made for a lower price (de Ridder & Noppen, 2009). This is depicted in Figure 1.

![Figure 1 - Normal transaction model (de Ridder & Noppen, 2009)](image)

Additionally to that, as the competition in the sector is fierce, the companies are forced to take increased risks without certainty of recovering the additional costs that follow, to get projects. Therefore, risk management is getting more and more attention from the companies not only to improve quality but also to increase the chances of finishing projects successfully, financially speaking.

The focus of this thesis is to look at in what way should the construction industry spend time and effort to improve its risk management processes to avoid unexpected cost increases, quality losses or to increase quality, i.e. to be able to offer higher quality product at a lower price. The thesis is written in collaboration with BAM Infraconsult, a subsidiary of Royal BAM Group, the largest contractor in the Netherlands. The company is currently working towards improvement in their in-house processes to keep its position as a leading contractor in the Benelux area. This work includes building a system to stimulate their organizational learning, while, at the same time, improving its project processes by moving them up to a higher level, according to the ISO/IEC 15504-6 (2008) standard, on large projects. For that goal to be achieved, their processes need to give feedback, collect data, and tools in place to monitor the process.
1.1 Report overview

The report is in four parts where each individual part is based on the previous one. This first part focuses on introducing the problem the construction organization is confronting, sets the objective and the research questions, and briefly looks at the current practice at BAM when it comes to risk management. This is done to determine the possible solution space on which part two elaborates. Part two uses the solution space from part one as a focal point for further theoretical research. This literature study, along with expert interviews, is used to determine the ingredients necessary for a solution to the problem to be a success. Part three builds a conceptual model capable of improving the process, by fusing the problem set forth in part one together with the knowledge supplied by part two. The solution is then verified and validated via expert interviews. The final part, part four, concludes the thesis, answers the research questions and identifies limitations to the solution and areas worthy of further research.

To complete the research, a strategy that takes both theory and practice into account is needed. The design-based research (DBR) method does exactly that and is therefore used throughout the thesis. DBR, is defined by Wang and Hannafin (2005) as an iterative cycle where the goal is not only to establish if the theory works but also how it improves current knowledge. It requires the subject to be studied in detail as well as the current practices in the “real-world” evaluated so that the end result, the model, is of value to both the academics and practitioners alike.

The application of DBR requires the researcher to work with the users of the theory or discipline. It is therefore clear that the interviews with experts in the risk field can prove to be a source of knowledge that can tie the theory and practice together. The relevant theory is provided and the model built on the knowledge of the theory and expert interviews.

The following chapter identifies the problem at hand, sets the objective and research questions, and introduces the basics of the risk management process.

2 Problem analysis

The problem that organizations in the construction industry are facing will be introduced in the following chapter. First of all, the problem background and challenges are explored to reach the research objectives and research questions, which are listed to form a foundation for the sub-chapters following thereafter. These sub-chapters touch upon uncertainties and risks, the risk process, post-project review and the trade-offs project teams have to make during projects. The sub-chapters will also familiarize the reader with the risk process and its concepts, and briefly look at changes in the procedures that could be beneficial to the organization.
2.1 Problem background

Each large scale construction project is based on the collaboration of various actors which makes it essentially a network-based organization. Construction projects have been described as being very diverse which is quite accurate in many ways. For instance, the geotechnical conditions, the project team, or the network might differ in otherwise identical projects. Apart from the dominating opinion of each project being unique, the conservative nature of the industry has hampered it in using technologies that have served other industries well (Styhre et al., 2004). Not only has the construction industry failed to capitalize on the successes of other industries when it comes to improved technology, it has fallen behind in innovation, leaving the field at risk of stagnation. The low profit margins of the sector, claimed to be as low as 2,5% - 3% (Akintoye & Skitmore, 1991), with BAM’s profit for first quarter of the year 2012 being only 0,2%, undoubtedly play a big part in the lack of technological innovations as little is left to reinvest in improving work processes. The stiff competition and high number of uncertainties also play a role, affecting the outcome of each organization (F. Hülsman, personal communication, March 14, 2012).

Love and Li (2000) point out that cost of quality deviations can be over 10% of overall project costs, with approximately 17% of that cost being caused by mistakes in the actual construction phase. Arguably, these numbers could, and perhaps should, be higher as they do not include indirect costs such as cost of arbitration. Low quality product increases the need for rework and increases material waste. Improving work procedures resulting in decreased need for rework can therefore be beneficial to both client and contractor as considerable savings can be acquired. The cause of rework can be changes made by the client or human errors made by the project team, for instance, or even because of unexpected risks firing (Love & Li, 2000). In his book, Feigenbaum (1991) divides the quality cost into cost of control and cost of failure control. Cost of control is further divided into prevention costs and appraisal costs. Appraisal costs is the costs incurred due to field tests and inspections, for example, to make sure the product meets the quality standards. Risk management and other procedures aimed at minimizing errors are examples of prevention costs. Cost of failure control is separated into internal and external failure costs where internal failure costs is the need for modifications or repairs before the product is handed over to the client. Rework needed after handover of the product is classified as external failure cost. The following figure shows schematically how these different definitions work together and form the total quality cost.

As can be seen in the following figure, there are considerable savings to be made in the future if work processes are improved. Most importantly, the prevention costs should be increased as it will lead to lower failure and appraisal costs. Extra time spent by the project team on coordination of drawings and specifications, and risk management are examples of how improved preparation at the early stages of the project can lead to lower overall cost during the project life cycle.
As a result of the aforementioned costs, the management of risks is becoming an intrinsic part of construction management, especially in the tender phase where the risk exposure needs to be calculated quantitatively and/or qualitatively to decide the price offered to the client. However, there is always room for improvement. This is especially true for the risk management part (see Figure 7) of the process as the following sub-chapters will illustrate.

2.2 Challenges facing organizations
The common misunderstanding of theoretical knowledge being more important than practical knowledge exists in most, if not all, fields of research (Flyvbjerg, 2006). This could fit especially well with construction as the link between practitioners and researchers, such as universities, has been somewhat weak in the past (Gann, 2001). As this connection and feedback mechanisms are generally frail or missing, both time and money are wasted as companies have not been able to fully use their intellectual capital, e.g. the experiences of staff members (Gann, 2001; Persson & Landin, 2010). Companies need to tap into the experiences of employees of different departments, exploiting their knowledge for the better of the organization. However, in practice, this is hard to implement as the staff works under time constraints and move quickly from one assignment to another. This leads to vast amounts of so-called unknown knowns; where individuals have no platform to share their information and experiences with others within the company, which make the lessons learned in a project only available to members of that project’s team. As a result, both time and money are unnecessarily wasted as different projects experience the same risks firing as the wheel is reinvented for every project. Current risk management practices are focused on individual projects which does not use the capabilities of the personnel as management of knowledge and organizational learning are not used to their full potential, aiming for a reduction in mistakes (Abdul-Rahman, Yahya, Berawi, & Wah, 2008; Persson & Landin, 2010).

2.3 Research objectives and questions
“Today’s industrial pace demands that the manager, not accident, be the master of the situation” (Juran, 1995, p. 61). Although his book was first published in the 1960’s, Juran (1995) pointed out that things should not be left to chance and first hand actions should be made to
control projects, the focus should be on fire prevention, not firefighting. This still applies even though the industrial pace has done nothing but increase in the last half a century. One of the tools applicable for risk prevention is risk analysis and risk management. The current situation is less than optimal as a lot of effort is made when it comes to the risk process of projects while resources could, perhaps, be used to better means if the right tools were available to the risk team (Hansen, Nohria, & Tierney, 1999). Nonetheless, the time pressure often experienced means that the projects resources are moved on to new tasks as the project approaches its end making the last phase of risk management, post-project review, almost impossible to accomplish in a systematic manner. However, by not finishing this final step, companies unintentionally add to the waste of valuable resources. This leads to the objective of this paper: To develop an easy-to-use conceptual model which facilitates improved risk management processes of a construction company.

From the objective, the following main research question is formulated:

In what way can a construction company improve its risk management process?

In order to be able to fully answer the main question, the following sub-questions need to be addressed as well:

1. What are the difficulties concerning the current risk management process?
2. What are possible solutions to these difficulties?
3. In what way can a solution be implemented in practice?

Now that the research questions are clear, an overview of the scope of the report becomes clear. The rest of the chapter will be used to describe the current risk management system employed in practice.

2.4 Definition of uncertainties and risks

Before going any further, uncertainties and risk need to be defined. Milliken (1987, p. 136) describes uncertainty as “an individual’s perceived inability to predict something accurately”. Risk is the combination of the probability of an event and its consequences on project objectives, either positive or negative (AIRMIC, ALARM, & IRM, 2002). In other words, risks are quantified or evaluated uncertainties. Furthermore, risks (or causes) are categorized in many different ways according to the preferences of the risk manager or analyst, or the organization in question. As an example, the ASCE (1979, pp. 208-210) categorization of risks in construction projects follow:

1. Construction related – e.g. changes in the work and availability of labor and materials.
2. Physical – e.g. subsurface conditions.
3. Contractual and legal – e.g. delays in dispute resolution and delays in payment.
4. Performance – e.g. productivity.
5. Economic – e.g. inflation and cost of labor and material.
6. Political and public – e.g. environmental and rules and regulations set by the government.
The following chapters introduce the theoretical concepts behind the problem at hand. Special attention is granted to uncertainties and risks, the risk process, post-project review, and trade-offs between cost, time and quality.

What are uncertainties?
Deviations from the iron triangle: cost-time-quality, can often have financial repercussions as contracts can have clauses of financial penalty in case of a late handover or insufficient quality. As projects need to yield a positive return of the initial investment it is fitting to look briefly into uncertainties in regard to cost estimations for construction projects. While the project budget is being decided, there are three kinds of uncertainties that need to be kept in mind (Vrijling, 2008; Vrijling & Verlaan, 2011):

- Uncertainties related to normal events
- Uncertainties related to special events
- Project uncertainties

Furthermore, there are two methods used to include the uncertainties in the budget: deterministic and probabilistic (Vrijling, 2008).

Uncertainties related to normal events
Uncertainties related to normal events handles events that are very likely to happen without the actual duration, cost or quantity being known. The range of the expected value is spread due to lack of knowledge of the duration, cost or quantity (Vrijling, 2008). This can be seen in Figure 4. An example of a normal event is wind speed exceeding limits for safe crane operations or fluctuations in commodity prices.

![Figure 4 - Probability density function of uncertainties related to normal events (Vrijling, 2008)](image)

Uncertainties related to special events
Special events, such as natural disasters, can have an effect on the project’s cost and/or duration. As the name suggests, special events are events that are deemed unlikely, or are not meant to happen such as municipal decision making delays or collapse of markets (CROW, 1999; Vrijling, 2008). The likelihood of a special event is usually small, making them hard to predict, but the consequences can have a major effect on the project (CROW, 1999). The following figure depicts the probability density function of such an event where the consequences are uncertain.
The special events, sometimes referred to as black swans, are those that companies in any discipline should be aware of. In their paper, Taleb, Goldstein, and Spitznagel (2009) note that black swan risks have no precedent, and the small changes made today can have a major impact tomorrow. Furthermore, they add that “less than 0.1% of risky events will cause at least half your losses” (Taleb et al., 2009, p. 79). Currently there is a gap between theory and practice when it comes to those special events. The effects of the special events can vary, thus trying to estimate the resulting risk can be very difficult. So difficult, in fact, that roughly 20% needs to be added to the budget if theory is to fit to practice (J.K. Vrijling, personal communication, April 17, 2012). This is most likely due to the large standard deviation in the curve representing special events, which is approximately $\frac{1}{\sqrt{N}}$ times the quantified value of the risk (Vrijling & Verlaan, 2011).

**Project uncertainties**
The project uncertainties arise if there are more than one alternatives in the solution space. When the solution has yet to be chosen, it affects the cost estimations as multiple estimates have to be made. Figure 6 shows how two different alternatives have an effect on the budget or planning of a project. Project uncertainties will not be further discussed in this paper.
Regardless to the type of uncertainty faced by projects, the number of uncertainties is reduced over time, unless changes are made to the project; as decisions on variants are made and improved knowledge is available for the decision makers.

**Deterministic and probabilistic budgeting**

There are two main approaches used to include uncertainties in project planning and budgeting, deterministic and probabilistic approach. Both methods will be shortly described in the following paragraphs.

The deterministic method adds a percentage to the estimated cost of the project to cover the costs expected by uncertain and unforeseen events, such as natural hazards or accidents. The actual percentage chosen is dependent on the nature of the project, the experience of the estimator and the company culture.

The probabilistic method looks at the different types of uncertainties as described on the previous pages and adds them to the foreseen (uncertainties related to normal events and project uncertainties) or unforeseen (uncertainties related to special events) costs. This method allows for an added clarity on the effects of each uncertainty on the overall costs (Vrijling, 2008). There are two different ways to apply the probabilistic method in practice, the so called Level II and Level III.

Level II is the simpler of the two methods. “The problem is linearized around a certain, carefully selected, point. Correlations between variables are to be avoided. Not normally divided variables need supplementary approaches. Because of the providing insight results and the speed of calculating, Level II methods are very popular” (Vrijling & Verlaan, 2011, p. 77).

Level III includes methods such as Monte Carlo simulation and are made based on probability distribution functions of all variables. The parameters are either based on expert opinions (Bayesian estimations, often using triangular distribution) or by examining the historical data (statistical estimation) (Vrijling & Verlaan, 2011).

**Explaining the risk process**

As most, if not all, construction projects are faced with several risks during their implementation, the need for risk management becomes clear as these risks can have serious consequences for the projects feasibility, time or cost. It is therefore important to prevent the risks from firing, or increase the likelihood of positive consequences. When asked about what risk is, people often note that risk is the chance of something negative happening. This is a misconception as the risk events in question can affect the project objective positively (opportunities) or negatively (threats), making risk management revolve around maximizing the opportunities and minimizing the threats. It is generally considered an acceptable practice that the management of a specific risk should be handled by the party most capable of handling it, although it depends somewhat on the contract in effect.

The ISO/IEC 15288 (2008, p. 30) standard defines the risk management process as “a continuous process for systematically addressing risk throughout the life cycle of a system product or service. It can be applied to risks related to the acquisition, development, maintenance or operation of a
system.” By going through the paces of the risk process, the organization in question takes advantage of the benefits of risk management. Those include, but are not limited to, discouraging the organization to accept financially doubtful projects; increasing the possibility of the project staying on schedule and within budget; common understanding of risks, i.e. risk awareness; demonstrating a responsible approach to clients; reducing cost and providing a less stressful working environment for the employees (Hillson & Simon, 2007). In addition to that, Hillson and Simon (2007), note that effective risk management is based upon four pillars:

Supportive organization

Competent people

Simple, scalable process

Methods, tools and techniques

The supportive organization makes sure the risk management process has support from higher levels of the hierarchy, the objectives are clear and proper resources available. Employees are kept up to speed with constant training, ensuring their competence. By having the risk management a simple, scalable process, the organization focuses on questions like: “What are we trying to achieve?”, “What could stop/help us?”, “Which of these are most important?”, “What should we do about it?”. Furthermore, as the project personnel have different backgrounds, it is important that processes are kept simple for the risk management team to get the most valuable input from actors (P. Beljaars, personal communication, May 29, 2012). The methods, tools and techniques used by an organization is based on its risk culture, whether it is risk averse or risk seeking, the availability of resources such as funds and expert personnel. Once the position of the company regarding these points is clear, the proper support needed by the management can be decided. That can include employee training, appropriate software etc. If the right environment is not in place, the benefits of the process are reduced (Hillson & Simon, 2007). Apart from the possible effectiveness of risk management, the pursuit of its benefits must be economically justified (Han Vrijling, personal communication, May 21, 2012).

Now that the basic purpose of risk management is known, the focus turns to how it is utilized in the industry. The theories on the application of risk management can differ quite a bit. However, they are all based on the basic idea that it is the logical process of pinpointing, evaluating and responding to project risk. Whatever method is chosen, the steps may overlap and are iterative in nature. The following pages describe the outline of two different methods of risk management, the methods described by Project Management Body of Knowledge (PMBOK) and RISMAN. These specific methods are chosen as they originate from two different continents, PMBoK from the USA and RISMAN from the Netherlands, and should, therefore, portray the differences in risk management in USA and the Netherlands, if any.

The method proposed by the PMBoK is, in many ways similar to the RISMAN method. The main difference between the two methods is in the first step. The steps of the PMBoK method are:

1. Risk planning
2. Risk identification
3. Qualitative risk analysis
4. Quantitative risk analysis
5. Risk response planning
6. Risk monitoring and control

To further elaborate on the abovementioned steps, a short introduction will be made on the next few pages to introduce the process of risk management to the reader. The seventh step,
post-project review (see chapter 2.5), is not as habitual as the other steps in construction but is widely used in other industries with good results.

**Risk planning**
This first step of risk management decides how risk management activities will be conducted for the project. The risk planning usually takes place in planning meetings between the key actors of the project where the above mentioned points as applicable. Once the meeting, or series of meetings, are concluded, the output of this first phase of risk management is a risk management plan that expresses how the next steps should be conducted, the roles and responsibilities of actors, the risk management budget and timing, scoring and interpretation of risks, risk thresholds and how the risks are tracked and reported.

**Risk identification**
Identification of risks is an iterative phase that starts at identifying uncertainties that might have an influence on the project. The phase uses documentation review and information gathering techniques such as brainstorming (used by BAM), the Delphi technique and SWOT analysis, along with checklists and diagramming techniques, to name a few, to find and identify potential risks and their triggers. It is important that uncertainties relating both to normal and special events (if possible) are taken into account as possible as both can have severe consequences to the end result of the project (Hubbard, 2009).

**Qualitative risk analysis**
The qualitative risk analysis assesses the likelihood and impact of the identified risks. It prioritizes the risks according to the possible consequences on the project objectives. The qualitative risk analysis should be reevaluated during the project’s lifecycle to keep it up to date with changes made in the project. The probability/impact matrix can be made once the identified risks have got their value which makes the overall risk ranking for the project possible as well as the list of prioritized risks is produced. The risks scoring high in this analysis deserve a closer look by the risk management team. Other possible outputs of the qualitative risk analysis are cause-and-effect diagrams, or fishbone diagrams, and flowcharts and influence diagrams to name a few.

**Quantitative risk analysis**
The quantitative risk analysis looks at the numerical possibility of each individual risk and its effect on project objectives. This phase uses methods like Monte Carlo simulation to look at the probability of achieving project objectives; dependencies between risk events and activities; the total risk exposure of the project; the contingency funds needed; points out the most dangerous risks; and identifies realistic target in terms of cost, scope and time. The quantitative analysis can be used parallel with the qualitative analysis. The main tool generally used in this phase is Monte Carlo simulation. However, this is not the case in construction where values are assigned to different categories according to the estimators knowledge and/or experience (F. Huisman, personal communication, May 11, 2012). Interviews can be used to get the best possible values for input in the simulation and sensitivity analysis can identify the risks most likely to have the biggest influence on the project. Once the simulation is complete, the risk team knows the probability of finishing the project within time and budget as well as forecasting of possible dates and costs is available.
Risk response planning
Risk response planning looks at the identified risks and determines appropriate actions to prevent, or lower the consequences of negative risks and enhance the chances of a positive risk firing. The risk response has to be proportional to the severity of the risk, be accepted by all key actors and owned by a team member.

There are four possible responses, the so called 4T’s, available for each risks. They are (with corresponding opportunity response in parenthesis):

Treat (Enhance). When a treat response is chosen, the risk owner tries to find ways to lower the probability of the risk firing or the consequences if the risk fires, that is acceptable according to the risk acceptance level previously determined. Example of a treat response is to choose a known technology instead of a new, untested one or having extra tests done on dubious materials. If no mitigation is available, a contingency plan can take its place but it can be less effective as the response is implemented after the risk has fired.

Transfer (Share). Transferred risks are usually of the financial kind. By transferring risks, the risk owner moves the risk to a stakeholder more capable of mitigating it, such as insurance firms, banks or contractors. The transfer of risks does not lower the probability of it firing but lowers the consequences suffered by the organization in question.

Take (Accept). If a risk is taken, no changes are made to the project plan but a contingency plan should be in place in case a risk fires.

Terminate (Exploit). If a risk is terminated, changes are made to the project so the risk cannot fire or its consequences are none. Changing from new technology to an existing, tried and tested one terminates the risk of the new technology needing additional testing and additions.

Once the risk response plan is completed, all risks should have their probabilities and impacts assessed along with mitigations or contingency plans in place. The residual risks, the risks that are still left after mitigation, are evaluated and secondary risks, risks that arise as a result of a mitigation strategy, are assessed and appropriate response planned. Contracts between actors might, out of necessity, specify risk responsibilities in case a risk fires and a reserve for contingencies needs to be put in place to reduce the risk of overruns. The outcome of the risk response planning can be used as an input for other processes, e.g. changes for the project plan.

Risk monitoring and control
The last step, apart from the post-project review, is risk monitoring and control. It takes the identified risks and the risk response plan, and keeps the documents up to date, identifies new risks and makes sure the mitigation strategies are implemented and the contingency funds are available. Even if not precisely followed, the risk monitoring plan should offer the risk management team rectifying actions on both unidentified and identified risks, project change requests resulting from the rectifying actions and updated risk response plan and risk identification checklists.
The other method discussed, the RISMAN method, was developed in the late 1990’s by number of Dutch organizations. It can be split into the following steps (Van Well-Stam, Lindenaar, Van Kinderen, & Van den Bunt, 2004):

1. System description
2. Identification of risks
3. Determining the most important risks
4. Identifying the control measures
5. Choosing control measures
6. Implement control measures
7. Evaluate control measures
8. Update risk analysis

This method puts more emphasis on iterations than PMBoK where steps 5, 6, 7 and 8 are repeated until the outcome of the risk management procedure is acceptable. The following figure illustrates these iterations, according to the RISMAN method.

![Risk Management Iterations Diagram](image)

**Figure 7 - Risk management iterations. Adapted from van Well-Stam et al. (2004)**

**System description**

The first step of risk management is to determine what the scope and goal of the risk analysis is. In this step an overview of the system, including a description of system components and purpose is provided. This first step is important as it decides how the risk analysis is performed. According to van Well-Stam et al. (2004, p. 30) there are several questions that need to be answered during this phase of the analysis. Those are:

- **What do you hope to achieve with the risk analysis?** E.g. increased control, prioritizing, better decision making or a better basis for estimates.
- **Which control aspects does the analysis target?** E.g. time, cost or quality.
- **Which segment of the project and which phase of the project does the analysis target?**

See the following figure for an example of when risk analysis is performed. It is worth mentioning that the process is more continuous and iterative than the figure suggests and not necessarily only focused on specific project phase.
Figure 8 - Example of risk analysis in project phases (M. Wehrung, personal communication, March 26, 2012)

- **Is a qualitative or quantitative risk analysis required?** See Table 1 for examples of usage of each type.
- **What type of information is available/usable?** E.g. the project plan, schedule, cost estimates etc.

It is important to keep in mind the perspective of the analyst while answering the questions. Personal perspectives can vary greatly and thus can the project risks be perceived differently by different players or analysts (van Well-Stam et al., 2004).

<table>
<thead>
<tr>
<th>Qualitative risk analysis</th>
<th>Quantitative risk analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>When to use it</strong></td>
<td><strong>When to use it</strong></td>
</tr>
<tr>
<td>- for risk management purposes</td>
<td>- demonstrate/support feasibility of the estimate/schedule</td>
</tr>
<tr>
<td>- support the contingency items</td>
<td></td>
</tr>
<tr>
<td><strong>Advantages</strong></td>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td>provides a quick and clear picture of the risks, one that is easily understandable for everyone</td>
<td>- effect of the measures may be mapped out more clearly</td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td>- prioritization provides less information</td>
<td>- analysis requires a great deal of time and effort</td>
</tr>
<tr>
<td>- figures/outcomes may take on a life of their own, starting points/assumptions disappear</td>
<td></td>
</tr>
</tbody>
</table>

**Identification of risks**
This step is identical to the risk identification step of the PMBoK method.

**Determining the most important risks**
This step is identical to the qualitative and quantitative risk analysis of the PMBoK method.

**Identifying the control measures**
The control measures, the 4T’s, are explained in the chapter risk response planning on page 12.
Choosing control measures

Choosing a control measure for a risk involves looking into the cost, time of completion, expected effects and residual risks, for example, in either qualitative or quantitative manner. Once a control measure has been chosen, this process is done once more to make sure the chosen measure is the appropriate one. After the choice is made, the budget, time and quality of the measures is made clear and a risk owner is allocated to each risk who is made responsible for the implementation of the control measure. Once this step is completed, the following should be clear (van Well-Stam et al., 2004):

- A list of all important risks in the project
- The measures chosen for each risk
- Each risk allocated to a risk owner
- Time, budget and quality of measures

Implement control measures

As the name of this step suggests, the chosen control measures are implemented. van Well-Stam et al. (2004) suggest that the measures are put into reports, action lists and drawings so the risk management becomes a part of operational project management.

Evaluate control measures

Once the control measures have been implemented, the effectiveness of the measures are periodically evaluated. van Well-Stam et al. (2004, p. 93) suggest the following points to be kept in mind while the evaluation takes place:

- What might have led to the desired effect being (or not being) achieved?
- Was the frequency with which discussions took place in this regard satisfactory?
- Should the manner in which information is provided be modified?
- Was the necessary information communicated?
- Have the responsibilities and authorities been assigned correctly, and why or why not was this the case?

Updating the analysis

When the previous steps have been completed, the risk analysis (steps 1, 2, 3 and 4 on page 12) can be updated if needed. During this update, the benefits of mitigations is assessed, e.g. if it is financially beneficial, and risks added or removed from the list of most important risks, keeping the risk analysis constantly up to date. This step is identical to the risk monitoring and control of the PMBoK method.

The two methods described on the previous pages both focus on providing the risk team with tools to prepare for possible risks. However, neither one strongly suggests adding an additional step which could assist the organization to learn from its mistakes and improve its processes. The following chapter will look at post-project review which helps organizations to capture the lessons learned as project outcomes are documented.

2.5 What is post-project review?

Although risk management is used in most modern construction projects, there seems to be a frequent failure in the risk process as the last step, post-project review, is seldom applied. It is a
rather common misconception that this last step is time consuming and does not add value to the project (Anbari, Carayannis, & Voet, 2008), therefore organizations fail to close the learning loop. Feigenbaum (1991) points out that changing an organizations mentality from “quicker and cheaper” to “make-it better” is a difficult managerial task. As the world grows smaller, the number of possible competitors increases, making improving quality a necessary step to stay ahead of the opponents. This means that the organizational culture needs to accept and embrace the possibilities of learning through past projects and enable managers and personnel to spend time reviewing and sharing the lessons learned. The actors participating in the review process must accept the process and not perceive it as an unreasonable amount of work for it to be a success, therefore the support of the hierarchy is important to facilitate the acceptance of the procedural changes (D'Igazio, 2011).

The benefits of post-project review have been known for decades (Anbari et al., 2008). Regardless of this knowledge, it is often not implemented as a part of the risk management procedure. The execution of large construction projects can span over several years making the post-project review a time consuming, and often not a very accurate process if only one review is carried out at the end of the project. Regardless of these shortcomings, post-project review can help the company to systematically capture the lessons learned and use it in other projects, resulting in increased benefit for the organization (Anbari et al., 2008). The literature suggests one overall post-project review session should be held after the completion of the whole project. One source, Thomas and Thomas (2005), suggests having three different post-project reviews, the first one two months after project completion, the second one six months after completion and the third one thirteen months after completion. Regardless of the number of meetings used to find out different success factors of the project, they all should include the following (Thomas & Thomas, 2005):

- Reviewing how successful the project team was in completing the project objectives
- Reviewing how successful risk mitigations/contingencies were
- Completing key performance indicators (KPI) of the project
- Identify success factors that should be quantified and shared with other teams within the organization
- Developing actions that enhance the value of the lessons learned for future projects

Contrary to the name, post-project review does not necessarily have to take place at the end of the project. Having reviews at the end of each phase of the project would ensure information is as “fresh” as possible, thus minimizing the risk of the selective memory of the actors and maximizing the benefits of the review (Carrillo, Harding, & Choudhary, 2011). This fits well with the sixth step of risk management as used by PMBOK: monitoring and control, where the risk register is kept up to date, as well as the cyclic process introduced by RISMAN’s steps 5-8. Combining the two, the post-project review and the last step/cycle of the risk management process, would therefore add value to the risk management with minimum effort, without sacrificing the added value of the post-project review. Not only does this fit with the two methods but also the ISO/IEC 15288 (2008, p. 31) standard which states that “throughout the life cycle, collect risk information for purposes of improving the risk Management Process and
generating lessons learned. [...] The risk information includes the risks identified, their sources, their causes, their treatment, and the success of the treatments selected.”

Furthermore, Tan et al. (2010, pp. 32-33) identify five characteristics of reusable project knowledge, or proven theories. Those are:

- **It is borne out of a set of particular circumstances that exist on a recurrent basis.**
- **It is adaptable (i.e. the new application may not be identical but the knowledge is capable of adaptation to make it work in the new context).**
- **The reuse of project knowledge is not limited to the same project or other similar projects, but also in other departments.**
- **It is capable of being transferred across sectors for reuse (e.g. from construction to the manufacturing sector).**
- **It is the amalgamation of an industry’s and a company’s previous knowledge complemented by new research findings, new ways of working and new ideas, which ultimately leads to innovation and improved best practice.**

Depending on the source, the exact ingredients of a post-project review can differ. One of the most interesting points in the paper by Yu, Yang, Tseng, Liu, and Wu (2010) is the multi-dimensional ontology. The dimensions are three: (1) lifecycle code, which describes the phase of the project, design, changes etc.; (2) product code, which describes the product, the proposal, drawings etc.; and (3) technical code, which describes the resources used, testing etc. Based on the three dimensions, it allows for the reviews to be sorted according to the content. Overall, the review should contain a full account of the project’s, or the phases’ history, therefore playing a key role in organizational learning and being a foundation for a repository of experiences. Furthermore, Carrillo et al. (2011) note that a post-project review should not be made without using the result as a contribution for future projects. This view helps the reviewer look for knowledge that assists organizational learning. In their paper, Tan et al. (2010) introduce the live post-project review, which requires the project team to make the reviews on a regular basis during the project. Through their research, Tan et al. (2010), identify the end-user requirements for knowledge capture and reuse. They are:

- **Cost.** Adding post-project review to the current process should not add significant cost to the risk management procedures and those costs incurred should generate benefits that cover those expenses.
- **Workload.** Post-phase reviews should be integrated into current practices and not add significant workload to the project team members. This is identified as they key factor in establishing post-phase reviews as a standard practice.
- **Legal issues.** Some contracts do not allow actors to share the knowledge gained in the project. The post-phase review needs to take this into account.
- **Accuracy.** The post-project review has to be able to capture and express the knowledge exactly, this solely depends on the actors conducting the review.
- **Representation of knowledge:** Standardized approach. This is required for the users to be able to find the information needed in the shortest amount of time.
Case studies. The case studies help the users to fully understand the information available, which helps them to use it in the correct context.

Short description. This basic information helps the user to see if the review is related to his/her project.

Conditions. If there are any conditions for using the knowledge, it must be made clear.

Contact information. In case the review has imperfect information required by the user, contacting the person responsible for the review can reduce the risk of misinterpretation.

The following two sub-chapters look at the perceived problems and benefits of post-project review as described by the literature.

Problems concerning post-project review

Many sources state that a post-project review, or hindsight review, should be held at the end of each complete construction project. In large scale construction projects this is both very impractical and reduces the benefits of the review. By having one review at the end of an execution spanning over several years, the procedure becomes gruesome, excessively time consuming and risks becoming a “box-ticking” meeting, thus missing out on important details due to the time passed (Bartholomew, 2008).

Building a document usable for others as a guideline takes considerable time and effort by those in charge of the task. It can therefore be a demoralizing experience if the reports are seldom read and stay in the file cabinet unread for years, as often is the case (Bartholomew, 2008); making the review even less attractive to the project actors. The reports written are often tainted with peoples will to keep professional relationships positive, therefore critique is often lacking or missing, making the actual report next to useless. Another downside of reviewing is that actors can feel the obligation to contribute, even though they have nothing to add to the current knowledge; actors can think their input is less valuable than others, even though all participants should have equal status in the review process and personal experiences and views may differ from actor to actor which can lead to negative criticism. The management also has to be sure not to place blame on any actor for mistakes made as that discourages the individual from sharing potentially important information (Bartholomew, 2008). In addition to that, reviewing during the last days of the project removes any possibility of the project team to improve the project by incorporating the lessons already learned during the execution (Tan et al., 2010). Furthermore, the staff turnover has an effect on the review as personnel move from one organization to another and from project to project before a review is made (F. Huisman, personal communication, May 11, 2012).

Apart from the previously mentioned reasons why post-project review is not often implemented, one has to consider that it is not always appropriate as smaller, straight forward projects add little to the already extensive knowledge of the designated project team.

Carrillo et al. (2011) put together a list of possible difficulties with post-project review:

- The instructions set by organizations for the post-project review procedure is seldom efficient or followed in the organization, risking making the process unsystematic.
• As members of staff are moved from project to project, key actors might be unable to participate in the post-project review.
• Companies often choose to have the review at the end of the project in order for the project’s outcome to be clear. At that time, personnel has moved to other projects.
• Project team members are afraid of possible consequences when revealing mistakes that lead to risks.
• The post-project review must be clearly set up, of appropriate length and content.
• The information registered in a post-project review is not shared as expected.

Possible benefits of post-project review
An active company in a quality driven market, like the construction industry wants to be, needs to protect its position and strive for supremacy in the marketplace (Feigenbaum, 1991). To stay ahead of the competition, a company must be able to offer a higher quality product at a competitive price. Reducing time and material waste, mistakes and number of risks is one way possible to achieve that goal. Companies can improve their product by learning from faults in order not to experience them again, reduce the uncertainty and/or minimize the effects they have on the product. This can be done with post-project review. The clear purpose of such review is only to reflect on lessons learned in the project and document them in a format easily accessible and understood by other members of the organization (Bartholomew, 2008). It focusses on what happened, why it did happen and how can the team do better. To reach its full potential, each report should not shy from including acknowledgement of things gone wrong and should include chances or recommendation on improvements (Bartholomew, 2008). Yu et al. (2010) furthermore add that this kind of knowledge documentation suits the construction industry as the technical and procedural details are verified and assessed while being written down, making the information both dependable and practical.

Carrillo et al. (2011) compile a few benefits of post-project view in their paper. They note that:
• To do a post-project review, team members join together and take a look at how the project (or project phase) was executed, allowing exchange of views and discussions which results in new perceptions of problems and solutions.
• Post-project review minimizes the loss of knowledge as teams are not broken up before knowledge has been shared in an appropriate manner.
• It promotes continuous improvement to conduct a post-project review and the client perceives it as an effort to improve future projects.

By registering the outcomes of project phases and comparing them to the estimated outcomes, the accuracy of future risk management processes is more likely to improve. For instance, when the final financial outcome of a phase is known and registered after a post-project review, future projects can benefit as risks, their mitigations or contingencies and their result is documented and stored. Due to this documentation, the accuracy of the cost related to those risks improves over time as more projects experience them in one form or another. The term post-risk review will be used for reviews after risk occurrence from now on, and therefore is not meant as the review which takes place once a project is finished.
Most project managers face problems during the projects implementation. Often trade-offs have to be made, e.g. between time and budget, where the project management, perhaps, does not have all the information necessary to make the most optimal decision. Projects that are carefully planned, where risk management is applied and the project simulated (e.g. through Monte Carlo analysis), can help the management to identify areas where these trade-offs benefit the project the most. Including trade-offs in the post-risk review can therefore help future projects to make decision regarding trade-offs based on prior experiences.

2.6 Introduction to trade-offs between cost, time and quality

The iron-triangle, which consists of quality, cost and time, has been used to measure project success in the past. As demands of the client are changing towards sustainability and safety, for example, new ways of measuring project success are needed (Toor & Ogunlana, 2010). How performance is measured should be customized to the objectives of each project. This means that the perception of project success can differ from one project to another (Toor & Ogunlana, 2010). A famous example is the Sydney Opera House. At the time of completion it was about 1400% over budget and years behind schedule, destroying the architects career, and generally considered a failure at first (Flyvbjerg, 2005). However, today it is one of the most iconic buildings in the world, attracting vast numbers of visitors annually.

Through their research, Raz, Shenhar, and Dvir (2002) observed that risk management plays a bigger role in keeping projects on time and within budget than keeping the quality of projects up to required standard. This point is rather interesting as satisfying, and fulfilling, the scope and specifications set by the client, contributes to better relations between contractor and client. Furthermore, this contradicts Lipovetsky, Tishler, Dvir, and Shenhar (2002) whose research show that benefits to the customer is the key to success. As success of projects is often based on perception of the end user, or the client, it is hard to determine beforehand what factor will be the one that eventually plays the biggest part in a project's success. Regardless of what piece of the iron triangle, or other success measure, is used, there are always problems with estimations, or plans, made at the beginning of a project (Maylor, 2010). For duration estimations, Maylor (2010) mentions a few problems he calls typical. Those include rough estimates made by individuals or project teams eventually used as target time; unfitting data used as a basis for estimates without the validity being assessed; and estimates do not take changes into account, e.g. changes are made to the design without reassessing the time needed for completion of the project.

Cost estimations are often based on the experience of individuals in the same or similar projects, where estimated costs can be based on experiences of previous projects; forecasts; the amount of repetitive actions in the project; and wishful thinking (which will be described in chapter 4.4) (Maylor, 2010). Quality is based on expectations and perceptions of individuals. In his book, Maylor (2010) names several perspectives on quality management. A couple of those are:

The mathematical perspective. In the past, this was the only approach available to project managers for the pursuit of quality management. If statistically significant changes are noted in the output of the process, corrective changes are made to ensure quality goals are met. In the
current environment of project management, this approach is considered limited and is used in parallel to other methods.

Control-organizational perspective. The key aspect of this approach is how both the client and employees are considered as main elements of quality. This perspective works well in organizational transformations, e.g. changes made from an organizational culture which does not encourage the cooperation of different sectors to more interactive work environment where different sectors work together to reach a predetermined goal.

2.7 The current process
To be able to form a solution which improves the current process, the existing risk procedures need to be looked into. To do so, data received from two different projects will be used to get an idea about how project focused the risk process is and if there could be a foundation for knowledge sharing. The case studies are used as a verification of the problem at hand, i.e. to see if there are risks shared between two different projects where the time needed for risk formulation could have been reduced, for example.

To get a good cross-section of the risk management practices, the cases selected need to differ as much as possible. After consultation with BAM, two cases were chosen for further study, based on two different contracting methods; design-build (DB) and alliance. They were chosen as they are ongoing infrastructure projects, but differ in scope, budget and time; and have different risk managers, each working according to his/her preference. The boundaries chosen within these projects are the cables and pipeline risk registers and their application in the projects. A short introduction to the projects follows.

A4 Burgerveen – Leiden (DB)
The widening of the A4 between Burgerveen and Leiden, is roughly a €300 million project based on a design-build contract between BAM and the ministry of infrastructure and the environment. Its execution started in 2006 and its main objective is to increase the capacity of the current facilities. At the moment, the road is used to its full capacity with over 100,000 vehicles travelling per day and thus improvements must be made to facilitate the growing number of users. Once the project is finished in 2014, the A4 will be a 2x3 lane highway on a 20km strip with fifteen bridges, viaducts, aqueducts and other infrastructure necessary in place; all accomplished without interrupting the highway traffic during construction and with as little interruption as possible to the hundreds of utility cables in the area of construction (Rijkswaterstaat Zuid-Holland, 2005).

OV SAAL (Alliance)
The OV SAAL project aims at improving the rail connection between Schiphol airport and Lelystad in three phases with overall budget of €1.4 billion reserved for the project. The project is realized due to expected increase of travelers in the next decade as the Zuidas, the office area close to Amsterdam Zuid, is expected to become the most important international business center in the country. Furthermore, the city of Almere is expected to expand by some 60,000 new homes before 2030 (Rijksoverheid, 2012). The contract for one phase of OV SAAL, Zuidtak Oost, was awarded to BAM as they submitted the economically most advantageous tender.
There is an alliance in place for this project, based on design-build contract, between BAM Civiel, BAM Rail and ProRail under the name of Alliantie Amstelspoor. The contract includes work on the railway track west of train station Amsterdam Zuid to the station at Duivendrecht where the number of existing tracks will be doubled, new platforms made and new viaducts built, for example.

Results of the case studies
The risk category chosen for further analysis was cables and pipelines (kabels & leidingen, k&l). The category is one of the categories that can be expected to exist in most, if not all, infrastructure projects; thus making it a good option for further inspection regarding usability of identified risks between different projects, and reuse of knowledge. The project specific events are left out to simplify the comparison.

The two risk registers can be seen in appendix A. As expected, the risk registers differ and are in accordance to the preference of each risk manager, and are made by using two different software solutions, making the comparison difficult and time consuming. The comparison is only done qualitatively as quantitative analysis is not possible due to different quantitative values requested by the clients in the project requirements. In order to be able to compare the different risk registers, a categorization was made which includes all k&l events in the risk registers of the projects.

Appendix B shows the k&l risks of the two projects where the categories are visible and risks shared between projects are marked in grey. In those two projects, four risks are repeated. The risks repeated are damage to third party k&l, unplanned movement of k&l necessary, k&l not moved in time, and k&l knowledge not reliable. Although it is hard to estimate exactly how long it takes to fully formulate each risk as it depends on multiple factors such as the project and the risk in question, it is guesstimated that it takes roughly 1.5 man hours. This number is estimated by assessing the current process at BAM where risk sessions with 8-14 individuals use about 3 minutes per risk which equals 42 minutes, maximum, in total. Input to risk software takes one person about 3 minutes as well per risk and the assessment of mitigations and quantifications take 3-5 persons 5-10 minutes per risk, which equals about maximum 50 minutes spent per risk. Given the number of risks shared between projects and the guesstimated amount of time needed for each one, 6 hours is spent on risks that are already in use in another project for cables and pipelines. Again, it is hard to back up such a statement with facts so it will only be used as an indication of possible time savings that could be acquired if data from previous projects could be used in current projects. Since time is saved during the risk formulation process, that time could be used to fill out a post-risk review form thus making the post-risk review a non-time adding activity.

3 Discussion
The risk management procedures commonly used by contractors is based on attempts to prepare the project for the risk events that might occur during the execution. The current practice treats each and every project differently as they can vary in scope, budget and time as well as the individual preferences by the risk managers are as different as they are many.
Regardless of these differences, there are several similarities shared by projects. Those include, but are not limited to, political and public risks, equipment used on site, or underground cables and pipelines; there is always something that is shared with other projects. By re-using knowledge gained in previous projects, companies can reduce the time and effort used in every project. This would gradually lead to reduced waste by the organization as labor can be put for better use, improve learning, and help the organization to stay ahead of the competition.

This first section of this thesis has given the reader insight into the problem the construction sector is currently facing. The objective of the research was set and the research questions identified. The basic risk process has been presented to set the boundaries and describe the system in place when it comes to risk analysis and risk management. The research has identified the prevention cost as the key ingredient in improving the current processes of construction companies where special attention was paid to post-project review, a step that is often missing from the risk management procedure. Therefore, it will serve as a focal point of the solution which will be introduced in part 3. This is due to post-project, or post-risk, review, along with lack of feedback, being perceived as the weakest link in the risk process at present and therefore the area where most improvement can take place. Furthermore, the trade-offs faced by project teams were introduced where both the mathematical quality perspective and the control-organizational quality perspective got special attention. This was done to highlight the need for a tool that facilitates learning as the project evaluations of the construction sector have been somewhat limited, especially when it comes to feedback for ongoing projects, making it hard to pinpoint significant changes in the output. Adding to that, the need for a cooperation between all project actors was highlighted, which plays a lead role in the implementation of change. Lastly, a case study of two projects was conducted to evaluate the current process and to assess the required capabilities of a possible solution.
PART 2

Through literature study and expert interviews, this second part of the thesis identifies the necessary ingredients of a successful solution as well as exploring the solutions used by companies in other industries.
4 The background of knowledge sharing

In this chapter, the components needed to add value to the current process are introduced. The first step of the proposed solution is to enhance organizational learning so personnel can use the lessons learned in previous projects for the benefit of current processes. Organizations learn through knowledge sharing which is touched upon in the chapter about knowledge management strategies where codification is identified as the appropriate strategy for the construction industry. Codification requires information to be put in a written format, to be shared with the organization which makes a database an essential tool. A database can be helpful in other ways than to only store and share the input information. Mining techniques can help identify patterns and help the user to connect the dots. Furthermore, a database can help project estimators to see how their estimates compare to other similar projects through reference class forecasting and help project actors see how their project compares to others, e.g. in terms of cost of mitigations or risk fired. The final sub-chapter addresses early warning indicators which can reduce, or enhance, the effectiveness of mitigations.

4.1 Individual and organizational learning

This chapter will look into how the learning process of individuals is and how individual knowledge can be transformed into organizational knowledge.

Kim (1993) points out that learning has two meanings, know-how and know-why, where both meanings are equally important. Know-how learning is when an individual acquires the skill to perform a specific task where the know-why is the understanding of why the task is performed and what purpose it serves. A basic learning cycle used in total quality management is the plan-do-check-act cycle, sometimes known as the Deming cycle. In another learning cycle, the Lewin’s learning cycle, the individual goes through a four step continuous process while learning. Starting at observing and reflecting on previous experiences, the person forms abstract concepts and generalizations based on the observations and reflections. The new ideas are tested in new situations, leading to new concrete experience, or knowledge, and the circle starts again. This is depicted in the following figure (Kim, 1993).

![Lewinian learning cycle](image)

**Figure 9 - Lewinian learning cycle. Adapted from Kim (1993)**

If formal post-risk reviews are conducted, the result must be shared with the rest of the organization to ensure the knowledge gained by individuals in one project is used in other projects by other people. This is where knowledge transfer comes in. There are two different viewpoints when it comes to knowledge transfer. The more common view sees knowledge as a transferrable asset, making a knowledge repository a possibility. The less common view argues
that it is impossible to share tacit knowledge, i.e. individual experiences, only in figures and printed documents and should rather be shared via verbal communication (Dikmen, Birgonul, Anac, Tah, & Aouad, 2008; Persson & Landin, 2010). Dikmen et al. (2008) argue that the two different viewpoints do not contradict each other but the knowledge of the two differences can help in improving knowledge sharing by putting emphasis on the why and how in relation to the risk in question.

The following figure illustrates the SECI (Socialization, Externalization, Combination and Internalization) model which takes a closer look at knowledge transfer and how individual knowledge can be transformed into organizational knowledge. The symbols I, G and O stand for individual, group and organization. The figure depicts the transformation of knowledge between explicit and tacit knowledge as an iterative process where, in the end, the organization as a whole is built on the knowledge of both groups and individuals. The figure also introduces a new dimension, the Ba. Ba is derived from Japanese and means context or place and with the four quarters of the SECI model builds the knowledge spiral. Ba is made of:

1. Originating Ba: venue where people can share their feelings, emotions, experiences and other perceptions.
2. Dialoging Ba: a place where tacit knowledge is written down and transformed to explicit knowledge. Two key methods to do this is through dialogue and metaphor creation.
3. Systematizing Ba: a virtual space where information technology is used to combine existing explicit knowledge to new explicit knowledge.
4. Exercising Ba: a venue where explicit knowledge is transformed to tacit knowledge.

![Knowledge sharing through the SECI model with Ba dimensions](image)

**Figure 10 - The SECI model and Ba dimensions. Adapted from Rice and Rice (2005)**

Figure 10 shows how the SECI model with the Ba dimensions can be used to transform tacit knowledge held by individuals into tacit knowledge held by the organization through expressions and documentations of information and data. Firstly, the individuals, having their own knowledge and perceptions, share it with other individuals during the socialization phase where the originating Ba helps to create a sharing forum. Once the individuals have shared their knowledge, a group is made out of the individuals with that specific knowledge. Here the knowledge is put on paper, i.e. transformed from tacit to explicit, with the help of the platform
made by dialoging Ba. As the group of individuals has completed the transformation of tacit individual knowledge to explicit group knowledge in the externalization stage, the group moves to stage three, the combination stage. Here the group shares the knowledge written down in the previous stage with other groups within the organization, combining the knowledge of many groups into the knowledge of the organization. The systematizing Ba helps facilitate this transformation and encourages the use of IT solutions to keep all the gathered information on an accessible format for future use. The last stage, the internalization, the knowledge of the organization has become the knowledge of its individuals. As each individual now has the knowledge of the organization, it becomes tacit over time. Individuals can then start building on that knowledge, starting the knowledge transfer spiral once again.

One of the main influence of knowledge sharing is, according to Gann (2001), the type and turnover of staff, the individuals. According to CIPD (2004), staff turnover in the construction sector in UK and Ireland was over 20% in 2003 and has been persistently high. On top of that, the staff needs to be adequately technically qualified for the company to build on new technical knowledge. Apart from the technical abilities, the internal structure needed to support these kind of activities must be in place. As most construction companies are of too small scale to have a support department and do not have enough technically trained staff, they are not likely to adopt new knowledge gained by research organizations into their way of working (Gann, 2001).

A high rate of internal learning is needed in order to stay ahead of the competition, to improve current practices and to implement new and better ones (Hyland & Beckett, 2002). Figure 11 shows the continuous process of organizational learning. At the top of the model is an external source of knowledge which can be universities or research centers, for example, that are committed to developing new technology and train future personnel in the newly available developments. This external knowledge bank also holds knowledge gained by interaction with other participants in the industry, therefore, the knowledge bank grows in size over time (Maqsood, Finegan, & Walker, 2006).

![Figure 11 - Integrated knowledge management, organizational learning and innovation model. Adapted from Maqsood et al. (2006)](image-url)
The figure also shows the transformation of the learning organization. At the start of transformation, there is a gap between research in the field and the application of the knowledge gained. The external sources try to push the organization to adopt theoretically better approaches through new knowledge and the organization pulls the new information from the knowledge bank. As the organization improves its learning, the push/pull ratio changes. In the ideal state, the organization has a stronger pull for new technology, making technology push less important. In this state, the gap has become smaller as the use of new knowledge gained by research is a part of the organization’s culture (Maqsood et al., 2006). The transformation of knowledge within the organization is also visible in the figure and resembles the ideology of the SECI model, where the knowledge of the individual is transformed into the knowledge of the organization.

The model furthermore claims that the improvements of the internal knowledge bank are due to the knowledge management actions and accomplishments in the organization, transforming it to the ideal transformed state.

Dikmen et al. (2008) suggest that there is a learning-based method that could reduce the difficulties experienced by risk management in practice. They point out that by changing the risk management procedure from a project level approach to a corporate level approach (see Figure 10 and 11), companies could regard risk management as a helpful tool in their quest for improved performance when it comes to learning and internal growth. According to them, an increased attention to “learning from risks” can boost the risk management process and increase the corporate memory which can support organizational learning (Dikmen et al., 2008). This is also one step of the SECI model, the internalization.

In his book on management, Juran (1995) notes that breakthroughs, i.e. reaching improved levels of performance, has, for centuries, been reached by combining the following three steps (Juran, 1995, p. 59):

1. Discovery of new knowledge
2. Dissemination of this discovered knowledge to those who could use it
3. Application of the new knowledge to the solution of old problems

One of the methods mentioned applicable for discovery of new knowledge is to observe and analyze in an organized manner, this is already done in the risk management processes described previously (Juran, 1995). Dissemination, or transfer, of discovered knowledge allows the new knowledge to be used by individuals in need of the newly acquired information to solve problems currently faced by projects. The third point is therefore perhaps best changed to “application of the new knowledge to the solution of current, or new, problems” to fully fit with risk management procedures.

Going back to post-risk review, the number of reviews must be sufficient to fully utilize the possibilities offered by such evaluations and to improve organizational learning. If the number of projects are not adequate, the risk of information being misleading occurs (Ogunlana, 1991). Ogunlana (1991) points out several discrepancies in the theory of learning and the practice of learning. First of all, he points out that learning is based on a mixture of knowledge and
experience. However, tender values, for example, are not compared to the tender estimates which leads to no learning made by the tender estimator. Research shows that people tend to think they do not need to continue learning after a certain point in life is reached and only look into the theory if results are not as expected. Therefore, people tend to not add to the existing knowledge as there is no system in place that requires them to look back to previous projects (Ogunlana, 1991). According to Ogunlana (1991), there is a procedure, broken down in four steps, to learn from experience. The steps are:

1. Increase the amount and immediacy of useful feedback. Also described by Juran (1995)
2. Create social surroundings which require learning
3. Train personnel to become specialists in a specific field
4. Do not expect perfection

Regardless of all the ways previously mentioned to increase the learning capabilities of organizations, the company culture is perhaps the most important one. The support of the organizations hierarchy in this matter is vital as it helps to establish learning norms in the company. There has to be some kind of incentive in place (e.g. a belief in the added value) to motivate team members to write high quality reports and share their experiences (Tan et al., 2010). What that incentive should be entirely depends on each situation and will not be discussed further in this paper.

Now that the foundations of organizational learning are known, the next step looks into how knowledge can be managed in different settings via knowledge management strategies.

### 4.2 Explaining knowledge management strategies

There are two elementary strategies for managing knowledge: codification and personalization strategy (Dikmen et al., 2008). According to Bartholomew (2008) codification, i.e. recording experiences, is the only way to make sure knowledge is independent of uncertain memory and make sure knowledge is free of personnel being available with faultless memory. It cuts the connection between examples and simulations, time and space; puts together a knowledge that is too extensive and/or complicated for one individual to possess or share verbally or via demonstrations. When that knowledge is available to everyone, whenever, where ever, without delay, even after its originator is no longer available, an actual organizational memory has been created (Bartholomew, 2008). Hansen et al. (1999) further add that this strategy is centered around a computer database where reliable information from previous project(s) and fast information retrieval separate the winners from the losers. Databases based on codification are, for example, used in consulting firms working in fields where most projects are of similar nature like often is the case in construction industry (Hansen et al., 1999; Kankanhalli, Tanudidjaja, Sutanto, & Tan, 2003). Personalization strategy is sharing knowledge by individual communication, either verbally or by demonstrations. It is more often used where the user is required to find specific solutions to specific problems, such as a creative solution to a highly strategic problem. The role of IT solutions here is mainly to assist people to communicate with one another (Hansen et al., 1999). Consultants that use databases built on personalization strategy use the knowledge provided by the database to select players and build new project teams for highly unique projects, for example (Hansen et al., 1999; Kankanhalli et al., 2003).
Kankanhalli et al. (2003) divide industries in two separate dimensions, product/service based and high-/low-volatility context. Risk management in the construction sector is typical for service based, low-volatility context industry as it provides service to clients in a slowly changing environment. The most common knowledge management tool for companies in this field are databases built on codification. These types of databases are explored in chapters 4.3 and 7. In product based industries, information is shared in a different manner and mostly face to face. The following paragraphs briefly look at how things are done at an organization in the product based industry.

Learning in practice in the product based industry

In the product based industry, timing is of the essence. Putting the product on the market before the competitor can make a company and, consequently, the failure to do so can break it. Therefore, companies in this environment have leaned towards knowledge management solutions built on the personalization strategy as information is often too tacit, unclear, or technically complicated to codify in a simple manner. Solutions used by the product based industry can range from a global virtual communication network linking specialists with field personnel; knowledge yellow pages aimed at helping employees finding other staff members with the required knowledge; to transferring employees between departments, geographical locations, subsidiaries or even suppliers, as has been done in the Japanese automobile industry for years (Kankanhalli et al., 2003). The Japanese automobile industry has been a leading force in quality improvement and costing. The following paragraphs will take a quick look at system used by Toyota to facilitate learning amongst itself and its suppliers.

According to Dyer and Noboeka (2000), one of the reason why productivity in Japanese automobile industry increased from 1965-1990 is their knowledge sharing routines, with Toyota being the leading organization in the field. In the words of Dyer and Noboeka (2000, p. 347): “Toyota’s “network” appears to be highly effective at facilitating inter-firm knowledge transfers and may be a model for the future.”

Dyer and Noboeka (2000) identify six routines which enable knowledge sharing. Those are:

1. Supplier association
   This routine has three objectives, “(1) information exchange between member companies and Toyota, (2) mutual development and training among member companies, and (3) socializing events.” (Dyer & Noboeka, 2000, p. 352).

2. Operations management consulting division
   This routine revolves around a team of consultants Toyota sends to the suppliers for specific amount of time, all depending on the problem at hand. The cost of these consultants is borne by Toyota, who in return require the companies to be willing to share the information with other member companies. In many cases, the problems are only solved once cultural and organizational changes have been implemented.

3. Voluntary learning teams
   In this routine, suppliers are placed in groups based on geographical location, if they are in direct competition or not (direct competitors are not put in the same group) and experience with Toyota (at least one highly experienced Toyota supplier in each group).
Each group focuses on one problem each year, e.g. reducing inventories. Once a year, Toyota schedules a meeting with all the groups to share the lessons learned. This routine has been found to be extremely beneficial to the manufacturers in the groups as it involves hands-on approach where work is done on site instead of a virtual environment.

4. Problem solving teams
   If a supplier is experiencing problems with its product, Toyota builds a team of its own employees and other suppliers to find the root cause of the problem. Once the source is found, Toyota gets its specialists to take the lead to work on a solution, or get other suppliers to help if they are a better source of knowledge. This way, the suppliers of Toyota are of similar quality and competition is stimulated.

5. Inter-firm employee transfers
   Here knowledge is shared by transferring employees from Toyota to a supplier. By doing this, the employee shares the knowledge and training done by Toyota which facilitates the information sharing as the new employer gets a better knowledge of how things are done at Toyota while Toyota gets a better insight into how things are done at the supplier, and what could be improved.

6. Performance feedback and monitoring processes
   Toyota pushes its suppliers to learn and provides regular feedbacks in various areas to make sure suppliers are implementing the new knowledge, e.g. by using checklists to see if targets are being met.

The learning method of Toyota has been an inspiration to many organizations, and fields of research are somewhat based on the same principles as introduced by Toyota’s engineers in the past, such as lean construction (Howell, 1999). The method used by Toyota can be described as a system based on personalization strategy as it revolves around the creation and evolution of a knowledge sharing network. As codification is more fitting to the construction industry, the next chapter will look at databases and their possibilities.

4.3 Databases based on codification strategy
   Currently, the project management or risk management procedure, as introduced in part one, includes compiling statistical (e.g. cost and time) outcomes regarding the project in question. The causes of risks firing, which can cause delays in time and cost overrun (or reduction in time and cost), are, on the other hand, not recorded as thoroughly (Dikmen et al., 2008). Lowe and Skitmore (1994) point out in their paper that only a minority of estimators keep record of the results of tenders and their experiences relating to it, the same can be said about risk managers. They also note that the estimators are unaware of the technology available for recording and sharing those experiences for future use. One of the available formats are computerized databases. Such database can provide the project team with just-in-time access to relevant information, e.g. based on post-risk reviews, therefore reducing the risk of information overflow.

In their paper, Yu et al. (2010) come up with a tool they call the “proactive problem-solver” for construction. Their tool is based on lessons learned files (or post-risk reviews like suggested previously) and uses those files to find solutions to problems fast and easily. According to their research, there is considerable time savings to be had at a low price, given that the lessons learned files of previous projects exist. Moreover, the tool helps knowledge sharing in the
organization. To stimulate learning, data or text must be put into a format that can be easily
transmitted between different team members. This is where a database can come in handy as it
can keep the input information stored in an organized manner, and is open to all permitted team
members (Hyland & Beckett, 2002). The following figure can be used to explain how a database
(marked data in the figure) can be used by the task performer, in this case risk manager or
analyst, to estimate the risks of the project. This figure also expects the system to give the task
performer an immediate feedback which allows for improved learning.

![Figure 12 - Feedback in cost estimating (Ogunlana, 1991)](image)

As databases grow in size, i.e. the number of kept records increase, the need for practical system
that can find patterns in the database, making its use easy and effective, grows. As a risk
database contains both quantitative and qualitative values, there is a need for a system that can
fish out the most valuable data of each category, so called knowledge discovery (Fayyad,
Piatetsky-Shapiro, & Smyth, 1996). The following sub-chapter looks into the attributes needed
by a database to utilize post-risk reviews and add value to the risk management process by
finding relevant information buried in extensive digital databases.

Data & text mining in databases
Data mining is the usage of specific algorithms for extracting patterns from data. It focusses on
the analysis of a structured, numerical data stored in a database. It has been used, successfully,
in the field of astronomy for several years, helping astronomers to classify and catalogue various
images sent from observatories. Data mining has not only been used in the scientific field but
also in marketing and manufacturing for example. It can find the patterns needed for users such
as customer behavior e.g. if product A is bought, it is likely that the consumer will buy product B
as well (Fayyad et al., 1996).

![Figure 13 - Division of data mining](image)
Data mining is divided into verification and discovery as can be seen in Figure 13. Verification is used to verify the hypothesis put forward by the user. For the purpose of a risk database, the discovery phase is mainly used where the system finds new patterns. The discovery is further split into prediction and description where the prediction capabilities can be used as an early warning indicator (see chapter 4.6) to future risks and description looks for patterns to present to the user in an understandable format (Fayyad et al., 1996).

As reports, such as post-risk reviews, are seldom only made out of statistical values, there is a need for a process that uses text instead of numbers. Such process is called text mining and is derived from data mining and connected to natural language processing. As described by Carrillo et al. (2011), the goal of text mining is to allow the user to detect knowledge that no one yet knows and therefore no one has put on paper, or form new hypotheses for further research. A database with text mining abilities could reveal unexpected patterns in the information stored (Tan et al., 2010). There are numerous different ways to use the results accumulated by text mining. Here, two will be looked at in more detail, those are link analysis and dimensional matrix analysis.

Link analysis looks at if there is a link or correlation between keywords depending on predetermined phrases and rules used to find topics of interest. To find these areas of concern, the user of the program needs to have a good knowledge of the field; otherwise, the information extracted from the database can be of lower quality (Carrillo et al., 2011).

Dimensional matrix analysis matches key expressions with many others, resulting in a table showing the values connected to the key phrase. It uses online analytical processing (OLAP) which allows the user to explore multidimensional data from various perspectives. Like in link analysis, the user defines the key expressions and searches the database for connected phrases, however, the dimensional matrix analysis is capable of finding more complicated links between key areas of interest (Carrillo et al., 2011).

In their paper, Fuller, Biros, and Delen (2011) look at how different categories of text mining can be used successfully to solve “real world” problems. However, there are limitations to text mining as Leong, Ewing, and Pitt (2004) point out. Those are, for example, a computers inability to learn grammatical structures and understand words with more than one meaning. This suggests that although useful, text mining might need more research. The capabilities are promising though and merit careful optimism.

By using a database built on post-risk reviews, the organization in question can improve its accuracy in cost estimations as risk information, for example, are stored and easily accessible. This option makes cost assessment more accurate as it can be based on historical information of the same, or similar, project elements and improves quality as lessons learned in previous projects can be exploited for the benefit of both the project and the organization.

4.4 Reference class forecasting

In his paper, Flyvbjerg (2008) notes that average inaccuracy in cost estimation in large scale infrastructure projects is up to 44.7% and no improvements in accuracy has taken place in the
past decades, despite advancements in technology. This is not limited to construction activities as more than 70% of new manufacturing plants in the USA go under in the first decade of operation (Lovallo & Kahneman, 2003). The main source of these inaccuracies can be split between two areas: optimism bias and strategic misrepresentation.

When individuals look at things from a more positive viewpoint than experience warrants, optimism bias occurs, or as Lovallo and Kahneman (2003) put it, when people look through the rose colored glasses. Optimism bias can also be described as taking the inside view, meaning that the person, or persons, affected by the bias look too closely at the objectives of the project at hand, its resources and hindrances and build the plan according to that perspective. On the other hand, when personnel deliberately overestimate the benefits and/or underestimate costs in order to get projects approved, strategic misrepresentation is at work. Strategic misrepresentation mainly happens when political pressures are involved. To limit the effect of these two factors, reference class forecasting has been introduced, and tested on actual infrastructure projects in the UK (Flyvbjerg, 2008).

The antidote for both optimism bias and strategic misrepresentation is to take the outside view. The outside view does not focus on the specificities of the project but looks at reference classes, based on similar projects, where estimations are based upon experiences from those previous projects and the distribution of outcomes used as an indication of the cost and benefits of the project under evaluation. Research has shown that the outside view is much closer to the actual outcome (Flyvbjerg, 2008; Lovallo & Kahneman, 2003). “Reference class forecasting does not try to forecast the specific uncertain events that will affect the particular project, but instead places the project in a statistical distribution of outcomes from the class of reference projects.” (Flyvbjerg, 2008, p. 8).

Through his research, Flyvbjerg (2008) comes up with the required uplifts, i.e. the percentage needed to add to cost estimates, depending on the acceptable chance of cost overrun, which is set by the project owner. To take an example from his paper, if the acceptance level of budget overrun is 10% in a fixed link project (e.g. a bridge) the project owner needs to increase the budget by nearly 140% to cover the unexpected events, which certainly is a food for thought.

Reference class forecasting can be compared to benchmarking in some ways as both require the user to compare their current venture to past projects. Both can be a useful tool to help project actors to estimate how the project is going in respect to the iron triangle and in assisting to identify areas in need of improvement. The following sub-chapter looks into benchmarking and how it can be used together with risk maturity to help organizations estimate their most beneficial maturity level.

4.5 Explaining benchmarking

Benchmarking is a way to measure performance. It is a constant process used to document critical areas for improvement, it looks into how other organizations, or other projects, execute similar jobs more efficiently and finds the techniques that breed improved performance (Garnett & Pickrell, 2000). Mohamed (1996) breaks benchmarking into three different sections: internal benchmarking, project benchmarking and external benchmarking. A short description follows.
Internal benchmarking looks at how current processes and practices are performed and identifies needed improvements compared to those whose process is better. It is, according to Mohamed (1996), a process construction organizations should start using to support the need for enhanced understanding of the business customs and their customers perceptions. Most efficient internal benchmarking is achieved by rationalizing the differences in operating environments, levels and quality of service to minimize waste.

The second level of benchmarking is project benchmarking. It looks at the organization’s performance in projects and grades it. Organizations are encouraged to use the methods in project benchmarking to evaluate their performance, quantify their amounts of output and validate their cost-estimation databases. The output of this second level of benchmarking is used by the first level, internal benchmarking. To judge the success rate of the measures taken as a result of the internal benchmarking (Mohamed, 1996).

Implementing project benchmarking should be beneficial to design and construction professionals as it registers the performance for future use. Currently, the origin of each decision lies in the personal experience of the decision maker and experience is seldom captured systematically, making it hard to reach uniformity in experience and decisions in the organization (Mohamed, 1996). One of the important factors of project benchmarking is feedback. It should be used to check up on how the estimated values stand in relation to actual performance values, an important factor in learning. If given in time, feedback can serve as a link between projects in the early stages and execution as it can help the company to evaluate what strategies serve best to keep the project on time, budget and quality. In order to fully use the possibilities offered by project benchmarking, construction companies have to take a critical look at their projects, both quantitatively and qualitatively. Once that is accomplished, a full view of the project is obtained (Mohamed, 1996).

The third and final level of benchmarking, according to Mohamed (1996), is external benchmarking. It focuses on identifying useful developments made by other industries in order to exploit them to improve the organization. At the moment, external benchmarking is not seen
as vital tool for the construction sector but it still has an important role to play in increasing innovation in the field.

Risk maturity and benchmarking
One of the benchmarking possibilities in organizations is to compare the risk maturity level of projects. According to Hillson (1997) there are four different levels of risk maturity:

Level 1 – Naïve. The company is unaware of the need for risk management and its benefits and does not deal with uncertainties in a structured way. No learning takes place.

Level 2 – Novice. Risk management is applied in few projects without any real structure. The full benefits of risk management are not exploited.

Level 3 – Normalized. Risk management is a part of most projects. The processes are well-known and the benefits known but might not be achieved in all projects.

Level 4 – Natural. Risk management is a part of the culture and is used to gain the upper hand over the competition.

By evaluating the risk maturity level of projects at the beginning of a project, the project team can work towards a desired level. Once the execution is over, the risk maturity can be assessed once more and the benefits of any improvements assessed and registered. Furthermore, the profitability of the project can be compared with the risk maturity level to estimate the financial benefits of increased risk maturity, if any (M. van Staveren, personal communication, June 1, 2012). In a report from the consultant company Ernst & Young (2012), the authors claim that increased risk maturity will lead to both increased revenue and EBITDA (earnings before interest, taxes, depreciation and amortization) where companies with highest risk maturity (the top 20%), increased their revenues by 16.8% and EBITDA by 20.3% in the years from 2004-2011. At the same time, the bottom 20% increased their revenue by 10.6% and EBITDA by 7.4%. Their findings also suggest high correlation between risk management, its control and compliance, and financial performance (Ernst & Young, 2012).

As the maturity of risk processes increases within organizations, new tools can be implemented to improve performance. As post-risk reviews become a normal part of the process, the project team can identify the early warning signals, or root causes, of risks. This can benefit future projects by providing the risk teams with information about uncertainties that need to be inspected, or analyzed, at regular intervals to reduce, or increase, the probability of a risk firing.

4.6 What are early warning indicators?
As the name suggests, early warning indicators (EWI) are designed to warn the decision makers of possible risks that are likely to fire. The observer needs to discover the problem indicator in time to react to the possible risk and implement the response needed to lower, or increase, the consequences of that risk event. Early warning indicators are very much influenced by communication of team members. In fact, Nikander and Eloranta (2000), state that several of the main causes of uncertainties are related to communication: differences in project culture; management methods; problems relating to delivery of equipment; and problems related to
technical design, to name a few. The observer must be able to convince the decision maker that the early warning is a signal of a possibly impeding risk event. However, the signal is often clear but no one wants to listen to the bearer of bad news (Ilmola & Kuusi, 2006). This explains why the decision maker needs to be persuaded, which can often only be done via communication, supported by the company culture. Nikander and Eloranta (2000) also note that the most common responses relating to project problems, according to their research, were more effective monitoring and communication with management.

Mohamed (1996) notes that an early warning system should be integrated into an organization’s structure which allows for a quick and correct actions to be taken. It is important that as this system is implemented into the company culture and project personnel actively encouraged to take actions. The actions should be focused on reducing the future threat (or increasing future opportunities), instead of waiting and hoping for improved information which can cause the mitigation plan to be implemented too late (Nikander & Eloranta, 2000). At first, this early warning system would help to find the flaws that require rework and consequently lead to their aversion in the future. The early warning indicators, or weak signals, are hard to interpret and are sometimes filtered out as insignificant by the relevant actor thus making its documentation difficult in practice and sometimes based on individual perceptions (Ilmola & Kuusi, 2006).

In his paper, Ansoff (1980) uses the word ignorance when describing the imperfect knowledge about the character, timing or the effects of an event. Figure 15 portrays this interaction between forecasting horizon and response time. The 0 point on the state of knowledge axis represents the scale of ignorance where there is only a (perception of) certainty that a specific event will occur, such as natural disaster, without knowing the timing, location or magnitude of the event. Every risk event will go through a process similar to the one pictured. The important thing is when the impact will be realized (point T in the figure), it has become too late to respond to the risk. Therefore, if the project team is to have an effect on risks, the mitigation strategies

![Figure 15 - Interaction between forecasting horizon and response time. Adapted from Ansoff (1980)](image-url)
need to be implemented before point T is reached. The time needed for implementation of the risk response is shown by δ and the time available for implementation is shown by Δ. It can therefore be seen that for the response to be effective, 0 ≤ Δ, is necessary. Thus it can be stated that for an early warning indicator to be effective, it is vital that enough knowledge is gathered, not only to be aware of the risk but also to be able to reduce, or increase, the probability of risk firing.

As the complexity of the system grows, the risk response needs to take place at an earlier point in time but at the same time the time required for an effective response increases. Therefore, projects need to be dynamic and search for EWIs on a regular basis (Ilmola & Kuusi, 2006).

5 Interviews with experts

Researching the theory behind risk management or looking at risk registers from number of different projects would not result in an increased knowledge of the risk management procedures conducted in practice at BAM. Therefore, interviews with relevant personnel are vital in gaining understanding and insight into the process that takes place which results in the risk register. Interviewing experts working on, or around, projects with active risk management in place serves as a glue, tying the theory with practice. The focus of the interviews is to see how risk management is pursued on actual projects, to find out how the experts feel about a tool like a risk database and to get their feedback on the proposed solution which will be further explained in part 3.

For the interviews, a semi constructed list of questions, somewhat based on ideas by Yin (2009), was made in order for the respondent and the researcher to have a conversation about the projects and practices rather than the interview being perceived as a list of questions where yes or no would be an applicable answer (Stake, 1995). The interviews, that all lasted for about an hour, were based on 15 questions, or guidelines, that can be found in appendix C.

The seven individuals chosen for the interviews all have experience in the field of construction. Risk management as a structured process is not an old discipline within the sector so there are only a few persons with decades of experience but instead there are people eager to learn and take risk management to a higher level. The responses of the experts can be seen in appendix D.

The outcome of the interviews were used to make a set of criteria which the proposed solution needs to fulfill in order to add value to the users. These are:

1. Documentation of risk occurrence, the uncertainty that led to the risk, mitigations, success rate and recommendations for future improvements
2. Documentation made as soon as possible after risk occurrence, with as little added work to the project personnel as possible
3. Capability to search through multiple risk registers using different filters
4. Presentation of the most common risks of projects and their probabilities based on previous projects
5. Simple format of output presentation
6 Discussion

A standardized and streamlined process is the desired state of the risk management process. This would improve efficiency as the risk team could browse through other projects to look for similarities effortlessly and more accurately. Although this desired state is hard to reach, it is not impossible. The first step towards improvement is the application of a post-project review, or more accurately post-risk review. By documenting the successes and failures of risk mitigations, contingency plans, and the special events, the lessons learned by the project team in each project can be shared within the organization; making organizational learning based on knowledge from number of projects a possibility. By organizing the post-risk review after the completion of each milestone or project phase, the fresh mind of the key actors are put to good use and important details which otherwise could be forgotten are put on paper.

The post-risk review should not be a time consuming practice as it can be coupled to meetings that already take place on a regular basis, such as risk register update meetings (risk monitoring and control in the PMBoK method and updating the analysis in the RISMAN method). If the post-risk review becomes a part of meetings where the risk analyst or risk manager and other key actors meet, it becomes a natural part of the risk management process. This would, consequentially, lead to improved communication between project participants and serve as a foundation for a risk database where knowledge based solutions to risks are documented. Apart from serving as a basis for a risk database, post-risk review helps improving risk identification as historical information is documented in the review and give feedback to project actors. By not performing a documented review, or a similar process, the organization risks not having enough beneficial input for risk identification, little or no base for the implementation of early warning indicators and therefore only rely on the memory of the project team. Furthermore, if risk maturity level of projects are estimated, it is possible to assess the connection with profitability and identify areas worth improving in individual projects. Overall, this can perhaps be interpreted as the biggest risk in modern construction as companies fail to learn from practice and take the step onto the information highway.

As time passes and the number of reviews increases, a solution to systematically store them in an easily accessible format becomes the key ingredient in the facilitation of organizational learning. A database and the application of proper filtering methods is the solution used by industries similar to construction. By using mining techniques like data and text mining, the database will eventually resemble a clustered network of risks. These clusters become “visible” as more projects identify similar risks in their risk registers and use them in their post-risk review. As a result, these risks can serve as a repository of generic risks that can be used as groundwork for risk analysis of future projects and as reference class projects. The downside of the mining techniques is that the process might identify the outliers, the project specific risks, as data noise and therefore delete them, which needs to be prevented. Furthermore, building a risk database fits to the SECI model’s C and systematizing Ba, where the combination of existing explicit knowledge is bound together via information technology. Here, the new and improved knowledge is of higher value than the sum of the previously individual knowledge. This could facilitate inter-organizational knowledge sharing, similar to the methods used by Toyota as people become more accustomed to sharing and receiving new, valuable information and use it
in future operations. It is worth mentioning that within BAM Infraconsult lunch sessions are held on a regular basis where information is shared, either within departments or the whole BAM Infraconsult organization, depending on the knowledge in question.

The risk database, once implemented, would not only be used as a helpful tool in risk management, but it would also help to detect anomalies that can lead to a risk firing via the early warning indicators, as other project teams have tried to identify the root cause that initially started the risk. This early warning, or weak signal, can be used by others for early detection of risk event, to improve the mitigations for the risk, which leads to reduced costs, increased safety and/or quality, better environment or reduction in time. As EWIs are hard to detect and document, they require the project team to be experienced and well aware of the possible consequences of events. This process is a key element in building a system capable of warning the project team of imminent risks as it records the undesired occurrence or actions leading to the undesired event that triggered the risk. For the early warning indicators to work, the risk managers need to identify the very first indication of an event that lead to a risk in the post-risk review as accurately as possible. This information will serve as a valuable ground for limiting the consequences or evading negative risks in future projects, as well as helping to enhance the probability of positive risks. It is important, however, to keep the reviews as short and to the point as possible.

The database could also provide the users with the ability to easily search in risk registers of multiple projects at once, and filter risks according to their preference, e.g. by project phase or stakeholder. As the risks in the database would be collected from vast number of projects, the diversity of risks is high. To take an example of possible benefits one can think of a new infrastructure project in a politically instable area where the project or risk manager expect changes to be made in the authority during the execution of the project. By going into the risk database, the decision maker can look up projects where a similar risk fired to get an idea what problems might arise as a result and take appropriate measures. Additionally, the users have to be aware of not jumping to conclusions when looking at the recommendations made by the database and keep a critical mindset when assessing the outcomes. Also, the accessibility of the database has to be carefully considered. It must only be open to employees working on risk management and their supervisors to reduce the risk of data tampering aiming to cover up mistakes.

Project estimations, whether made during tender calculations or later during the project execution, can provide a platform for the project team to build the rest of the project on. However, these estimations can be based on various data, some more accurate than other, or some even missing. To counteract these inevitable imperfections in the estimations, project actors might be forced to make trade-offs such as increasing manpower in the project, which results in faster completion at a certain price. Adding to that, the perception of quality also plays a role. In construction it is often hard to identify the failure of objects before handover to the client, making the mathematical perspective, as discussed in chapter 2.6, only a useful addition to the project managers’ toolbox. In big infrastructure projects the control-organizational perspective, where high level of contact is had with external stakeholders, can prove to be the best method to ensure quality and success, as pointed out by Raz et al. (2002). This leads to
another possible benefits of a tool working with a database, the capability of improving estimations made with Monte Carlo simulations, or other similar methods. These benefits are acquired as past estimations and consequent real values of time and/or finances spent on projects are known, improving the level III estimations by providing documented historical data. Furthermore, the identification of the “uplift”, i.e. the percentage needed to add to estimated values for them to fit actual values and counteract optimism bias or strategic misrepresentation, becomes a simple process which provides a helpful input when deciding whether or not to submit a tender. In short, as more data is documented and made available, the organization can use the differences between estimates and real values to improve project estimations.

Lastly, it is worth to mention that considerable amount of time was used to search for options in other sectors to facilitate learning when it comes to risk management. This search, which included literary research and questions to risk experts, did mainly reveal two forms of knowledge sharing, the one that has been used by Toyota for decades, or similar, and a repository, e.g. database, which is used by service based companies working in low-volatile environment, such as construction. However, this search did not specifically find anything directly about any construction companies. This supports the notion made by dr. van Staveren in an interview on June 1st, where he mentioned that companies often forget to finish the risk cycle and stop after the measures have been put on paper. This is furthermore supported by Hillson (1997).
PART 3

The third part of the thesis proposes a solution for improvements of the current process based procedure as well as verifying and validating the solution.
7 The proposed tool

The literature uses two types of methods to capture project histories: process-based and document-based method. The process-based method collects the lessons learned from the finished projects while the document-based method gathers the experiences as they happen. An “easy to find” process, built on codification strategy, i.e. a database, with input built on the document-based method with a secondary function based on the personalization approach, e.g. contact information, would be the optimal mix according to Hansen et al. (1999). Furthermore, they point out that trying to equally follow both process-based and document-based methods can quickly undermine an organization. The biggest item of expenditure for the proposed method of improved organizational learning is building the database. The time and effort of project team members is minimized by coupling the post-risk reviews to risk update meetings that take place on a regular basis anyhow.

By implementing a risk database based on the codification approach, companies can add to their tools and techniques, one of the four critical success factors of risk management according to Hillson and Simon (2007). The knowledge captured and documented can not only be used as a helpful tool to share lessons learned between risk teams but it can also help future risk estimators estimate the likelihood of an event and the cost associated with it. This knowledge would enable estimates to be based on both experience of the individual estimator and the experience of all the estimators, e.g. the individual can find both the mean and standard deviation of the risk in the database to check if the estimate is in line with historical data.

The information gathered in the previous chapters is used to describe, and build, a conceptual model for a risk database. The following chapter looks to describe the model, its background and functions.

7.1 The conceptual model

If information, such as post-risk reviews, are to be shared within an organization, a medium is needed to facilitate the knowledge transfer between individuals. The model that will be introduced in the succeeding pages is somewhat based on ideas presented by Yu et al. (2010) as the “proactive problem solver” and aims to extract information provided by various risk teams in the form of a post-risk review.

Framework of the risk database

The model needs to be able to incorporate the capabilities discussed in chapter 4 with the knowledge gained and criteria put forth in chapter 5. The model should therefore serve as a bridge between theory and practical knowledge. It is of utmost importance that the model is easily understood and the user interface of the database welcoming and appealing. Linking the database directly to the software in use at each time would provide an easy access to the knowledge base and lower the risk of data being lost in translation, which is always a possibility if data needs to be moved from one software to another.

The data input, e.g. the post-risk review, needs to be of good quality to be of service to others and the term “rubbish in, rubbish out” should be kept in mind at all times. The database has to be able to connect words and phrases in the input and count the similar risks of different
projects, be able to filter risks affecting project promises and present the highest scoring, or ranking, risks of different projects. The implementation of the database, or a similar tool, would help the project team to identify the uncertainties, or EWLs, that need to be monitored constantly, which should lead to a decreased, or increased, possibility of the resulting risk firing. This is possible with the technology currently available on the market if the risk team uses predetermined keywords in both risk registers and post-risk reviews. Once the database is in place and the necessary reviews start being made, the learning begins as soon as personnel get accustomed to the possibilities of the tool. Finally, once the database has been in use for several years and has enough data to supply the risk managers with a helpful information for their risk registers it accomplishes its final goal of being both a learning tool and a mechanism that adds value to projects through improved risk management processes.

With that in mind, the model should be able to provide future risk managers with the know-how of past projects and supply them with the connections needed for further research, if needed. The main objective of the database is that it is a dynamic tool, supplying the project team with the most common risks of all projects at each time, their triggers and mitigations/contingencies and ultimately their effect on project objectives, based on post-risk reviews. Furthermore it allows the project team to see how the project is going compared to other projects of the organization and act accordingly.

Description of the risk database
Now, as the framework of the database has been defined, the steps of the database can be described. The model itself is in three phases: the input, the database tools, and the output. Figure 16 represents how the model should work in practice with the input at the top of the picture, the database itself in the center, and the output at the bottom of the picture.
Input to database

1. The database has access to the requirements made by the client as it is put into the risk software currently in use, to which the database is linked. As the database is directly connected to that software, all specifications made by the client is accessible through the database.

   This step allows the data and text mining capabilities of the database to connect risks with specific client requirements which can be of use for future users using the search capabilities of the database (see step 9).

2. The risk register of each project is made in the risk software and thus becomes the first input in the database by the project team.

   Once the risk registers are accessible to the database, it can start sorting out the most common risks, or extract almost anything the user requests from the data provided. Example of risk registers can be found in appendix A.

3. During the implementation phase of a project, post-risk reviews are made where risks fired, mitigations were applied, successfully or unsuccessfully, and the predecessors are identified and described along with cost and time information.

   This step is the most important step regarding organizational learning. Once completed, the database can identify the risks that are more likely to fire than others based on historical information thus allowing the project team to pay extra attention to the preceding uncertainties, or root causes. The information that needs to be included in the post-risk review can be seen in the sub-chapter ‘Evaluate control measures’ on page 15 and in bullet points on page 16. Additionally to those items, the cost or savings, direct and indirect, and time allotted to risks needs to be in the review as well as knowledge on EWI. This input helps future estimators as results from previous projects are known and easily accessible. This can lead to better estimations on budget needs and improve planning. An example of a post-risk review form can be seen in appendix E. It should be noted that the review should ideally be a web-form, making it possible for the reviews to become an instant part of the database once submitted, if required.

Database tools

5. Text mining.

   The database ties keywords of the post phase reviews together, making searching through different projects relatively easy. It can also connect the risks with keywords in the requirements set by the client, if the user requests so.

6. Data mining.

   As all values, or quantifications, given to risks are known, the database can calculate the most likely risk, based on historical data and give the risk manager a list of those risks. See chapter 4.3 for further information on mining techniques.
7. The SECI model.

As project information is now accessible via one program, the knowledge sharing becomes easier. As experiences are documented and stored, the individual tacit knowledge can become organizational tacit knowledge over time.

Output of database

8. A generic risk list, made out of risk registers and post-risk reviews from previous projects.

This list can be used as a base for risk registers of new projects. This dynamic, generic list includes the strategies implemented, and EWIs in previous projects which should decrease the amount of time needed to formulate risks and increase the probability of successful mitigations. The list can also be filtered according to the users wishes to only contain specific kinds of risks, e.g. cables and pipelines, a certain risk category, or risks related to a specific project phase, where the EWIs, cost/savings and time spent or saved is gathered from multiple project sources.

9. Users can search the database for uncertainties or risks that have been documented in previous projects.

This step can help risk managers to identify new cause, event or consequence, based on either their own old registers or registers made by other managers. Mitigations, contingency plans or EWIs can also be found by using the search. Furthermore, the user can limit the search according to a specific criteria such as risks connected to a specific stakeholder, or specific risk category, for example.

10. Contact information for risk managers, or team members, that have handled specific risks in other projects.

As documentation sometimes does not include all the specific information requested by risk teams, contact information about the project team members can connect the experienced individuals with the less experienced ones when it comes to a specific risk event.

11. Risk managers can see how the project stands compared to other projects, i.e. feedback is provided.

That means, answers to questions such as “how is this project risk budget spent compared to other projects?” or “are there more uncertainties that have led to risks?” can be found in the database. This is directly connected to the benchmarking done by the database. The feedback can then be used to improve the current processes in the project and future projects.

Furthermore, the database can provide the user with statistical information of risks such as average cost and standard deviation of a specific risk fired, average cost and standard deviation of a specific mitigation strategy, and average cost and standard deviation of the savings once mitigation has been applied.

Now that the actual database model itself has been presented, verification and validation of the tool is needed in order to see if it could be of use to the project team. The verification phase looks at if all the criteria set by the experts are fulfilled, if all the requested elements are in place.
for the tool to have a chance of success. The validation introduces the solution to experts to get their view on if the model could actually serve its purpose and add value to the current process.

8 Verification and validation of the tool

As the proposed solution has been described, the next and final phase is the verification and validation of the solution. Verification is done via check list to see if all items identified by experts in chapter 5 on page 38 are covered by the proposed tool. For the validation of the solution, the applicability is assessed with another round of expert interviews where a form for post-risk review is introduced with a schematic presentation of the output and the expert asked for their critique.

8.1 Verification of criteria fulfillment

The criteria based on the expert interviews needs to be fulfilled in order for the database and its tools to be of value to the organization. The following table shows the validation criteria and where it is fulfilled:

<table>
<thead>
<tr>
<th>Criterion no</th>
<th>Description of fulfillment</th>
<th>Fulfilled in step no</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Post-risk review includes all the items listed in the criteria. The execution of a post-risk review, therefore, fulfills this requirement.</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Coupling the post-risk review to existing practices such as risk update sessions limits the extra work required by staff and makes sure reviews are made on a regular basis, e.g. monthly. Furthermore, if the review is a web-based form, the additional work of the project team in relation to the review is further reduced.</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>This is one of the cornerstones of the database. The user must be able to search through the organization's previous experiences to make use of the lessons learned.</td>
<td>9</td>
</tr>
<tr>
<td>4</td>
<td>The user can choose if the most common risks overall are viewed or if a certain criteria, e.g. certain stakeholder, is used to filter the risks.</td>
<td>8-9</td>
</tr>
<tr>
<td>5</td>
<td>The fulfillment of this criterion is mainly based on the actual design of the tool, and is therefore not completely fulfilled in the concept as presented previously. However, by standardizing the format for post-project review, the main input in the database, the users can search through the information supplied by the database in less time.</td>
<td>(8-11 &amp; appendix F)</td>
</tr>
</tbody>
</table>

As can be seen in the table above, the conceptual model fulfills the first four criteria with the steps being the numbered items on pages 45 and 46. The fifth and last criterion, simple format of output presentation, is difficult to verify as the actual database has not been designed yet. However, a schematic representation of how the output could possibly look is provided in appendix F.
8.2 Validation of model
As the first step of the solution is to perform a post-risk review, an example of a review form was made and presented to members of the risk teams for the A4, OV SAAL and Sluiskil tunnel projects.

The individuals partaking in this phase were first presented by the ideas of the model, then the picture of the possible output where the possible benefits were explained. Once that was done, the exemplary form for post-risk review (see appendix E) was presented and the individuals asked to study it, and critique it.

The experts noted that the form presented could use a bit of a trimming and should be about one page in length. However, it is rather easy to follow although it sometimes needs a bit of an explanation from the researcher, as was to be expected. The form captures the key issues needed in a post-risk review aimed for learning from risks and should provide the organization with a tool for improvements, according to the experts. One of the individuals noted that the form should look at quality of materials used for mitigations as well, however, the researcher feels those notations should be more at home in a deviation document than a post-risk review. Furthermore it was noted that some of the information required by the review form were not applicable for all risks and would thus be omitted.

Over all, the individuals were positive about the form and its intended use. They noted that this kind of review should be done and the form would be helpful for the organization to reach the milestone of conducting post-risk reviews besides helping the company to learn from its projects. Furthermore, one expert added that the introduction of the possible benefits and support of the hierarchy, e.g. by allowing the project team to get used to the procedural changes, were essential in order to get the project teams to fill out the forms in an acceptable manner. The experts liked the simplicity of the proposed form and noted that filling it out should help the risk team improve its processes and, ideally, lower the required risk budget eventually.

The revised post-risk review form can be seen in appendix E.

9 Discussion
This chapter has proposed a tool which allows risk teams to share and use the codified knowledge residing in the organization. Previously, it was proposed that post-risk reviews would be documented on a regular basis making the reviews a document based method, which is a change from the process based norm of post-project reviews, as presented by Thomas and Thomas (2005), for example.

The suggested risk database could help organizations to improve the risk management part of the process as it requires a post project review to be made, helping the organization to critique its current methods and make appropriate changes. However, it must be kept in mind that a database is only an information medium. The real usability of it depends on the quality of input by the risk team and the support of the company culture where actors can share what went wrong without risking penalties or discharge. Without those two key ingredients, quality input
and culture, the benefits of the tool become next to none. This brings up the question on what risk managers should do with the information in the database. The information can be used as tool to reduce the time needed for the brainstorming sessions as some generic risks can be (at least) partly reused. The information includes knowledge about the successes of mitigation strategies, which helps the management to choose the appropriate response and strategy in each case. As the cost and success rate of mitigations is known, it can be used to support the choice of mitigation strategies and risk responses and help projects become more profitable. Furthermore, the information in the database can be used to look for trends, assess average cost and standard deviation of risk and their mitigations, for example.

Although the model complies with the criteria set by the experts and has been validated by current members of different risk teams, it is important to note that a database can never replace an experienced team member as it is only a repository of knowledge and does not have the insights necessary to apply risk analysis or management in a real life setting.
PART 4

This final part of the thesis concludes the research, answers the research questions and identifies limitations and areas for future research.
10 Concluding arguments and recommendations for the future

This chapter will tie up loose ends left by the previous chapters, answer the research question and sub-questions, identify possible limitations to the proposed solution and recommend areas for further research.

The first step towards improved risk process is to start conducting post-risk reviews to get actors familiarized with the new procedures. It is expected that some change resistance will take place which makes careful explanations of the future benefits of the model important as those are only available if good quality post-risk reviews are made. The reviews should be filled out by one or two persons; e.g. the person responsible for the risk, i.e. the risk owner, and the risk manager, so it stays short, concise and takes as little time as possible. A person capable of helping the project team to fill out the reviews should be available in the beginning while actors are getting accustomed to the form. To get the new process starting it is advised to only make the reviews in the large scale projects (>€100M) for the top 20 or 30 risks while actors are getting used to the new process. During this start-up phase the players will learn the new procedures and imperfections of the process can be smoothened out.

The company culture needs to adjust to the new addition to the process and, as noted before, for that the support of the organizations hierarchy is of utmost importance as without it the project is unlikely to be a success. Furthermore, as construction projects generally span over several years, it will take time for enough information to be gathered and stored in the database. This means that the benefits of the database itself will not come to light immediately but gradually as the number of reviews and projects increase. However, the benefits of documenting the lessons learned should be attained sooner as the project team can critique its decisions and improve its processes accordingly.

As a risk database is based on reviews of past projects, it can be argued that its usability in new and innovative projects is limited. This logic can be answered by pointing to chapters 2.1 and 3 where it is noted that although projects might be different, there is usually some elements that can be shared between projects. For unique, one off projects the database itself might not be of much help but the change in the process which starts by writing post-risk reviews can help the project team to critique their decisions and receive feedback on regular basis.

The risk process
The most notable difference between the two methods of risk analysis, and risk management, PMBoK and RISMAN, is in the first step. The system description, where the foundation for the analysis is laid (see page 13) is a vital step, or as dr. van Staveren put it in his interview, “if you don’t have your objectives clear, you don’t have risks”. This step is completely omitted in the PMBoK method which starts the process without determining the scope and goal of the analysis which makes the real applicability of the method questionable. Furthermore, the risk process is even more iterative in practice than Figure 8 suggests as changes are constantly made to the risk register to keep it up to date by removing the risks that are no longer applicable, adding new ones or changing the mitigation strategies, for example.
Case studies were conducted to familiarize the researcher with the risk processes in place at BAM. The studies, a short comparison of risks, took a considerable amount of time for the researcher. In fact, the projects studied were limited to two as the third risk register proved to be too complex and difficult to maneuver which made its inclusion impossible. The excluded register, in the form of a risk fault tree can be seen in appendix G. The exclusion of one of the projects only supports the notion of why construction companies should improve the risk processes currently in place as more standardization and transparency is needed to facilitate sharing, and learning, within organizations. Although the projects and experts differ in many ways, the risk registers show that there are some similarities that can be shared even though the focus of the case study in this paper was only on cables and pipelines. For example, the things that appear simple, such as appointing a specialist overseeing excavation works (as is done at the A4 project), have proved to reduce the number of risks firing. This should serve as an example for future projects.

“Culture eats strategy for breakfast”
The tool introduced in this paper is useless if it does not get the support required from the organization’s hierarchy. A cultural change is needed in order for the post-risk review to be systematically implemented and the backing of the right individuals is vital to support the implementation of the database. The quote, accredited to Peter Drucker, “culture eats strategy for breakfast” serves as a good example of the real power culture has on the implementation of strategy which holds the key to get actors to share information as well as receiving and implementing it. Furthermore, the organization needs to be open to project team members to share their views about areas possible of improvement. However, the company culture can never eliminate the differences in interpretation of data by the personnel. These differences in interpretation are difficult to handle which makes the proposed tool only a helping hand in the risk process. It can provide valuable information but that information should only be used as an input in the risk process and never as a fully formulated risk event. The idea behind a database based on the proposed model is, therefore, not to replace any members of the risk team but to help them make decisions based on previous experiences in the organization and to speed up the process. Experienced personnel will always play a key role in the risk process as they have the insights needed for a successful execution of projects.

Expert opinions
It is interesting to see how risk management is perceived in the field. Before the interviews were made, it was expected that risk management would be considered a waste of time by some project actors. It was therefore surprising that only one interviewee mentioned that view sometimes being present on site. Of course, that does not mean that there is no one who thinks that way but just maybe people are starting to think about risk management as an effort to prepare projects for what could happen instead of a tool to predict the future.

All interviewees agreed that documentation of the risks fired, as proposed in this paper and the literature, is a necessary first step in the improvement of the risk management process, which is considered to be the weakest link in the risk procedure. Having a tool at hand that takes those reviews, or evaluations, and enables the users of the future to look up previous experiences would most likely improve the current processes. The risk managers could also find support, or
criticism, on their proposed mitigations by looking back through history. They furthermore add that a systematic data collection can supply the organization with information about its processes and identify areas for improvement, and also allow for better statistical evaluation, and comparison, of projects. The biggest advantage offered by a database, according to the experts, would be the possibility to search through risk registers of other projects, to be able to motivate decisions by providing historical evidence and to look for inspiration for solution to problems.

10.1 Research questions answered
In order to be able to fully answer the main question, the following sub-questions need to be addressed first:

1. What are the difficulties concerning the current risk management process?

The literature suggests that the documentation of risks is lacking in many organizations. This is especially true when it comes to the last step of the risk management process, where organizations are required to document the lessons learned from projects. By not completing the risk management cycle, companies miss out on potentially value adding information which could improve their profitability, or increase quality, in the future for instance. This is supported by the experts interviewed who some stated that almost no documentation takes place which is focused on the risks fired. Additionally to that, two of the experts noted that there is evidence of a gap between risk analysis (steps 1-4 in the RISMAN method) and risk management (steps 5-8 in the RISMAN method) as risk management is less developed than the risk analysis.

The reason why this last phase of risk management is often omitted is the tendency to move employees from one project to another under the pretense of optimizing the allocation of resources. This is usually done right when a certain milestone is achieved, making evaluations or reviews of past performances hard to accomplish. Furthermore, as the risk process is conceived today, a post-project review is thought of as a stand-alone process executed at the very end of a project, requiring additional work and taking up valuable time, the most scarce of resources. Although many companies do not systematically require reviews or evaluations to be made, those who do might not have a guideline in place for the review to follow which can result in an unsystematic process, taking place at the end of the project. In that case, the memory of the participating individuals has most likely decreased which can result in important details being missed in the review. Making a review that is suitable to share with the organization can also be perceived as a daunting task, especially if a lot of work is put into it and the result is then never used.

2. What are possible solutions to these difficulties?

The most straightforward solution, according to both literature and experts alike, is the implementation of obligatory post-risk review, or a similar evaluation, where risk occurrences are documented and compared with the risk analysis predictions at the earliest convenience. To fully get the benefits of such evaluations, its results and the lessons learned, the outcome should be shared with others in the company. This makes a platform where information sharing is facilitated, a necessity. It is not enough to save the documents in a central server accessible to all
but a tool must be built that is capable of extracting knowledge from these reviews, helping the risk analysis and management alike. The main objective of this tool is to improve knowledge sharing within the organization as the data provided by it is based on information from past projects and project teams. This objective is reached by providing current risk analysts and managers with information based on historical data to stimulate the brainstorming sessions, reduce the amount of time needed for those sessions and provide information on the most dangerous, most expensive or most time consuming risks (or the positive opposites) in the past. In addition to that, the post-risk review form proposed requires key team members to be identified so individuals with similar risks in different projects can get in touch and gain improved insights into the problem, if necessary. The review does not have to add any significant workload on personnel as it can be a web-based form filled out during risk update sessions, incident reporting or once a project phase is finished.

The IT possibilities explored in the previous chapters of this paper can be categorized in two categories, solutions built on codification and solutions built on personalization. It has also been shown that the personalized approach is better suited for strategic problems which each require individual solutions. Those types of solutions consume more time and money of both the client and the organization but relieves the personnel from writing reviews on topics perhaps too complicated to put into words. The codification strategy is better suited for organization that partake in an industry where projects are of a more repetitive nature. The solution to the problems currently facing construction companies like BAM should, therefore, be based on codification.

3. In what way can a solution be implemented in practice?

As has been said previously, the company culture must support any changes made to current practices if they are to be implemented. The change in culture must incorporate sharing and receiving new knowledge as well as making reviews, or evaluations, on regular basis. The changes in the process need to be made gradually, and be given time to become a habit. Immediate results should not be expected and the process not hurried, in which case the process can be perceived as forced and thus gain adversity amongst actors.

The first step in the change is to require the project team to fill out a form, such as the one in appendix E, on a regular basis – the post-risk review. The form needs to be simple and structured, where the input needed from the individuals is clear as well as having areas where people can freely write their perception of the risk event, and its source, for example. The review reduces the need for knowledge to be shared via word of mouth and increases the circulation of the knowledge through the database. The database needs to be able to work flawlessly with the risk management software in use at each moment in time and use recent improvements in computer learning. Although computers are able to learn, they are quite far from knowing language like humans do, therefore some standardization by the risk managers is necessary, e.g. using key words in the description of cause and effect of a risk event. If the database can be built into the current software it should not add much additional cost to the maintenance of the software and minimize the learning effort needed by its users. However, a gatekeeper whose function is to keep the database clean, i.e. to make sure reviews are filled out.
correctly and of sufficient quality, might be necessary. Adding to that, a database can serve as a platform to share experiences and knowledge, which is especially important as risk managers often work on site and seldom meet. This sharing can improve risk management of the organization in question as risk managers all have the knowledge, or the tool to gain the knowledge, of lessons learned in projects and can thus implement them on their own projects. In addition, it is important to note, as mentioned in chapter 2.5, that the changes in the risk process, e.g. implementing the post-risk review, needs to generate benefits that cover the additional cost incurred but it also important to keep in mind that it takes time for a knowledge base to be built and thus should direct organizational benefits not be expected immediately.

Now, once the sub-questions have been answered leaves only the main question to be addressed:

*In what way can a construction company improve its risk management process?*

The answer to sub-question a. shows that the risk management part of the risk process is not as well established as the risk analysis part of the process. The first step towards a solution is making reviews, or evaluations, on a regular basis to close the learning loop. These reviews can take place after each project phase or once a month and require the risks fired, or risks prevented, to be documented in some detail. The first benefit of this documentation is that individuals can reflect on the positives and the negatives of the experience, get feedback from the project team and immediately use the lessons learned for the benefit of the project. The second benefit is that this documented knowledge can easily be shared within the organization and consequently used by other project teams where applicable. The third benefit is that analyses of data can be easily achieved. The downside of documenting reviews is, firstly, that people can perceive this as too much additional work and, secondly, if the reviews are not shared, no organizational learning takes place.

To enhance the benefits of documenting the risks in projects, a tool is needed that can extract information from the reviews that identifies new, previously unknown, knowledge and allows the user to find relevant information with ease. A database, or a repository of the knowledge, could store all the codified knowledge and allow tools like data and text mining to find new connections between risks and their expenditure, in time, money and quality. The database could provide information on the correlation between risk maturity and profitability, for example, identify trends, and find reference class projects for the improvement of tender values. For the risk manager, the database could provide information on the most, and least, successful mitigation strategy for certain risks, information on risks connected to a certain client or even if a client is more focused on a specific risk areas, such as the environment. It is important to note, once again, that documenting projects and storing them in a systematic way, such as in a database, will never replace the intuition and expertise of the project team but only serve as a helping hand in identifying, and mitigating, the risks faced by projects, based on historical evidence. A risk database should aid in reducing the time needed to respond appropriately to an event while, at the same time, reduce the pressure on project actors. Additionally, building a risk database with the objective of covering all possible risks for construction projects is next to impossible, not to mention the usability of such database can be questioned.
The documentation of lessons learned in the review can help the organization and other actors to improve the processes and identify actions that could be used as an early warning indicators in future projects. It also facilitates the sharing of information which leads to less amounts of the unknown-knowns as tacit information held by individuals becomes tacit information held by the organizations as the SECI model shows. The reviews can also help the project team to evaluate how they stand compared to other projects and with a tool like a database, it is simple to calculate the average time, cost and standard deviation of the same, or similar, risk event in different projects. The problem with that is, that risk legends, e.g. scores attached to cost, time and probability, is set by the client. This means that there is a possibility that projects have different risk score for otherwise identical risk event, which make using actual values, e.g. cost in euros, a necessity. Another interesting point is the change currently underway in risk cost estimation, from the expert calculations, or guestimates, to level III methods with Monte Carlo simulations — although the simulations are based on expert guestimates. This indicates the willingness of the industry to change from its known, but not so accurate, customs to practices supported by theory.

So, after reading through this thesis it should be clear how organizations can improve their risk management process by closing the learning loop. This can be done at a relatively low cost by starting to implement post-risk reviews for risks fired, or prevented. The review, along with the risk database should help BAM to reach its target of moving the risk process to level 3 on the ISO/IEC 15504-6 (2008) standard on large projects. As said before, Ernst & Young (2012) claim that companies with more mature risk management procedures increase their revenues and EBITDA faster than companies with less mature processes. Documenting, and applying, the lessons learned and improving the risk maturity level of the company can, therefore, both add value to the process and improve the company's bottom line. However, there are still some limitation to the suggested solution and areas that could use further research. These will be looked into in the following sub-chapter.

10.2 Recommendations for BAM Infracosult

For the solution presented in this thesis to be put into practice at BAM Infracosult, there are a few aspects that need to be considered. Those are:

- The new process is introduced to the risk team.
- The benefits of the new process are introduced to the risk team.
- The risk team is open to questions and comments from individuals.
- The risk team implements the comments from individuals where possible.
- The implementation of the post-risk review is started for a limited number of risks.
- The risk managers fill out the post-risk reviews at first.
- The risk owners fill out the post-risk review once the new procedure has been implemented.
- The risk managers support the risk owners while filling out the forms.
- The project team is not disbanded immediately once milestone is reached.
- The project team is given time to reflect on the lessons learned, closing the learning loop.
• The risk database is connected to the risk software in use.
• The usage of keywords is increased in both risk registers and post-risk reviews.
• The database is not used as a replacement for communication with colleagues.

10.3 Limitations and further research
The limitations of the proposed solution are mainly threefold. Firstly, as noted, risks are somewhat based on individual perception which can cause differences in the interpretation of the risk cause, risk event and/or risk consequence. Therefore it is important to keep in mind that the post-risk reviews and the database are only helpful tools to provide feedback and stimulate brainstorming sessions, for example, and will not change the human factor nor take it directly into account.

The second limitation is that it does not lower the chances of a special event, or a black swan risk, firing. These events are so rare and often very difficult, or even impossible, to prevent and as such are more likely to be swept under the rug. If a special event occurs, and a post-risk review is made it stays in the database but is unlikely to be used in other projects due to its rarity.

The third limitation is regarding the one-off project, or projects where new technology is used. During those projects, the usability of the database is limited as it is built on lessons from previously executed assignments. If there are no similarities with previous projects, the new and improved risk process which includes making a post-risk review can help actors to keep a more critical mindset and perhaps, the database can be used to find other unique projects to learn from, e.g. by contacting the project team.

The reliability of the system that is used to build and maintain the database should be researched further as it affects, amongst others, the lifetime of the database which is an important element in the overall benefits of the proposed solution. Furthermore, as text mining is still being researched it could be useful to look at how it best fits the construction sector as it could provide an understanding of the full capabilities of the proposed database. Adding to that, the statistical accuracy of a database, i.e. how many reviews are needed for it to reach a certain confidence level; finding the best way to connect a risk database with reference class forecasting; as well as looking into a possible connection between a risk database and BIM modeling, could be interesting topics for further research. Lastly, research into the cultural aspect of the new process should be researched to identify possible ways for organizations to stimulate knowledge sharing even further.
11 References


Ernst & Young. (2012). Turning risk into results: EYGM Limited.


