Exploring the nature of nonconformities

The development of a procedure that classifies construction project nonconformities into risks and non-risks.

Master thesis

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Colophon

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Preface

In January 2014, I was invited at BAM for a first meeting to discuss a possible graduation project. All I knew was that it had something to do with risks. After the meeting, it was clear that the coming eight months would be dedicated to risks and nonconformities. During this eight months I was supported by many people, who I would like to thank by means of this preface.

First of all I would like to thank Fokke Huisman, as my daily supervisor from BAM. He was literally always available for questions. His unlimited enthusiasm for risk management gave me the right motivation to work on the topic, and his network within the organisation made it possible that I could quickly reach the right people. Because of that I was even able to reach people who were not even working anymore within the organisation.

During this research I got the possibility to critically look at the organisation. This was only possible because of the open attitude of anyone within the organisation. Hence, I would especially like to thank all BAM employees I interviewed, who gave many new insights in my thesis.

I also would like to thank Joop Halman and Saad Al-Jibouri, who were my supervisors from the University of Twente. They were able to find and stipulate the limitations of my work and gave me insights how to tackle them. The feedback they provided me from was useful on all levels, from the full picture to the smallest detail.

Further, I would like to thank my daily colleagues from the department of RAMS/RISK/SE of BAM Infraconsult and of the department of process management of BAM ITM. Due to their presence I perceived my graduation process as very pleasant.

Finally I would like to thank my family and friends for the support during my graduation process. Especially my parents since they welcomed me back home to live at their place during my graduation period. Last but not least: Mimí, thanks for all your correcting works and for being a listening ear.

Enjoy the reading,

Chiel de Wit

Summary

During construction projects, many nonconformities occur. A nonconformity is a non-compliance of a requirement. Often rework is necessary to correct the nonconformity and ensure that is complied with the requirements. Therefore, these nonconformities increase the costs of construction projects and thus construction contractors often strive to eliminate them.

This research was conducted at one of these contractors: BAM Infra. Two problems were identified at contractor BAM. First, BAM developed a risk database in which risk data of finished construction projects is collected to be used as input for future projects. However, risk data of unidentified occurred risks is not included in this database and BAM does not know what unidentified risks occur. Second, BAM strives to eliminate their nonconformities, in order to eliminate nonconformities, insight in the nature of nonconformities is necessary and BAM does not have this insight.

While combining both problems, classifying nonconformities into risks and non-risks can contribute to a solution of both problems. It can provide insight into the nature of nonconformities and the nonconformities that are classified as risk can be unidentified risks and included in the database. Therefore, in this research a procedure is developed that determines in a few simple steps whether a nonconformity is a risk or not. The main question of this research is hence: What procedure can be developed in order to classify nonconformities into risk and non-risk?

This procedure can be used by many contractors to obtain insight in the nature of nonconformities. Moreover, it can be used by contractors to identify unidentified occurred risks. These risks can be included in a database to be used as input at future projects. In addition, this research contributes to the gap in literature by a new approach to classify nonconformities with a risk management perspective.

Method

First, a theoretical procedure was developed using the results of a literature study. This procedure was empirically tested on samples of documented construction project nonconformities. The insights obtained during these tests were used to adjust the procedure, resulting in an empirically tested procedure. This procedure was tested on the nonconformities of four construction projects. Two types of tests were performed, reliability and validity tests. The reliability tests were performed to obtain insight in whether the procedure provides comparable results when performed by two persons of the same nonconformities. The unreliability is considered to be high if the percentage of disagreement is higher than 15%. The reliability tests were performed on a sample of 100 nonconformities of two projects. During the validity tests all documented nonconformities of three projects were analysed, the results were used to obtain the validity of the procedure and determine the results of the procedure. The validity shows whether the results of the procedure are the expected results. Moreover, these tests were used to obtain the results of the procedure.

The procedure

The procedure consists of three main steps, which are divided into sub-steps. Figure 1 shows an overview of the procedure and appendix 1 shows the final procedure. The first step determines if a nonconformity is a risk or not and consists of four simple questions that need to be answered for each nonconformity. The second step selects the nonconformities that are risks and concludes if these risks were identified. The third and last step answers the question why the unidentified risks were not-identified in advance. This data can be used to improve the risk identification of future projects. The nonconformities that are non-risks can be

managed by improving standard processes, while the nonconformities that are risks can be approached through risk management.

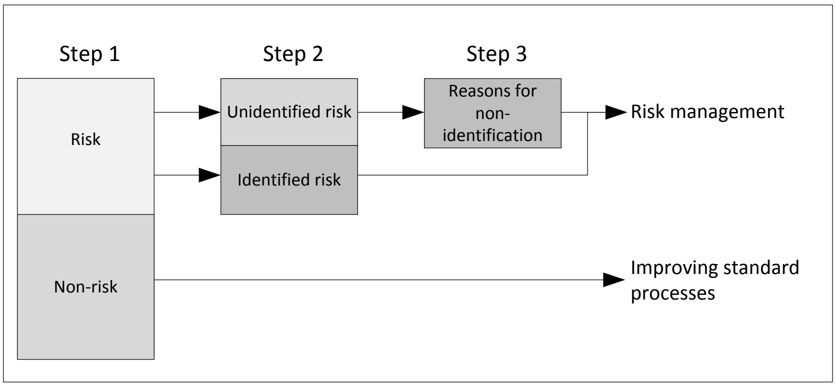

Figure 1 Overview procedure

Testing the procedure

The reliability results of the second project show an unreliability of the sub-steps of step one between 10% and 34%. When looking at the validity, the nonconformities that are risks are both identified and unidentified risks. The results of the three analysed projects show that the nonconformities that are not risks are on average 85% of the total impact. Eliminating these nonconformities that are no risks can lower the costs of projects by 1,2%. A total amount of 32 unidentified risks were identified out of 2116 nonconformities, of these risks the reasons for non-identification show no patterns.

Conclusions and recommendations

It can be concluded that the reliability of the procedure is low, the unreliability is higher than 15% for some of the steps. The unreliability can be explained by the low quality of the data that was used as input. The documented information did not contain clear information of the nonconformities, leaving space for interpretation. If the procedure is implemented, it is recommended to perform the first step of the procedure during the project directly after nonconformity occurred. Additional information is then available, by the responsible person.

In contrast, the validity is sufficient. The risks are in fact risks. However, it was not validated whether the non-risks are in fact non-risks. Further research can be performed to test this.

The results provide insight into the nature of nonconformities and the nonconformities that are risks can be included in a risk database. Because relatively few unidentified risks were identified it is recommended to perform the procedure at more and different types of projects. For BAM it is recommended to focus on the improvement of standard processes, since the category with the highest impact are these risks.

Thus, the developed procedure classifies nonconformities into risks and non-risks. It can be used to provide insight into the nature of nonconformities. It also identifies unidentified risks that can be included in a database. It provides a new approach of classifying nonconformities.

In order to successfully implement the procedure within the organisation, it is recommended for BAM to improve the way nonconformities are documented. It was determined during the research that nonconformities were not always documented completely; this could have affected the results of the results. The improvements should therefore result in clear unambiguous descriptions of nonconformities.

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Terminology

The terms below are often used in this research:

Mitigation measure:	Risk mitigation seeks to reduce the probability and/or impact of a risk to below an acceptable threshold (PMI, 2000). Two types of mitigation measures can be distinguished, cause oriented and effect oriented mitigation measures. Cause oriented measures tend to influence the cause of a risk. Effect oriented measures tend to influence the effect of a risk (van Well-Stam, Lindenaar, van Kinderen, & van den Bunt, 2003).
Nonconformity:	A non-compliance of stated, obligatory or generally implied requirements (see §3.1.2).
Non-risk nonconformity:	A nonconformity that is not an occurred risk. It is the result of (wrong) execution of standard processes. It can be managed by improving standard processes.
Quality:	Conformance to specifications (see §3.1.1).
Requirement:	Need or expectation that is stated, generally implied or obligatory (ISO, 2005). A requirement can be defined of a product, process or service (Burati, Farrington, & Ledbetter, 1992).
Risk:	The likelihood for an effect on the project objectives, caused by limited knowledge (non-frequent) within a project. Project risks can have a non-influenceable or influenceable cause (see §3.2.1).
Risk management:	The systematic process of identifying, analysing, and responding to project risk (PMI, 2000).
Risk nonconformity:	Nonconformity that is an occurred risk. Risk management can be performed to manage them.
Risk register:	Register that contains project specific risk information it contains the identified risks (Cárdenas, Al-Jibouri, Halman, van de Linde, & Kaalberg, 2014). Risk data of individual risks is collected in the risk register. Such as: cause description; effect description; quantification of the risk and probability of occurrence.
Uncertainty:	Variability, where the system/process under attention can react in multiple ways and/or Limited knowledge, which is a property of the analysts performing the study and/or of our state of knowledge (§3.2.1).
Limited knowledge (epistemic uncertainty):	A property of the analysts performing the study and/or of our state of knowledge. Uncertainty based on limited knowledge does not necessarily decrease when more information is acquired. More information can even increase uncertainty since new information can decrease understanding. It can invalidate understandings of systems or processes (Van Asselt & Rotmans, 2002).
Variability (aleatory uncertainty):	The system/process under attention can react in multiple ways. This is also referred to as 'stochastic uncertainty' (Helton, 1994, cited in Van Asselt and Rotmans (2002).
Unidentified risk:	A risk that has not been identified, and has not been documented in the project risk register. Those risks can be distinguished in two types, based on their underlying uncertainty: unidentifiable unidentified risks and identifiable unidentified risks (see §3.2.2).

1. Introduction

The picture on the front page shows a construction project in its execution phase. During this execution phase often nonconformities occur. For instance, sheet pile leakage. After sheet piles are driven and the pit is excavated it can be discovered that the sheet pile is leaking. This situation, in which a product (sheet pile) is constructed and afterwards it appears that not is fulfilled to a requirement (no leakage), is called a nonconformity. After a nonconformity occurs often rework is necessary to ensure that the final product complies with its requirements. Many of these nonconformities occur during construction projects. In case of the example of the sheet pile, some measures can be taken to stop the leakage. These measures increase the costs of construction projects and therefore construction contractors often strive to eliminate them.

BAM is one of the contractors that strive to eliminate nonconformities, this research is performed at BAM. It is a European contractor, which is active in the sectors construction and mechanical and technical services, infrastructure, real estate and public private partnerships. BAM Infra is the Dutch infrastructure contractor of BAM. BAM Infra consists of the infrastructure companies: BAM Civil, BAM Rail, BAM Roads, BAM Infra Technique, BAM Infra Asset Management and BAM Infraconsult. This research is conducted at the department of RAMS/Risk/SE of BAM Infraconsult, which is the engineering company of BAM Infra. The department RAMS/Risk/SE facilitates the risk management of large multidisciplinary projects starting with a turnover of approximately 10 million euro.

Van Staveren (2014) states that good risk management results in less nonconformities of safety and quality. Therefore, BAM performs risk management. The risk managers, who facilitate the risk management within BAM Infra, ensure that the risk management process is performed correctly. Risk management is the systematic process of identifying, analysing and responding to risk and its incorporated uncertainties (PMI, 2000). As reported in their annual report of 2013, BAM strives to intensify their risk management practice. Therefore, BAM formulated strategic objectives in their annual report. Two of these objectives are an accurate and complete identification of key opportunities and threats at strategic, tactical and operational levels; and supporting a learning and sharing environment (BAM Group, 2014, p. 17).

BAM Infraconsult developed a risk database in order to contribute to these two strategic objectives. In this database, risk data of completed construction projects is collected. Future construction projects can use this information as input for the identification, analysis and mitigation of risks. Figure 2 illustrates that the total project risk consists of identified risk and unidentified risk. Both identified and unidentified risks can occur. The identified risks are included in the database. However, unidentified occurred risks are not included in the database. The unidentified not occurred risks will remain unknown; there is no effect of these risks on the project objectives. However, the unidentified occurred risks can possibly be identified because of their impact on the project objectives. It is therefore important to include these risks in the database. In the current situation it is unknown what these risks are, they are not included to the database and not used as input for the risk management of future construction projects. Consequently, recurrence of the same unidentified occurred risks at future construction projects is possible. However, BAM does not know what these risks are.

To prevent the afore mentioned nonconformities from occurring BAM also performs Quality Management. Quality management concerns the optimisation of the quality activities involved in producing a product, process, or service (Burati et al., 1992). An example of a quality management activity is the development and improvement of standard processes within the organisation. Moreover, quality management standard ISO 9001 requires nonconformities to be detected, corrected and prevented from recurrence during the execution phase of a construction project. Within BAM the QA/QC[1] manager is responsible for the quality management at construction projects. Unless BAM performs quality management, still nonconformities occur. Although some of these nonconformities have a positive effect on the project objectives (for instance if the client requests to not-conform to a requirement), most of the nonconformities have a negative impact on the project objectives. In order to eliminate these negative nonconformities, insight in the nature of the nonconformities is necessary. Within BAM there is little or no insight of the nature of these nonconformities. An analysis of the nonconformities to obtain their nature can provide BAM from useful information about how to eliminate them in the future.

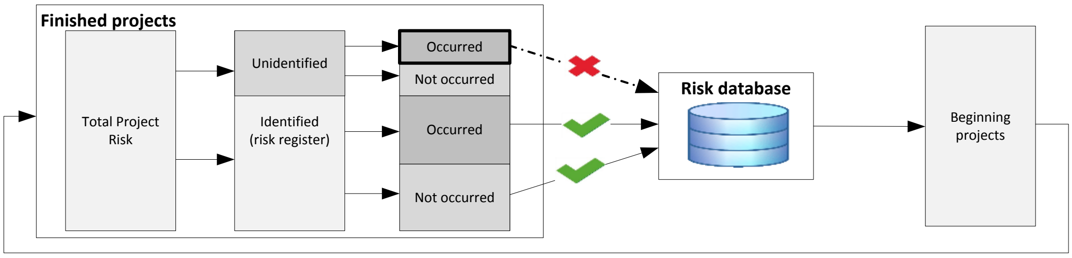

Figure 2 BAM and the risk database without unidentified occurred risks.

In summary, BAM has two problems. First BAM does not know what the unidentified occurred risks (further called: unidentified risks) are. Second BAM has no insight in the nature of their nonconformities. While combining these problems, it can be questioned whether nonconformities can be classified into risks and non-risks. This can provide insight in the nature of nonconformities, namely risks and non-risks. If many of the nonconformities are occurred risks, it can indicate that the risk management process should be improved. If many of the nonconformities are non-risks, it can indicate that the execution of standard processes should be improved. It can also provide from unidentified risks, because the nonconformities that are classified as risks can also be unidentified risks. These unidentified risks can be included in the risk database and be used as input for future projects.

Preliminary research

Within BAM Infra there is no insight in whether the nonconformities can be classified as risks or non-risks, and because of the large amount of documented nonconformities of one project (a nonconformity register can contain more than 500 nonconformities) it is not readily possible to make this analysis. Therefore, a preliminary research was performed using a sample of nonconformities.

The results of this preliminary research (appendix 2) show that nonconformities can be classified into risks and non-risks. During the preliminary research the two risk managers of a construction project classified a sample of 200 nonconformities into risk and non-risk. The results show that some of the nonconformities are occurred risks (further called risks) and other nonconformities are no risks. Some of the nonconformities that are risks are unidentified risks. However, the disagreement between the risk managers who classified the nonconformities was high, there was a disagreement of 26% of the nonconformities. Next to this disagreement, it can also be discussed whether all nonconformities that were classified as risks are in fact risks. Therefore it is concluded that a procedure is necessary to classify nonconformities into risks and non-risks.

[1] QA/QC stands for Quality Assurance and Quality Control

Thus, this research proposes a procedure that determines, in a few simple steps whether a nonconformity that has occurred is a risk or not. This procedure is developed based on the results of a literature study and empirical tests on construction project nonconformities. Risk managers[2] are the intended users of this procedure. The procedure has relied on information from three infrastructure projects and uses documented nonconformities as input. The input is obtained from nonconformity registers of construction projects. In these registers, information of nonconformities is documented. Of this information the procedure uses: cause, effect, correcting measures (to correct the nonconformity) and preventing measures (to eliminate the cause of the nonconformity).

Relevance:

This research can be relevant for any contractor within the construction industry, because it strives to provide insight in the nature of nonconformities. With this insight a first step can be made into eliminating the nonconformities. The nonconformities that are unidentified risks can be included in a database to enable managing them at future projects. Documenting nonconformities in a nonconformity register is one of the requirements of standard ISO 9001 and contractors of large infrastructure projects are obliged to be ISO 9001 certified (Rijkswaterstaat, 2014). Therefore, large infrastructure contractors document their nonconformities in a comparable way. Dutch contractors Heijmans, Ballast Nedam, Volker Wessels and BAM all document cause, effect, and measures of nonconformities and many more infrastructure contractors are ISO 9001 certified. This research will use that information of nonconformities and therefore the procedure is widely applicable by these infrastructure contractors.

The procedure is also theoretically relevant since little research has been carried out on this subject, and a procedure that classifies nonconformities into risks and non-risks has not been developed before. Much has been written about the causes and the costs of nonconformities (Abdul-Rahman, Thompson, & Whyte, 1996; Burati Jr, Farrington, & Ledbetter, 1992; Love & Li, 2000; Love, Manual, & Li, 1999). Nevertheless, little literature is found about the relationship between nonconformities and risk. For instance, Josephson and Hammarlund (1999) determine risk as one of the causes of nonconformities. In contrast with Josephson and Hammarlund (1999), Aven (2014) states that all nonconformities are consequences of some type of risk. This research does not consider all these types of risk as risk and contributes to the research of Aven (2014) by providing empirical data of classifying nonconformities.

[2] Risk managers are the intended users of the procedure because of their affinity with risks, they can be assisted by the QA/QC manager, who has affinity with nonconformities.

2. Research design

This chapter contains the research design which describes the problem, the objective and how this objective was achieved. It defines the deliverables of this research (Verschuren & Doorewaard, 2007).

First the research problem is defined using the results of the preliminary research (§2.1). After that the objective of this research is determined (§2.2). It is followed by a description of the scope (§2.3). The main research question is described using the problem and objective. This main question is divided into several sub-questions (§2.4). Finally the method of this research is described (§2.5).

2.1. Problem definition

Two main problems were identified within BAM:

During construction projects, occurred nonconformities are recorded in nonconformity registers. These nonconformities often lead to rework and increase the costs. In order to be able to eliminate the nonconformities insight in the nature of the nonconformities is necessary. However, within contractor BAM there is little or no insight in the nature of the nonconformities.

The second problem concerns the risk database. This database, in which risk data of completed construction projects is included, does not include data of unidentified occurred risks. It is unknown for BAM what unidentified risks occur. Therefore, recurrence of these risks at future projects is possible.

Combining these two problems results in the following problem definition:

As a construction company, BAM does not know what unidentified risks occur during construction projects and there is little or no insight in the nature of the nonconformities that are documented during construction projects.

2.2. Objective

The objective of this research is divided into two parts: the objective **of** this research project and the objective **within** this research project.

Objective of this research project:

To provide insight in the nature of nonconformities.

Objective within this research project:

To develop a procedure that classifies nonconformities of construction projects into risk and non-risk.

2.3. Scope

This research is limited to investigating documented nonconformities. As a consequence, the nonconformities that are not documented are not included in this research.

This research focuses on the risks concerning the project objectives(financial, time, quality). Within the construction industry, often three types of risk management are applied. Risk management that focuses on the reliability and availability of products; safety risk management where is focused on personnel safety; and the risk management that focuses on the project objectives. This research focuses on the risk management concerning the project objectives.

2.4. Research questions

The central question of this research is:

What procedure can be developed that classifies nonconformities into risk and non-risk?

The following sub questions were derived from the central research question:

1.1. What are the theoretical conditions for a nonconformity to be considered as risk?	Chapter 3
1.1.1. What is a nonconformity? 1.1.2. What is an unidentified occurred risk? 1.1.3. When is a nonconformity a risk?	
1.2. What empirically tested procedure can be developed that classifies nonconformities into risks and non-risks?	Chapter 4
1.2.1. How do risk managers classify nonconformities using a simplified version of this procedure? 1.2.2. How does the theoretical procedure work in practice? 1.2.3. How do experts judge the usability of a procedure that classifies nonconformities into risks and non-risks?	
1.3. Is this procedure valid and reliable?	Chapter 5 and 6
1.3.1. What is the reliability of the procedure, when performed by risk managers and QA/QC managers? 1.3.2. What is the validity and what are the results of the procedure?	
1.4. How can this procedure be used within the organisation?	Chapter 7

2.5. Method

In this section, the research strategy and data collection of each research part are discussed. First the literature study is described, then the development of the empirical procedure is elucidated. After that, it is described how the procedure was tested. Finally it is described how the conclusions are drawn and the report is finalised. Figure 3 shows the research model, which incorporates all steps of the procedure.

2.5.1. Literature study

A literature study was performed in order to answer the first sub question. The literature that was analysed consisted of books and scientific literature. The literature was searched using scientific search engines; Scopus was used as the main search engine. Specific articles were searched using Sciencedirect and Google scholar. In addition, articles and master theses were extracted from the Blackboard site "platform risk management" from the University of Twente. The search terms that were used are described in appendix 3.

2.5.2. Development of empirical procedure

During the empirical research, a focus group study was performed and finally expert interviews were performed.

Focus group

Firstly, a focus group research was performed to answer research question 1.2.1. How do risk managers classify nonconformities using a simplified version of the procedure? During the focus group research it was determined whether the theoretical steps are all necessary for risk managers as intended users to classify nonconformities into risks and non-risks.

First project nonconformity registers and risk registers were studied. Twenty-four nonconformities were selected from the nonconformity register of a multidisciplinary project. Three questions of each of these nonconformities were answered by ten risk managers.

- What is the impact (no impact, low, middle, high)? The higher the impact the higher the risk. Because the impact of nonconformities is not documented in the nonconformity register, this question was asked to determine whether risk managers are capable of estimating the impact.
- Is the nonconformity an occurred risk?
- Would you register it as risk in the risk register of your project?

If the results of each of the questions show a high disagreement between the risk managers, it indicates that a simplified version of the procedure does not provide the desired results. The answers of these questions were discussed during a focus group discussion with five risk managers.

Tests on samples of nonconformities

The theoretical procedure was tested on samples of nonconformities of a multidisciplinary project in order to answer research question 1.2.1: How does the theoretical procedure work in practice? These tests resulted in the draft procedure.

Expert interviews

The draft procedure was discussed during semi-structured interviews with eleven experts. During these interviews the research problem was discussed and all steps of the procedure were discussed. The interviews resulted in the answer to research question 1.2.2. How do experts judge the usability of the procedure? The experts that were interviewed were risk managers, QA/QC managers, project managers and directors. Appendix 4 shows a list of interviewed persons.

2.5.3. Test procedure

The procedure that was developed was first tested on reliability. After that the procedure was tested to obtain the results, these results were also used to conclude the validity of the procedure.

Reliability

The reliability of the draft procedure was tested. Reliability is the extent to which a measurement gives results that are consistent when the entity being measured has not changed (Leedy & Ormrod, 2010).

The reliability was tested on two representative multidisciplinary infrastructure projects. The main project type of project one is roads, and of project two the main project type is civil works. The contract value of both projects is high: 120 million euro for project one and 207 million euro for project two. Because of their size and the focus of different disciplines can be concluded that these are representative large multidisciplinary projects for the organisation.

To test the reliability, the risk manager and QA/QC manager of the project, performed the procedure for a randomly selected list of 100 nonconformities of the project under consideration. Then, the results of the risk manager and QA/QC manager were compared. Fewer differences indicate a higher reliability. The risk manager and QA/QC manager were interviewed separately to determine the reasons for the differences. After the reliability test on project one, the procedure was changed using the reasons for the differences between the QA/QC manager and risk manager of project one.

The reliability is considered to be low if less than 85% of the nonconformities are classified equally. This because during the preliminary research both risk managers classified 74% of the nonconformities equally. 85% will therefore indicate an improvement of the reliability.

Finally a cross case analysis was performed to determine the differences between the first and the second project.

Validity test and test the results of the procedure

After conducting the reliability test on project one a concept procedure was developed. This procedure was tested on validity. The validity is the extent to which the instrument measures what it is intended to measure (Leedy & Ormrod, 2010). The procedure was also tested to determine the results of the procedure. By performing the procedure on construction projects both results were gathered.

The tests were performed on three representative multidisciplinary projects. Project one, project three and project four. The main project type of project one is roads. The main project type of project three is rail and the main project type of project four is civil works. The contract value of the three projects is high, 120 million euro for project one, 171 million euro for project three, and 141 million euro for project four. Because of their size and the focus on different disciplines, it is assumed that these are representative large multidisciplinary projects for the organisation.

The procedure was performed for all documented nonconformities of these three projects. This study was performed by the author because the analysis is very time consuming. Ideally the procedure is performed by the future users, the risks managers, however this is expensive due to the time consumption. Therefore, the author performed the analysis of all nonconformities.

The nonconformities that were unknown for the author, were discussed with the risk manager. To check the results of the author, the project risk manager performed the procedure on a random sample of 10% of the nonconformities. In case of no or little differences (<10%) between the results it was concluded that the results of the author are sufficient.

The results of the procedure were identified and unidentified occurred risks. With these results the validity can be tested: it is an indication that the results are valid if identified occurred risks are the result of the procedure, because the procedure tends to classify nonconformities into risks.

The project risk manager was interviewed concerning the unidentified risks.

The results of each project were analysed to determine the nature of the nonconformities. Thus, which nonconformities are risks and which are non-risks. In addition a cross case analysis was performed after the results of the three projects were collected. This analysis was performed in order to map patterns between the three projects. The validity results of the three projects was used to determine the overall validity.

2.5.4. Conclude

After the validity tests were completed, the results were discussed and the central research question was answered. Finally, the report was finalised.

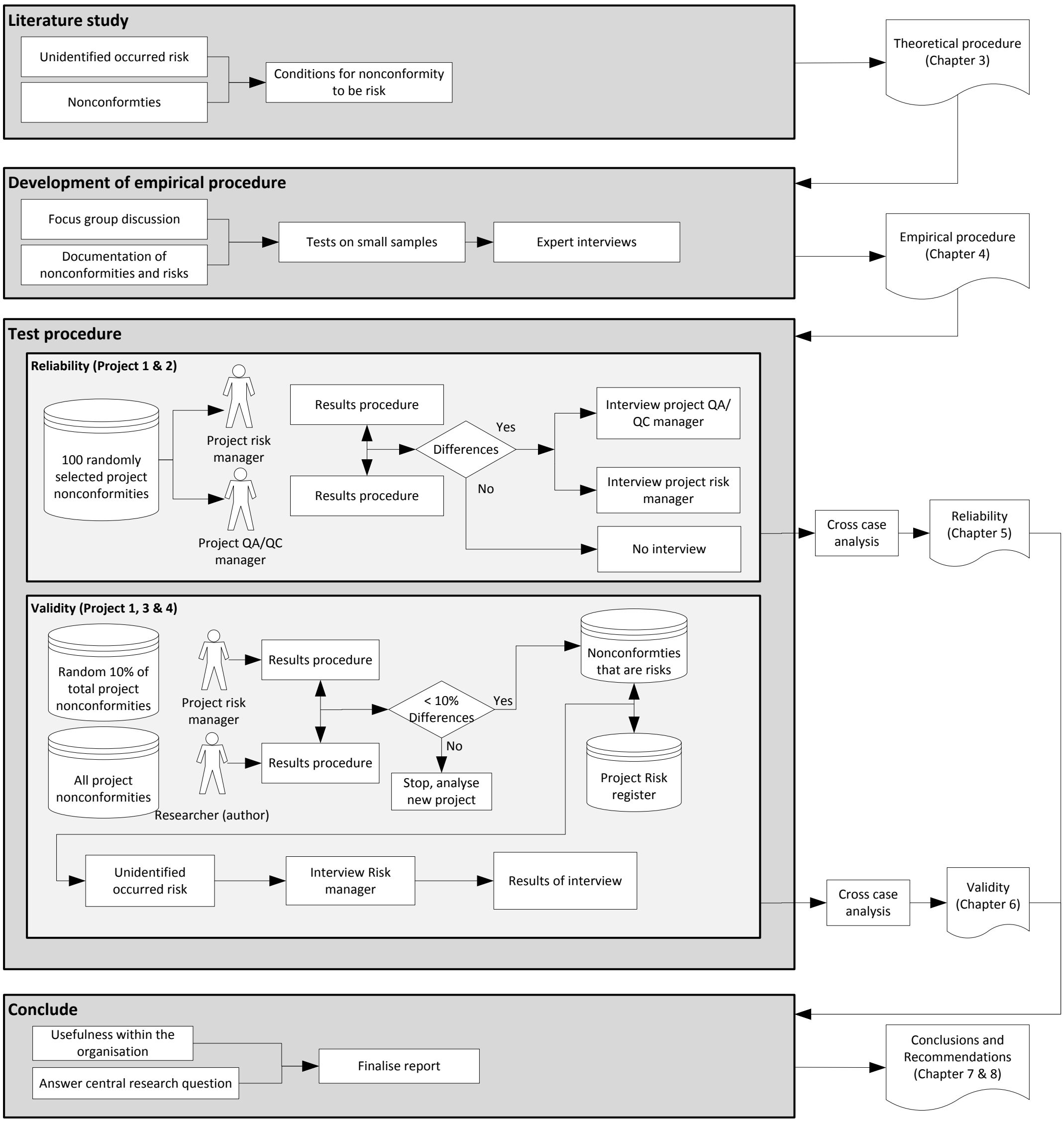

Figure 3 Research model

3. Theoretical Background

This chapter contains the results of the literature study that was conducted to determine the theoretical conditions for a nonconformity to be considered as risk. First nonconformity and risk are defined. After that is elaborated on reasons for non-identification that can be assigned to unidentified risks. Finally, the conditions for a nonconformity to be a risk are determined.

3.1. Defining nonconformity

In this section nonconformity is defined. Because documenting nonconformities is part of quality management, first the concept of quality is discussed, followed by an elucidation of the concept of quality management. Consequently, nonconformities are defined.

3.1.1. Quality management

This section elaborates on the concepts of quality and quality management.

Quality:

Multiple definitions of "quality" can be found in literature:

- "Fitness for use" (Juran, 1951)
- "Quality is resulting from the integrated effects of four attributes: serviceability, safety, durability and compatibility" (Bea, 2006)
- "Conformance to established requirements" (Crosby, 1979) (Burati et al., 1992)

Two of the three definitions define quality in terms of fitness or conformance to "something". Juran (1951) defines this "something" as use, Crosby (1979) and Burati et al. (1992) define it as requirements. It is possible that a product can be used, but does not fulfil all the requirements. For example, a bridge without a hand rail is fit for its primary use but it can be imagined that it does not fulfil all its requirements.

The definition given by Bea (2006), can be used without measuring quality to established requirements. Products with high serviceability, safety, durability and compatibility have a high quality. This definition differs from the definition of Burati et al. (1992), who define quality as conformance to established requirements, while Bea (2006) defines quality as a more "stand alone" definition that can be used without measuring it against established requirements. The serviceability, safety durability and compatibility of a product can be seen as general functional requirements for each product. The definition of Bea (2006) is therefore more specific than the other definitions.

Concerning these differences Reeves and Bednar (1994) point out that a universal definition of quality does not exist. Moreover, the different definitions of quality are inconsistent. ISO attempted to make a universal definition for quality: "a degree to which a set of inherent characteristics fulfils requirements". A requirement is a need or expectation that is stated, generally implied or obligatory. In this definition, quality is measured compared to a set of characteristics (ISO, 2005). The better it complies with these characteristics, the higher the quality.

Nevertheless as Reeves and Bednar (1994) point out, each quality definition has its own strengths and weaknesses. Next to that, the definition of quality can differ regarding the type of person using it. Managers need a different definition of quality than consumers. This is supported by Juran (1998). He stipulates that it is unlikely that the definition "fitness for use" can provide enough information for managers needing to take action concerning quality.

Reeves and Bednar (1994) explicate four quality definitions that are the roots of all other definitions:

- Quality is excellence
- Quality is value
- Quality is conformance to specifications
- Quality is meeting and/or exceeding customer's expectations

The above given definitions can be used in different situations. This research focuses on infrastructure projects in the construction industry. Quality in case of this research, is often used as a managerial instrument. During the tender phase, contractors specify the quality they will reach in their solution. During the execution phase, the contractor has to prove to the client that the quality they promised is reached, and conforms to specifications. Therefore this research uses the following definition of quality:

Quality is conformance to specifications.

Quality management:

Burati et al. (1992) define quality management in the construction industry: "Quality management concerns the optimisation of the quality activities involved in producing a product, process, or service. As such, it includes prevention and appraisal activities."

Quality management is thus about production, and will take place during the execution phase. During this execution phase, projects, processes or services are "produced" at a certain quality. Quality management is about optimisation of the quality activities. The quality activities are performed to produce the project, process or service at the desired quality.

The appraisal activities that are described in the definition of quality management imply that it is possible that projects, processes or services do not meet the quality required. The next section elaborates on those nonconformities.

3.1.2. Nonconformity

Terms such as: quality deviation, defect, non-conformance and nonconformity are all used to express the same meaning (Abdul-Rahman, 1995; Burati et al., 1992; Love & Edwards, 2005). In literature these words have been interchanged, creating ambiguity (Love & Edwards, 2005). In this research the term "nonconformity" is used.

Multiple definitions of nonconformity can be found in literature:

- "Non-fulfilment of a requirement" ISO (2005).
- "A deviation that occurs with a severity sufficient to consider rejection of the product, process, or service. In some situations the product, process, or service may be accepted as is; in other situations it will require corrective actions".
    - With a deviation being: "a departure from established requirements" (Burati et al., 1992).
- "not meeting quality" (Arditi & Gunaydin, 1997).

All definitions define nonconformity as non-compliance with requirements. Arditi and Gunaydin (1997) refer to not meeting quality, and define quality as conformance to specifications. As stated by Burati et al. (1992) a nonconformity has deviation with a severity sufficient to consider rejection of the product, process or service. If a product process or service does not fulfil its requirements, a logical next step is that it will be rejected until it fulfils its requirements.

An example of a product nonconformity is: "after demoulding a concrete wall it is discovered that the coverage of reinforcement is less than required". The product, the concrete wall, does not fulfil to its requirements. An example of a process requirement is for instance: "it is not detectable that the risk management process is performed as prescribed". The process, the risk management process, does not comply to its requirements. An example of a service nonconformity is: "the road was not opened on time after night construction works". There is not fulfilled to requirement for the service that the road has to be opened on time.

A requirement as defined by ISO (2005) is a "need or expectation that is stated, generally implied or obligatory". A requirement can thus be written down, obligatory (according to standards), or generally implied. Generally implied means that within the sector the requirement is custom or common practice that the need or expectation under consideration is implied.

As a result a nonconformity can be defined for this research as:

A non-compliance of stated, obligatory or generally implied requirements.

As defined by (ISO, 2005) a qualifier can be used for specific requirements, for example: product, process or customer.

A nonconformity has a cause and effect. Studies have been performed about causes of nonconformities (Brunson, 1982) cited in Josephson and Hammarlund (1999). After a nonconformity has occurred, often rework is necessary to recover it (Ashford, 1992).

Quality management standard ISO 9001, prescribes that nonconformities have to be detected, corrected by the contractor or accepted by the client, and prevented from recurring during a project. In accordance with the contractor, a nonconforming product can be accepted by the client for a lower price. Nonconformities have to be recorded in a nonconformity register (ISO, 2008).

3.2. Defining unidentified occurred risk

In this research, a procedure is developed that classifies nonconformities into risk and non-risk, and assigns reasons for non-identification to nonconformities that are unidentified risks. It is therefore essential to know what an unidentified occurred risk is. For that reason first uncertainty and risk are defined. Afterwards, construction project risk is defined, followed by the definition of unidentified risk. Finally, reasons for non-identification are obtained; knowing why a risk has not been identified can provide information to improve the risk identification process of future projects.

3.2.1. Uncertainty and Risk

This section elaborates on uncertainty and risk. First, the definition of uncertainty will be elaborated. Using the concept of uncertainty, risk will be defined.

Uncertainty

Van Asselt and Rotmans (2002) state that it is difficult to define uncertainty. Based on their study they define a typology with several sources of uncertainty that can be used for integrated assessment practitioners (Figure 4). Two types of uncertainty are distinguished:

- *Variability*, where the system/process under attention can react in multiple ways. This is also referred to as 'stochastic uncertainty' (Helton, 1994, cited in Van Asselt and Rotmans (2002).
- *Limited knowledge*, which is a property of the analysts performing the study and/or of our state of knowledge. Uncertainty based on limited knowledge does not necessarily decrease when more information is acquired. More information can even increase

uncertainty since new information can decrease understanding. It can invalidate understandings of systems or processes (Van Asselt & Rotmans, 2002).

Five different sources of *variability* are distinguished:

- Inherent randomness of nature, natural processes which are not predictable.
- Value diversity, differences in the norms and values of people which cause different problem perceptions and definitions.
- Human behaviour, “non-rational” behaviour, or variations in standard behavioural patterns.
- Social, economic and cultural dynamics. “Non-linear chaotic and unpredictable nature of societal processes”.
- Technological surprises, new developments in technology, or unexpected external effects of technologies. (Van Asselt & Rotmans, 2002)

Van Asselt and Rotmans (2002) point out that variability partly causes limited knowledge, but knowledge with regard to deterministic processes can also be incomplete and uncertain. Seven different sources of *limited knowledge* are described. This ranges from inexactness as lowest uncertainty to irreducible ignorance as highest uncertainty (Figure 4).

- Inexactness, every measurement is affected by measurement errors. *“We roughly know.”*
- Lack of observation/measurements, lacking data that could have been collected but haven’t been. “*We could have known.”*
- Practically immeasurable, lacking data that in principle can be measure, but not in practice (too expensive, too lengthy). *“We know what we do not know.”*
- Conflicting evidence, different data sets/observations are available, but allow room for competing interpretations. *“We don’t know what we know.”*
- Reducible ignorance, processes that we do not observe, nor theoretically imagine at this point in time, but may in future. “*We don’t know what we do not know.”*
- Indeterminacy, processes of which we understand the principles and laws, but which can never be fully predicted or determined. *“We will never know.”*
- Irreducible ignorance, there may be processes and interaction between processes that cannot be determined by human capacities and capabilities. *“We cannot know”* (Van Asselt & Rotmans, 2002, pp. 80-81).

The typology of Van Asselt and Rotmans (2002) is developed for integrated assessment practitioners, it can therefore be discussed whether this typology is applicable on construction projects. Hence the typology is compared with uncertainty sources used in construction literature and project management literature (Table 1).

It can be concluded that, the sources of uncertainty described in the construction industry literature and project management literature can be applied to the typology of Van Asselt and Rotmans (2002). Now uncertainty in this research can be defined:

As per the typology of Van Asselt and Rotmans (2002): Variability, where the system/process under attention can react in multiple ways and/or Limited knowledge, which is a property of the analysts performing the study and/or of our state of knowledge.

In conclusion, two types of uncertainty can be distinguished: variability and limited knowledge (Van Asselt & Rotmans, 2002). Uncertainty in project management and uncertainty in the construction industry can be applied to the typology of Van Asselt and Rotmans. Moreover, uncertainty can be applied to risk management. As stated by Van Asselt and Vos (2006) uncertainty and risk are intermingled.

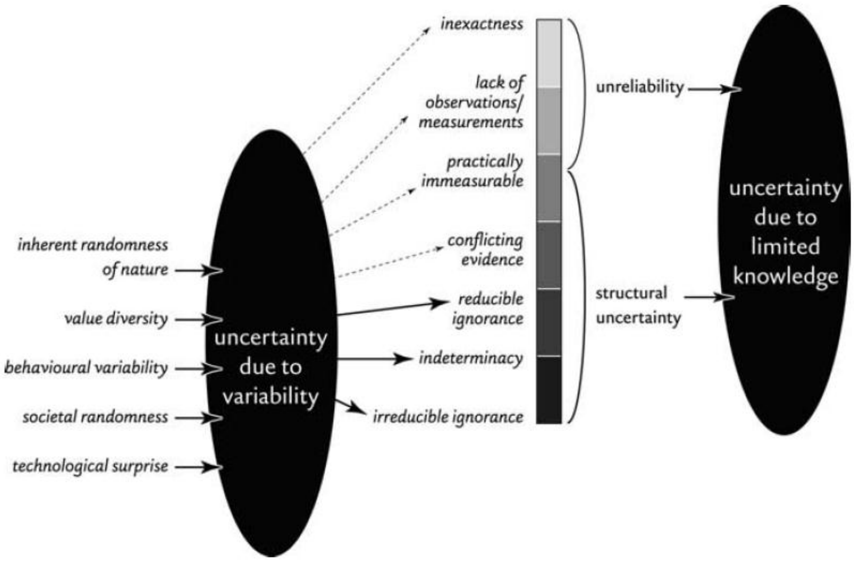

Figure 4 Types of uncertainty adopted from (Van Asselt & Rotmans, 2002)

Table 1 Comparison of typology of Van Asselt and Rotmans (2002) with construction and project management uncertainty definitions

Source	Source of uncertainty	Source of uncertainty of typology Van Asselt and Rotmans (2002)
Chapman and Ward 2002 cited in Chapman and Ward (2003) *(Project Management)*	Uncertainty about fundamental relationships between project parties	Variability (value diversity and human behaviour)
	Bias related to statistics and measurement errors	Limited knowledge (inexactness)
	Known unknowns: "we know what we do not know"	Limited knowledge (practically immeasurable)
	Unknown unknowns: "we don't know what we do not know"	Limited knowledge (reducible ignorance)
Blockley and Godfrey (2000) *(Construction Industry)*	Incompleteness: that which we do not know, most important, because least appreciated. I.e. soil research only researches a part of the underground.	Limited knowledge (all sources)
	Fuzziness: "imprecision of definition" since many definitions in the construction industry are fuzzy and can be interpreted in many ways. For instance weak clay, that can be defined differently by multiple experts.	Variability (value diversity)
	Randomness: lack of specific pattern. It is never certain that a specific pattern is random. At every moment a sequence in the perceived randomness can be found. For instance geotechnical soil data, there is no pattern within such data.	Variability (inherent randomness of nature)
Van Staveren (2010) *(Geotechnical Construction Risk*	Fuzziness: as "imprecision of definition".	Variability (value diversity)
	Randomness: lack of specific pattern.	Variability (inherent randomness of nature)
	Incompleteness: that which we do not know. Most	Limited knowledge

Management)	important, because least appreciated.	(all sources)
	Falseness: wrong information due to human error, it is natural to make mistakes however this can largely be prevented by applying quality management systems	Variability (behavioural variability)

Risk

Halman (1994) explains risk as a connected process-chain of cause, exposure, and negative effect (Figure 5). The example shows how the process-chain results in a negative effect.

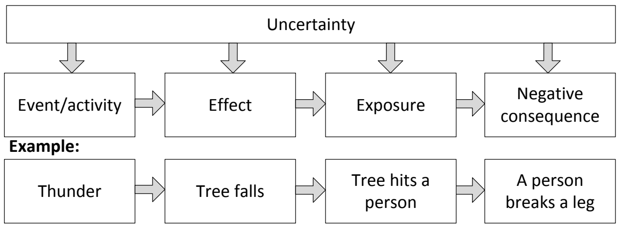

Figure 5 Risk as a process-chain adopted from Halman (1994)

However, not all sources state that risk has a negative effect. PMI (2000) states that a risk can have a positive or negative effect on the project objectives. As described in the introduction a nonconformity can have a positive or a negative effect on the project objectives. Therefore, within this research, a risk can have a positive or a negative effect. When only the impact is considered, a risk is higher when the effect (positive/negative) of the risk is higher.

The impact of a risk in this research is purely financial. Contractors often specify five types of objectives: time, money, quality, surrounding and employee safety (van Well-Stam et al., 2003). A risk can affect one or more of these objectives. Time, money, quality, surrounding and employee safety are strongly related in practice, and occurrence of these risks results in a financial impact. Delays have a financial impact, because the resources are used longer on site. Quality risks often lead to rework that has a financial impact. Surrounding and employee safety risks in infrastructure projects are often related to financial penalties from the client because it can affect the reputation of the client. Therefore, the impact of a risk in this research is chosen as purely financial.

The vectors between each element of the process-chain (Figure 5) are assigned with a likelihood. This likelihood is described by Van Staveren (2009) as a chance that can be defined, subjectively estimated or objectively measured. For example, there is a likelihood that thunder results in a tree to fall. Likelihood can also be indicated with classifiers such as likely and unlikely. Moreover, it can also be indicated in probabilities of occurrence. When only the likelihood is considered, a risk is higher when the likelihood is higher, however when the likelihood is 100%, it is no risk, because there is a certainty it is happening.

Several sources, such as PMI (2000), state that the size of a risk can be calculated by multiplying the (calculated) probability with the (objectively calculated) effect of the risk. However, as stated by Vercilli, 1995 (cited in Van Asselt and Vos, 2006), “risk refers to the possible negative consequences of uncertainty”. This probability or likelihood can thus be objectively calculated but also subjectively estimated. There can therefore be an uncertainty about the likelihood. If the likelihood is subjectively estimated the exact likelihood is uncertain.

This uncertainty, can also affect the effect of a risk (Halman et al., 2008). It can thus be uncertain what the effects of a risk are if it occurs, (Figure 5). Thus uncertainty can affect all elements of the "process-chain" and the likelihood of a risk.

A risk therefore has a likelihood and an effect. Halman (1994) analysed the risk definitions that are described in literature. These risk definitions can be distinguished by frequent and non-frequent risk definitions and by influenceable and not-influenceable risk definitions (Figure 6). This framework is explained in the next few paragraphs and then used to further define risk in this research.

Frequent risks are objectively measurable. Historical data can be collected on these risks. Using this data, the effects and probability of occurrence can be predicted. Because of their frequency standard processes/plans can be developed on how to manage these risks (Halman, 1994).

Frequent risks can be attributed to the type of uncertainty called variability. Variability indicates that the uncertainty can be calculated. Because of these risks cause and effect can be objectively measured and calculated using historical data.

Non-frequent risks can be subjectively estimated, because no historical data is available for these risks. The probability of occurrence and the elements of the process chains can only be subjectively estimated. Of non-frequent, no standardised plans/processes can be developed in order to manage these risks (Halman, 1994).

Non-frequent risks can be attributed to the type of uncertainty called limited knowledge. Because these risks are not frequent, there is a limited amount of knowledge of these risks; this can be about the probability of occurrence or the effects of the risks. This indicates the type of uncertainty called limited knowledge.

Not influenceable risks indicate the gamble definition of risk. There is no influence possible on the cause of this risk. By doing an analysis information can be obtained about this risk, and it can possibly be avoided. But when the risk is taken, you can only wait to see whether the risk occurs or not. The measures that can be taken are measures to minimise the effect if it occurs (Halman, 1994).

	Frequent	**Non-frequent**
Not influenceable "gamble vision"	*Objectively measureable:* Frequency of failure Example: Sickness absence in a contractors budget	*Subjectively estimated:* Extent of (reasoned) belief in probability of failure. Example: Acquiring shares
Influenceable "manage vision"	*Objectively measureable*: Frequency of failure caused by unmanaged process Example: Quality procedures in the processindustry	*Subjectively estimated:* Extent of (reasoned) believe in unmanageable process Example: Deformation of a highway due to construction works next to it

Figure 6 Risk categories adopted from Halman (1994)

In contrast, of influenceable risks the cause <u>can</u> be influenced. Therefore these risks can be influenced/managed by the risk taker before they occur. The lower the influenceability the higher the risk. Of these risks measures can be taken to prevent the risk from occurring (Halman, 1994).

Having the framework of Halman(1994) defined, risk can be further defined for this research. As outlined above, a risk in this research has a likelihood and an effect. In addition, a risk in this research is defined as non-frequent risk. Because for frequent risks historical data is available to predict the effects and the probability of occurrence, and these risks can be managed in standard processes. Within the construction industry, these standard processes are often defined already and managed. Therefore these type of risks are not considered as risk in this research. A risk in this research is thus not-frequent, and is affected by epistemic uncertainty.

A risk in this research has a limited or no influenceability. Two types of influenceability are distinguished because both can be useful for future projects. The influenceable risks can be managed before they occur, the non-influenceable risks can be avoided or measures can be taken to minimise the effect (Halman, 1994).

To conclude, project risk can be defined for this research:

The likelihood of an effect on the project objectives, caused by limited knowledge (non-frequent) within a project. Project risks can have a non-influenceable or influenceable cause.

3.2.2. *Unidentified risk*

The procedure distinguishes between identified and unidentified risks. Therefore this section elaborates on unidentified risk, which is a further specification of definition of risk defined in the previous section.

As stated by Van Staveren (2009) identified and unidentified risk correspond with known and unknown uncertainty. Unidentified risks cannot be managed because they are not identified before they occur, after they occur they can be managed by managing the effects of the risk. Unidentified risks can be assigned to different sources of uncertainty. As described in the previous section, Van Asselt and Rotmans (2002) distinguish seven sources of uncertainty referring to limited knowledge. Four of these seven sources relate to unidentified risks and are explicated in Table 2.

Table 2 Sources of uncertainty related to unidentified occurred risk

Source of limited knowledge	***Description:***
Lack of observations/measurements: lacking data that could have been collected but for some reason has been not (Van Asselt & Rotmans, 2002). Measuring soil conditions at a construction project is an example of this type of uncertainty. It can be measured but not enough investigation is done.	“We could have known”
Reducible ignorance: “Processes that we do not observe, nor theoretically imagine at this point in time, but may in the future”. “We don’t know what we do not know”. Taleb (2007) developed the black swan theory. Those black swans can be seen as uncertainty with the source “Reducible ignorance” (Van Asselt & Rotmans, 2002). Black swans are events with large consequences that can be strongly rationalised after. For instance, the accident with spaceship the challenger that was strongly rationalised after.	“We did not know, but now we know”.
Indeterminacy: Processes of which the principles are understood, however those principles can never be fully predicted or understood (Van Asselt & Rotmans, 2002). For instance weather dynamics.	“We will never exactly know”
Irreducible ignorance. There might be processes and interactions that cannot be determined by human capacities and capabilities(Van Asselt & Rotmans, 2002).	“We will never know”

Ramasesh and Browning (2014) define two types of unknown uncertainties, unknowable unknown unknowns (further called: unidentifiable unidentified risk) and knowable unknown unknowns (further called: identifiable unidentified risks). An unidentifiable unidentified risk is an unidentified risk that could not have been anticipated. An identifiable unidentified risk is an unidentified occurred risk that could have been anticipated. The above stated types of uncertainty can be assigned to those categories as follows: Identifiable unidentified risks: lack of observations/measurements. Unidentifiable unidentified risks: Reducible ignorance, Indeterminacy, Irreducible ignorance.

Finally, unidentified risk can be defined as:

Risks that have not been identified and can be distinguished into two types: identifiable and unidentifiable.

3.2.3. Reasons for non-identification

In this paragraph, reasons for non-identification are determined. Assigning these reasons to the nonconformities that are unidentified risks can give insight in the improvement possibilities of the risk identification of future projects. First it is explained which type of unidentified risks are focused on. After that, reasons for non-identification are determined from different risk identification methods.

Risk identification determines which risks might affect the project and register their characteristics (Mojtahedi, Mousavi, & Makui, 2010). Risk identification is considered by many to be the most important element of the risk management process, as once a risk has been identified, it is possible to address it (Chapman, 2001).

Unidentifiable unidentified risks cannot be managed (Ramasesh & Browning, 2014). “One can never know completely what one does not know” therefore risk identification will never be complete (Pidgeon, 1988). Thus, risk identification is always incomplete (Sjöberg, 1980). That is why in every project unidentifiable unidentified risks can occur. The reason why these risks were not identified, is that it was not possible to identify them (Ramasesh & Browning, 2014). For example the tsunami in the Indian Ocean in 2004 disrupted many construction projects but it is something that could not have been anticipated.

Identifiable unidentified risks are possible to know. Based on extensive literature and empirical research, Ramasesh and Browning (2014) developed a framework that describes the driving factors in a project that increase the likelihood for the occurrence of identifiable unidentified risks. If one of these factors is present on a project it indicates a high likelihood for the occurrence of identifiable unidentified risks. The presence of one of these factors can thus be one of the reasons for non-identification. Therefore the four characteristics of the framework of Ramasesh and Browning (2014) are described in the next paragraphs:

The first characteristic is complexity. Complexity of a system makes it difficult to understand and recognise all of the variables of this system. Two types of complexity are described: element complexity, (complexity of the project elements) and relationship complexity, (complexity of relationships among elements). An increased amount of complexity, increases the likelihood of experiencing identifiable unidentified risks (Ramasesh & Browning, 2014).

The second characteristic is complicatedness. Complicatedness is how complexity is perceived by its observers. Increasing complicatedness increases the likelihood of experiencing identifiable unidentified risks (Ramasesh & Browning, 2014).

Mindlessness as the third characteristic, is the opposite of awareness. Mindlessness is a failure to recognise key aspects of a situation. Increasing mindlessness increases the likelihood for identifiable unidentified risks (Ramasesh & Browning, 2014).

As fourth characteristic, project pathologies are described. Project pathologies are abnormalities a project can suffer from. Project pathologies such as project subsystem mismatches, fragmented expertise, stakeholders' unclear expectations and dysfunctional culture, could increase the likelihood of identifiable unidentified risks occurring on a project (Ramasesh & Browning, 2014).

The above explained framework of Ramasesh and Browning (2014), provides reasons why unidentified risks have occurred. However, more reasons for non-identification can be found. When a risk is not identified, it implies shortcomings in the risk-identification. Risk identification literature is studied to elaborate on these reasons.

Halman (1994) provides different aspects that are important for good risk identification. He points out that due to group dynamics, risks given by minorities can be overlooked. This is supported by Chapman (2001), who states that people of the same rank have to participate during risk identification. A reason of non-identification can therefore be group dynamics.

In his article about risk identification, Chapman (2001) demonstrates that several categories can be used to guide risk identification. Each set of categories tries to cover a whole project. Forgetting to stipulate one of the categories can be a reason of non-identification.

Hanna, Thomas, and Swanson (2013) state that cooperating with multiple parties reduces the likelihood of overlooking risks. Accordingly Chapman (2001) states that the success of the risk identification depends on the in-depth knowledge of the team and the selection of representatives. It can thus be stated that a reason of non-identification can be a lack of mobilisation of knowledge.

Finally, Chapman (2001) states that it is important that a facilitator (risk manager) has extensive knowledge of a project. This can be a reason of non-identification.

3.3. Conditions for a nonconformity to be a risk

Having defined the concepts of risk and nonconformity, in this section a theoretical procedure is developed that classifies nonconformities into risks and non-risks. First, is elaborated on current research about nonconformities as risks. Consequently, the theoretical procedure is elucidated.

Van Staveren (2014) states that good geotechnical risk management results in less nonconformities of safety and quality. Nevertheless, it is not explained under what conditions a nonconformity is a risk. Further research that discusses nonconformities is performed by Cárdenas et al. (2014). They used Bayesian networks to develop construction risk models. Some of the risk factors, or risks that have been used as input for these risk models are possible nonconformities of a construction project. These possible nonconformities, are derived from expert knowledge, not from what actually happened during a construction project. When a nonconformity is a risk is not explained.

While looking at previous research about nonconformities, much has been written about the causes and the cost of nonconformities (Abdul-Rahman et al., 1996; Burati Jr et al., 1992; Love & Li, 2000; Love et al., 1999). However, nonconformities have not often been related to risk. For instance, Josephson and Hammarlund (1999) determine risk as one of the causes of nonconformities.

In contrast with Josephson and Hammarlund (1999), Aven (2014) states that all nonconformities are consequences of some type of risk. Two types of risk are defined. Risk due to variability and risk due to limited knowledge. Additionally, Aven (2014) distinguishes two types of nonconformities, nonconformities with a common cause and a special cause. From extensive literature research, Aven (2014) concludes that variability can cause common cause nonconformities (variability is not considered as risk in this research). Additionally, Aven (2014) concludes that, limited knowledge can cause common cause nonconformities and special cause nonconformities. Since limited knowledge is attributed to risk in this research, a nonconformity with a special cause is a risk as well. However, when a nonconformity with a common cause is a risk (attributed to limited knowledge) is not explained. Hence, the research of Aven (2014) cannot be used to classify nonconformities into risk and non-risk. Moreover, Aven (2014) does not support his research with empirical data.

Apart from the afore mentioned, no sources have been found that explain conditions for a nonconformity to be a risk (appendix 3 shows the used search terms). This research aims to fill that gap.

Because previous research did not conclude a method to classify nonconformities into risk and non-risk, the definition of risk is used to develop this method. Figure 7 shows the theoretical procedure. The risk definition consists of four parts, **existence of likelihood, existence of effect, existence of a low frequency and a risk is influenceable or not.**.

Likelihood: a risk has a likelihood A nonconformity also has a likelihood before it occurs: there is a likelihood that a product or process does not comply with a requirement. Because both risk and nonconformity have a likelihood, it is excluded from the procedure.

A risk can have a positive or a negative **effect** on the project objectives (PMI, 2000). This effect is the financial impact. Nonconformities that have no financial impact are thus no occurred risks. This is the first step of the procedure.

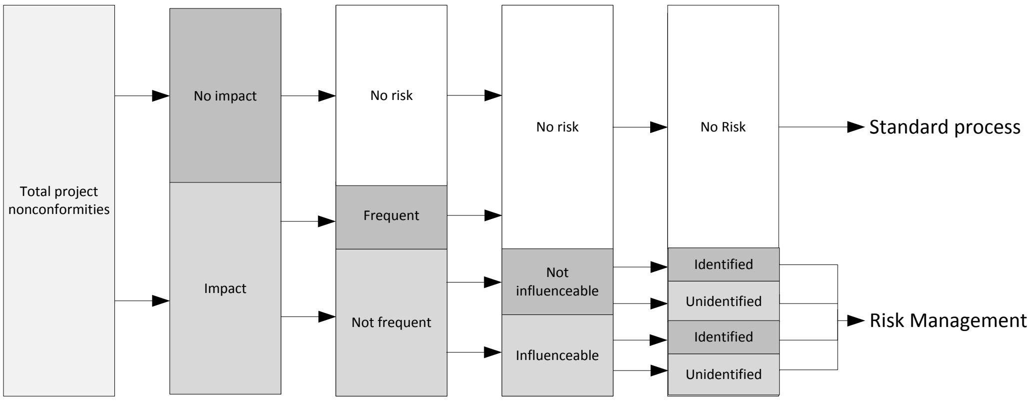

Figure 7 Procedure to classify nonconformities into risk and non-risk

A risk is defined as not-frequent. Therefore, for a nonconformity to be a risk, the nonconformity has to be **not-frequent**. A nonconformity is not-frequent if the probability of occurrence and the size its effects could have not been calculated before the nonconformity occurred, but can only be subjectively estimated.

A risk is **influenceable** or not. This distinction is made because a not influenceable risk requires a different type of management than an influenceable risk.

The non-frequent nonconformities with an impact are occurred risks. These risks can be identified and unidentified. The last theoretical step is to determine the reason for non-identification of the unidentified occurred risks.

3.4. Conclusion of background study

In this section the research questions of the literature study are answered. First the sub-questions are answered, together they results in the answer of the main research question of this chapter: *What are the theoretical conditions for a nonconformity to be an occurred unidentified risk?*

3.4.1. Sub question 1.1. 1. What is nonconformity?

Documenting nonconformities is one of the requirements of quality management standard ISO 9001. The concept of nonconformity therefore originates from the concept of quality; quality is defined as conformance to specifications. Quality management concerns the optimisation of the quality activities (Burati et al., 1992). When the quality specifications are not achieved, it is called a nonconformity; it is defined as a non-compliance of stated, obligatory or generally implied requirements.

3.4.2. Sub question 1.1.2. What is occurred unidentified risk?

The concept of unidentified occurred risk, starts with the concept of risk. Risk and uncertainty are intermingled (Van Asselt & Vos, 2006). Uncertainty is defined as: Variability, where the system/process under attention can react in multiple ways and/or Limited knowledge, which is a property of the analysts performing the study and/or of our state of knowledge. Using this definition of uncertainty construction project risk is defined: The likelihood for an effect on the project objectives, caused by limited knowledge (non-frequent) within a project. Project risks can have a non-influenceable or influenceable cause. An unidentified occurred risk, is a risk that has occurred, but has not been identified earlier.
Several reasons for non-identification can be assigned to unidentified risks; these can be attributed to specific project characteristics, or the risk identification process. Two types of unidentified risk are distinguished. Unidentifiable unidentified risks and identifiable unidentified risks:

Unidentifiable unidentified risks:

- Not identifiable

Identifiable unidentified risks:

- Complexity
- Complicatedness
- Awareness
- Project pathologies
- Group dynamics
- Forgetting categories
- Mobilisation of knowledge
- Lack of knowledge of the facilitator

3.4.3. Sub question 1.1.3. When is a nonconformity an occurred unidentified risk?

Using the definition of risk, a theoretical procedure was developed that can be used to classify nonconformities into risk and non-risk (Figure 7).

3.4.4. Question 1.1. What are the theoretical conditions for a nonconformity to be an occurred unidentified risk?

Now the sub-questions are answered, the main research question of the theoretical background study can be answered.

As determined in the previous section and showed in Figure 7, a nonconformity is an unidentified risk when:

- It has impact, a risk has an impact (positive or negative) on the project objectives.
- The cause of the of the nonconformity is influenceable or not influenceable; depending on the influenceability they can be managed differently.
- It is not frequent: the probability of occurrence and its effects could have not been calculated before if occurred.
- It is not identified earlier.

If this analysis is performed for nonconformities of construction projects, insight is obtained in the nature of nonconformities. Nonconformities that are non-risks can be managed by improving standard processes. Nonconformities that are risks can be managed by improving risk management. The nonconformities that are unidentified risks can be included in a database, which enables management of these risks at future projects. Reasons of non-identification can be assigned to these unidentified risks; these reasons can be used to improve the risk identification.

4. Empirical procedure

This chapter presents the empirical procedure (Figure 8). It starts with a nonconformity that was documented during the execution phase of a construction project, and by answering several questions it is determined whether the nonconformity is a risk, whether this risk was identified, and what the reasons for non-identification are.

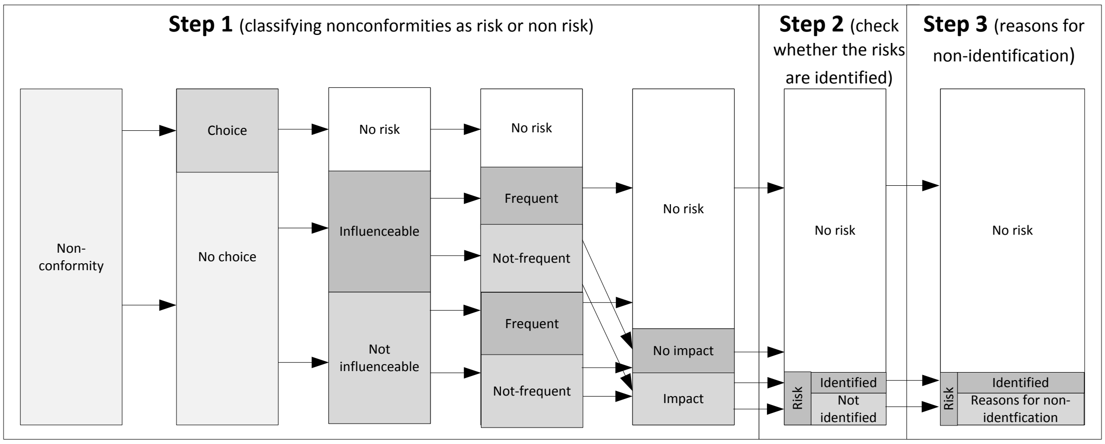

Figure 8 Overview of empirical procedure

This procedure is developed with the theoretical procedure as basis. It is the result of a focus group study with ten risk managers (appendix 5), interviews with eleven experts (risk managers, QA/QC managers, project managers, directors) (appendix 4) and tests with the theoretical procedure on samples of nonconformities of two representative projects. Both projects are large and multidisciplinary. One of the projects focuses on roads, the other project focuses on civil works.

As presented in Figure 8, the procedure consists of three steps, step one determines whether a nonconformity is a risk or not (§4.2). Step two determines whether this risk is identified (§4.3). In the third step reasons for non-identification are assigned to the nonconformities that are unidentified risks (§0). An overview of the procedure is given in appendix 1. First, the results of the interviews are described.

4.1. Results interviews

The interviews resulted in awareness of the problem within the organisation. Because experts with many different functions (from directors to risk managers) were interviewed a broad awareness of the problem was created. Overall, the experts agreed that within the organisation much improvement is possible on this topic.

It was also determined that within the organisation there is a need for an estimation of the impact of nonconformities. In the current situation the impact is not documented, therefore managers do not know whether a nonconformity influences the project objectives. Estimating the impact of nonconformities is therefore very welcome by directors and managers. Combining this with the nature of the nonconformities, the managers were particularly interested the classifications of the nonconformities in combination with the impact of the nonconformities in each category.

During the interviews the implementation of the procedure was discussed. It was determined that the first step can be best performed during the project, directly after a nonconformity occurred. At that moment information that is not documented can be accessed as well.

Finally, it was determined that the procedure can contribute to the “improvement database”. This initiative focuses on the improvement of standard processes within the organisation. Within this database all nonconformities of multidisciplinary projects can be collected, after which they can be assigned to all standard processes. The assigned nonconformities can be used to improve the standard processes. Because this proposed procedure determines which nonconformities are risks and which are non-risks, the non-risks can be included in the improvement database, the risks can be included in the risk database.

4.2. Step one, classification of nonconformities into risks and non-risks

During the first step of the procedure the nonconformities are classified into risk and non-risk. But first the input that will be used to perform the procedure will be described.

4.2.1. Input

The procedure uses information on nonconformities that is documented in the nonconformity register. The input to the procedure was determined during the expert interviews and during the tests on a sample of nonconformities. Cause, effect and the measures of nonconformities are used in the procedure. Cause and effect information provide insight into what is nonconforming and why it is nonconforming. The measures taken to correct or eliminate the nonconformity provide insight in to the impact of the nonconformity; the costs of the measures are often the impact of the nonconformity.

4.2.2. Step 1.1 Nonconformity or choice

Figure 9 shows step 1.1 of the procedure. During the tests on samples of nonconformities it was determined that some nonconformities are the result of an approved choice during the project that resulted in a non-compliance with a requirement. For example, during a project it was decided to leave a non-functional driven pile in the soil, while it was required to remove all non-functional elements. This was documented as a nonconformity, but it was a choice of the organisation, the organisation made this well considered choice, that resulted in a nonconformity. This nonconformity therefore has no negative impact on the project objectives and is thus no risk. It was also determined that of other nonconformities not enough information was available to determine whether it is a nonconformity or not.

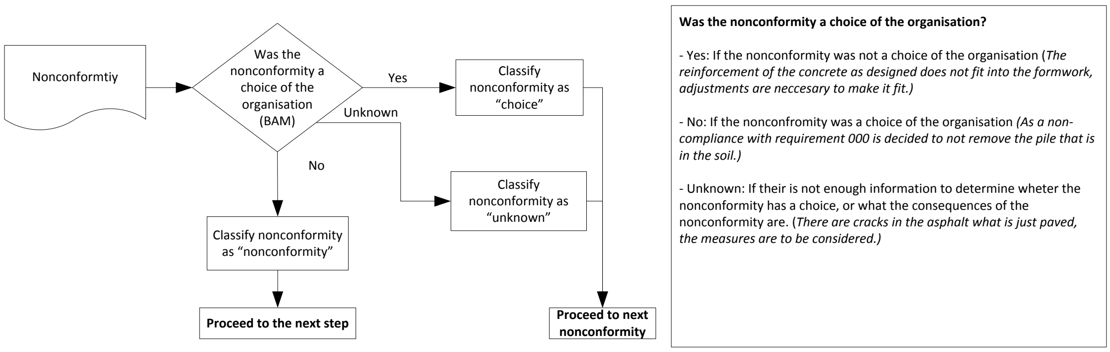

Figure 9 Step 1.1

4.2.3. *Step 1.2 Influenceability*

This step determines whether the nonconformity is influenceable or not. Although it does not contribute to the classification of nonconformities in risk and non-risk (a risk can be influenceable and not-influenceable), it does provide information about how these risks should be managed. Empirical tests showed that it concerns the influenceability by BAM as risk taker.

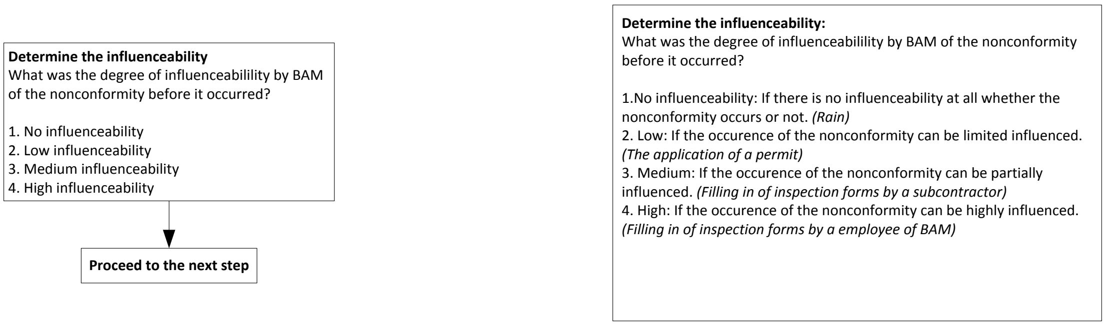

Figure 10 Step 1.2

4.2.4. *Step 1.3 Impact*

In this step it is determined whether the nonconformity has an impact or not (Figure 11), because the financial impact of a nonconformity is not documented.

A nonconformity that has no impact is no risk. A risk has an impact and if of two equal risks the impact of one risk is higher the risk is higher. During the tests on samples of nonconformities it was determined that few of nonconformities have positive impact. Therefore, only one positive impact category is used.

Most nonconformities have a negative impact. The size of this negative impact ranges. Therefore, the negative impacts are estimated as a percentage of the contract value of the project. As concluded from the focus group research, risk managers are consistent in the estimation of the impact of nonconformities (appendix 5). Hence, five negative impact classes are determined.

Impact classes are often used to quantify risks in the construction industry (van Well-Stam et al., 2003). The financial impact is often indicated as a percentage of the contract value of the project. The risk impact categories that are used within BAM were divided by twenty, this was determined during the empirical tests on samples of nonconformities.

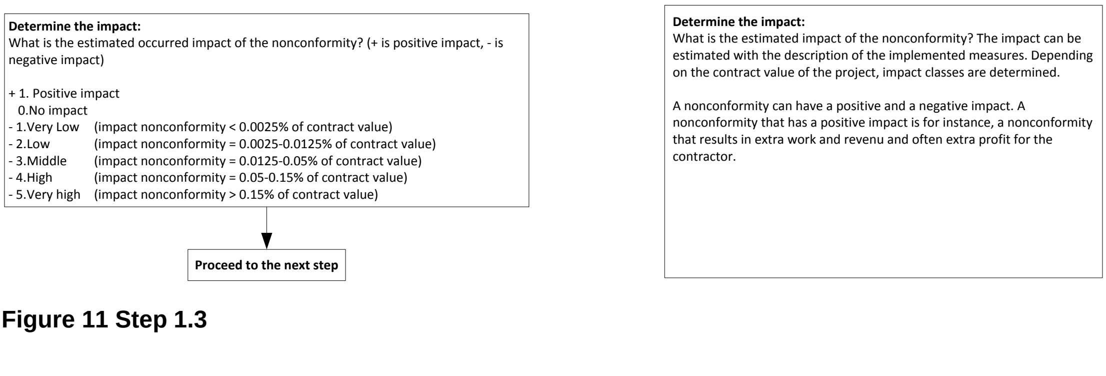

Figure 11 Step 1.3

4.2.5. Step 1.4 Frequency

In this step it is determined whether a nonconformity is frequent or non-frequent (Figure 13). Depending on the influenceability the frequency is determined:

Not influenceable:

As determined during the theoretical background study, a nonconformity is frequent if historical data is available to calculate the probability of occurrence of this nonconformity. It was determined that for frequent, not influenceable nonconformities such as the effect of rain, the probability of occurrence can be calculated. For these nonconformities the probability of occurrence is calculated within BAM. These can therefore be classified as frequent, if it is not possible to do this calculation they can be attributed to not-frequent. Which results in the procedural step as described in Figure 13.

Influenceable:

Although of the frequent influenceable nonconformities historical data should be available to determine the probability of occurrence, it was determined that within the organisation this data is not available. Explaining this procedural step by asking if it is possible to calculate a probability of occurrence will thus be confusing. Hence the following typology was empirically determined: the frequency is divided as frequency for the project portfolio of the organisation and frequency for the project. This frequency considers the frequency of which the specific construction process resulting in the nonconformity is executed within the organisation or at the project. A matrix with four quadrants can be developed (Figure 12). This study considers project risks; hence, a nonconformity that is frequent for the project and not frequent for the project portfolio of the organisation is defined as frequency number 3. While a risk that is not frequent for the project but frequent for the organisation is defined as frequency number 2.

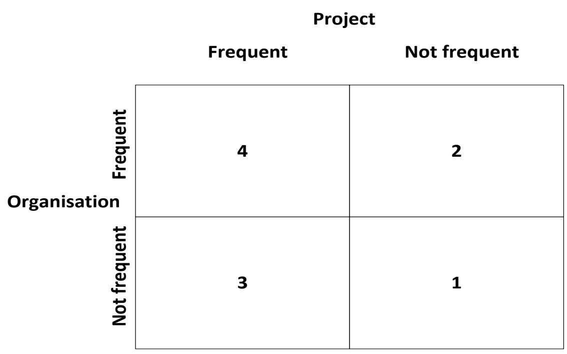

Figure 12 Frequency matrix

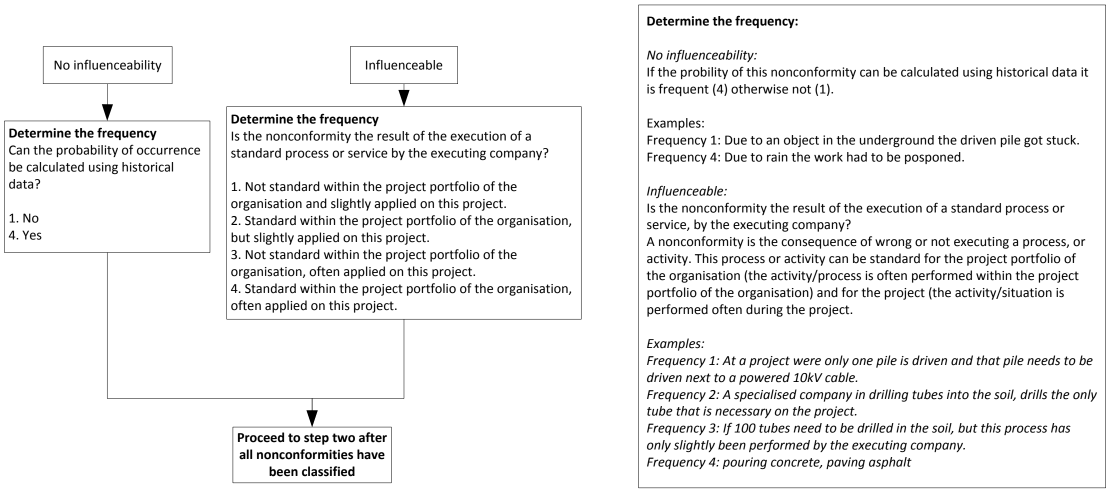

Figure 13 Step 1.4

4.3. *Step two, select risks and determine unidentified risks*

The steps presented in this section, select the risks and determine the unidentified risks.

4.3.1. Step 2.1 Risk no risk

The nonconformities that are risks are selected in this step (Figure 14). All classified nonconformities are the input of this step. The nonconformities that are classified as no choice AND are classified with a frequency number lower than three AND that have an impact that is positive or negative, are risks. The other nonconformities are no risk.

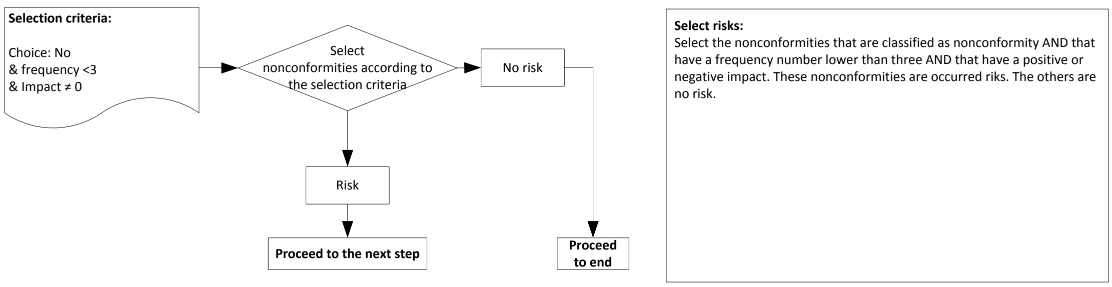

Figure 14 Step 2.1

4.3.2. Step 2.2 Identified or unidentified

This step determines whether nonconformities that are risks were identified (Figure 15). Four types of unidentified risks are distinguished. First of all a risk could have been identified and documented in the project risk register. Second, risk could have not been identified and not documented in the project risk register. It is possible that a risk is identified, but a cause or an effect was not identified. For example, sheet pile leakage can be identified as risk. A nonconformity can be documented that the sheet pile leaks, with a different cause than the cause that was identified in the risk register.

To determine which risks are unidentified, the project risk register will be searched through.

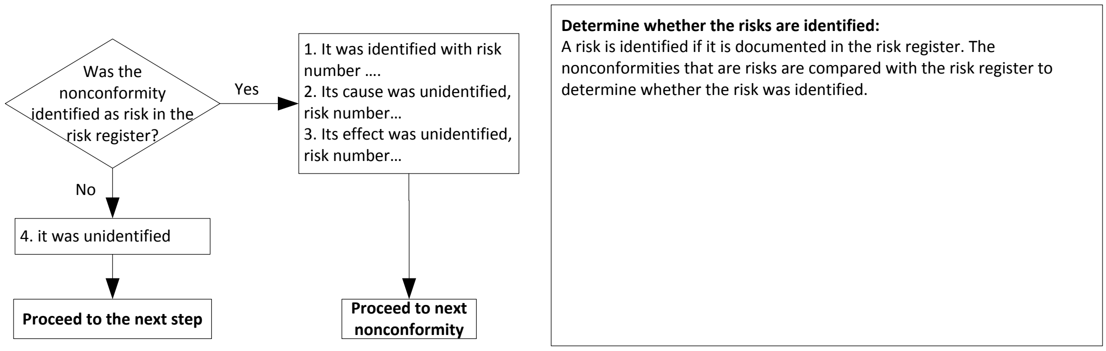

Figure 15 Step 2.2

4.3.3. Step 2.3 Calculate average impact

After the unidentified risks are determined, the average impact of each nonconformity is calculated. This is performed using the average impact of each impact classification (Figure 16). Using this the total impact of each classification group (risk / non-risk, influenceable, not influenceable) can be calculated.

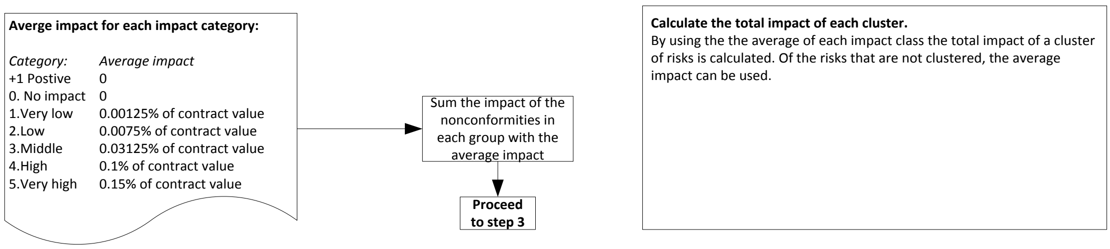

Figure 16 Step 2.3

4.4. Step three, reasons for non-identification

The previous section presented steps that classify nonconformities into risk and non-risk, calculate the total impact of each nonconformity group. In this section the steps are presented to assign reasons for non-identification to the unidentified risks.

The third step follows as a logical step after step two, and can only be performed after step two is completed. The reasons for non-identification can be used to directly improve the risk identification of future projects. Five questions that need to be answered of each unidentified risk were developed. These questions can be answered by the risk manager who attended the risk identification sessions.

4.4.1. Step 3.1 documented in the project risk register?

Figure 17 shows this step. By answering this question, the validity of the result can be determined, if the answer is yes, it means that the unidentified occurred risks should have been documented in the risk register and it can indicate that the result (an unidentified risk) is valid.

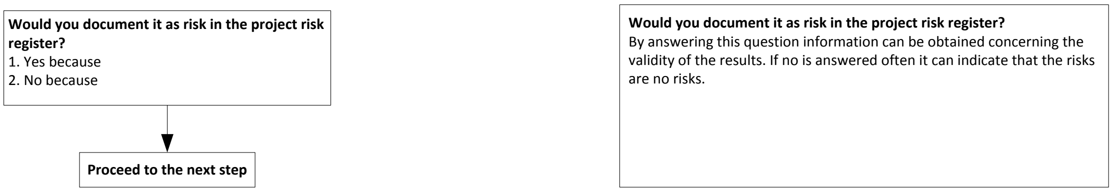

Figure 17 Step 3.1

4.4.2. Step 3.2 Identified but not documented

This step determines whether a risk was identified but it was decided not to include it in the project risk register. After the risks are identified, the most important risks are selected. These risks will be documented in the risk register. It is therefore possible that a risk has been identified during the risk identification, but that it has been decided not to document it in the risk register. As a result the question presented in Figure 18 has to be answered.

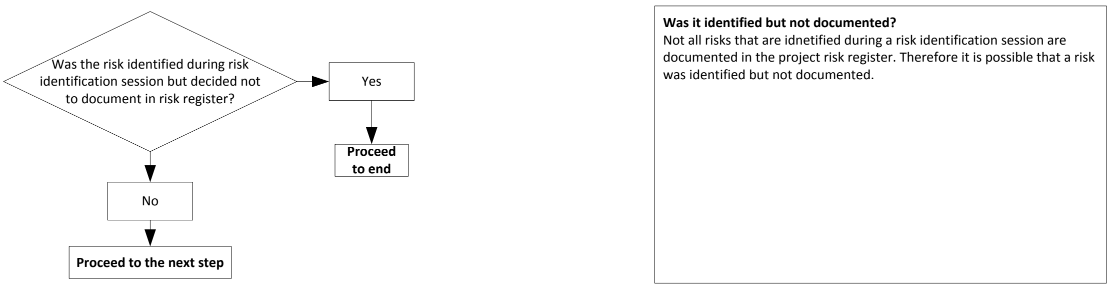

Figure 18 Step 3.2

4.4.3. Step 3.3 Could it have been identified?

Two types of unidentified occurred risks are distinguished in the theoretical background, identifiable unidentified risks and unidentifiable unidentified risks. Step 3.3 determines the type of the unidentified risk (Figure 19). The result of this step is based on the opinion of the interviewed expert and therefore subjective.

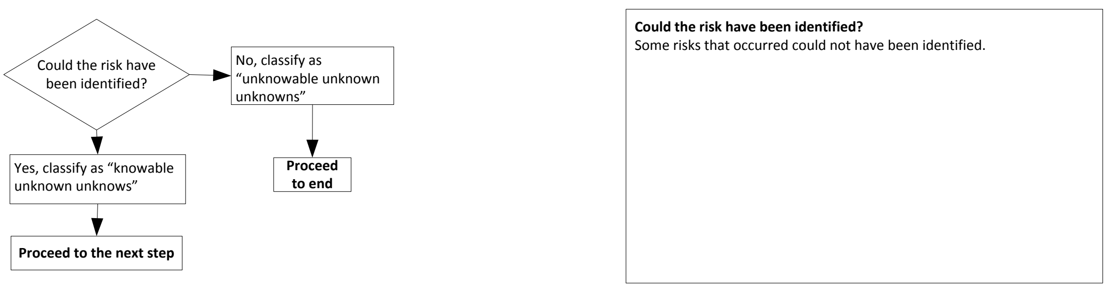

Figure 19 Step 3.3

4.4.4. Step 3.4 Reasons for non-identification

Seven reasons for non-identification have been determined from the literature study and can be assigned to the knowable unidentified occurred risks. These are: complexity, complicatedness, awareness, project pathologies, group dynamics, missing categories, mobilisation of knowledge and lack of knowledge of a facilitator. The reason that fits best to the unidentified risk has to be assigned (Figure 20).

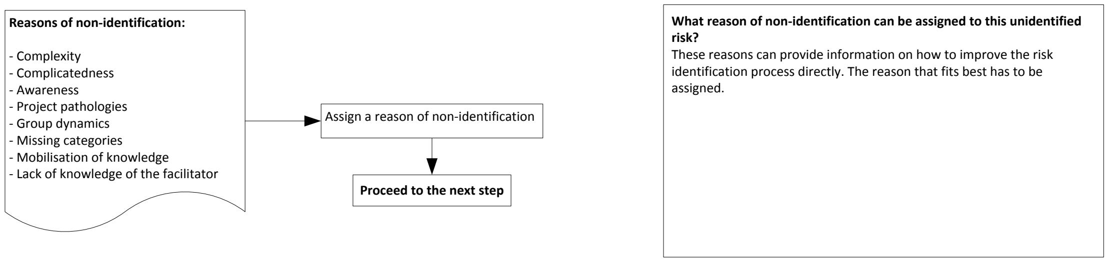

Figure 20 Step 3.4

4.4.5. Step 3.5 Risk category

Within this step the company specific risk categories are assigned to the unidentified risks. The category that fits best to the nonconformity should be assigned. This step is performed to in order to be able to find patterns in the unidentified risks. If to all unidentified risks the same risk category is assigned, it can indicate that the risk identification has to focus more on that risk category. Figure 21 shows this step, including the company specific risk categories.

Figure 21 Step 3.5

4.5. Conclusion of empirical procedure

The theoretical procedure was empirically tested in this chapter. As a result of these tests an empirical procedure was developed and research question 1.2. can be answered: What empirically tested procedure can be developed that classifies nonconformities into risks and non-risks?

Nonconformities can be classified by using the cause, effect and measures of a nonconformity. For each of the nonconformities of a project it is first determined whether they are risks (step one). After that, the risks are selected to determine whether these risks are unidentified (step two). These unidentified risks can be identifiable and unidentifiable. Reasons for non-identification can be determined of the identifiable unidentified risks (step three).

It can be questioned what the results of the procedure are when it is applied to construction projects. First, it is interesting to know whether the procedure provides similar results if performed by two experts (reliability). Next to that, it is interesting to know what the results of the procedure are when an entire construction project is analysed, this will provide insight in the nature of nonconformities within BAM. Next to that, the results will provide insight in the validity of the procedure. The next chapters consider the reliability and the results and validity of the procedure.

5. Reliability of the procedure

This chapter shows the results of the reliability tests. The reliability was tested on step one of the procedure by two experts. The reliability was not tested of step two and three. The first step is the most relevant step because it answers the questions to distinguish between risk and non-risk. The second and third step are therefore less relevant since they focus on the nonconformities that are unidentified risks.

First the results of the tests for both projects are given, which are presented as an unreliability percentage. This percentage refers to the amount of nonconformities that were classified differently. These are the differences that result in a different classification of frequent/not frequent, nonconformity/ not nonconformity, impact/no impact and influenceable/not influenceable. For instance, a frequency classification of two by the QA/QC manager and a frequency classification of four by the project risk manager of the same nonconformity. With a frequency of two a nonconformity is a risk and with a frequency of four a nonconformity is no risk.

The unreliability percentages are obtained differently for step 1.1 and steps 1.2 – 1.4. For step 1.1 a distinction is made between nonconformity and choice. Hence, the unreliability is determined of all 100 randomly selected nonconformities. Because the procedure stops if step 1.1 is answered with “choice”, the unreliability percentages of steps 1.2-1.4 were calculated as a percentage of the nonconformities that were classified in the first step by both the risk manager and QA/QC manager as “no choice”.

After the results of project one and two are given, the cross case results are given. The cross case results are presented as the unreliability percentages of project 2 minus the unreliability percentages of project 1.

5.1. Results of project 1

The first section shows the classification differences between the risk manager and QA/QC manager. Concerning these differences, the QA/QC manager and risk manager were interviewed. The results are presented in the second section.

Note that, the procedure that was used for this step was the procedure as presented in chapter 4 but without explanation or examples.

5.1.1. Classification differences

Table 3 shows the unreliability percentages of project one. The differences were discussed during the interviews with the QA/QC and risk manager, the results of the interviews are described in the next section.

Table 3 Unreliability project 1

Step	*% unreliability*	
1.1. Choice or no choice	32%	Of 100 nonconformities
1.2. Influenceability	12%	Of 58 nonconformities
1.3. Impact	48%	Of 58 nonconformities
1.4. Frequency	7%	Of 58 nonconformities

5.1.2. Interviews

The unreliability of step 1.1 can be explained by the definition of a nonconformity by the risk manager. According to the risk manager a nonconformity is a choice if: “work is executed wrong” or the nonconformity is caused by “stupid behaviour”.

Concerning the influenceability, the unreliability can be explained by subjectivity. The risk manager stated that the influenceability is the extent to which people can be influenced, while the QA/QC manager stated that the influenceability is the way the processes can be influenced by the organisation.

The impact unreliability can be explained by a different interpretation of the procedural step between the QA/QC and risk manager. The definition of impact used by the risk manager is the impact that could have happened, and is therefore more negative. The other impact unreliability can be explained by the fact that the step did not explain whether the impact is the impact of BAM as organisation or the impact in general. For instance a nonconformity that is caused by a subcontractor only has a limited impact for BAM because the control measures have to be taken by the subcontractor and will not be paid by BAM. These two explanations, the definition and the interpretation, cause the unreliability of this step.

The unreliability of the frequency step can be explained by subjectivity. For instance the following nonconformity: a bat gantry was hit by an opened asphalt truck during asphalt pavement works. This nonconformity was classified by the risk manager as not frequent, because a bat gantry is black and therefore it is harder to be seen by the truck driver. In contrast, the QA/QC manager classified it as frequent, because often asphalt is paved under gantries. This subjectivity can have caused the unreliability.

In addition to the unreliability percentages, it was determined that the QA/QC manager of this project had more insight into the nonconformities than the risk manager. The information that was documented of the nonconformities was less than the information available in the QA/QC managers mind. This can also result in a lower reliability because both persons are in fact not provided with the same information.

In summary, the differences of two of the four steps (steps 1.1 and 1.3) can be explained by a different interpretation of the definition. The difference of steps 1.2 and 1.4 can be explained by subjectivity.

5.1.3. Discussion

The unreliability differences of two of the four steps could be explained by a different interpretation of the definition. Consequently less interpretation possibilities within the definition can result in a higher reliability. Thus, in order to increase the reliability for the next test, an explanation of each step including examples was included in the procedure.

In contrast, the unreliability of steps 1.2 and 1.4 was caused by subjectivity between the risk manager and the QA/QC manager. This subjectivity can be lowered by the explanations and examples that will be included in the procedure. A lower subjectivity can result in a higher reliability of the procedure.

5.2. Results of project 2

After the reliability tests of project one, the proposed changes of the procedure were implemented. This improved procedure was used to test the reliability of the second project.

The first section shows the classification differences between the risk manager and QA/QC manager. Concerning these differences the QA/QC manager and risk manager were interviewed, the results are presented in the second section.

5.2.1. *Classification differences*

Table 3 shows the unreliability percentages of the second project. The differences were discussed during the interviews with the QA/QC and risk manager, the results of the interviews are described in the next section.

Table 4 Unreliability of project 2

Step	*% unreliability*	
1.1. Nonconformity or choice	22%	Of 100 nonconformities
1.2. Influenceability	10%	Of 48 nonconformities
1.3. Impact	35%	Of 48 nonconformities
1.4. Frequency	24%	Of 48 nonconformities

5.2.2. *Interviews*

The unreliability of step 1.1 can be explained with a different definition of a choice by the QA/QC manager. The QA/QC manager classified nonconformities that are due to mistakes in the design as a choice. According to his perception, when design mistakes are discovered by executing personnel on site, it is a choice.

The impact unreliability can be explained by a different interpretation of the procedural step by the QA/QC and risk manager. If a measure of a nonconformity consists of work that had to be performed as well without a nonconformity, the QA/QC manager classified the impact as zero. While the risk manager classified it as an impact. In addition, of the other impact differences between no impact and impact are of the categories “very low” and “low”.

The influenceability and frequency differences cannot be explained using the results of the interviews. No reasons were identified that could have resulted in these differences.

During the interviews it was determined that the risk manager and QA/QC manager changed their classifications. Those changes often resulted in a higher reliability.

In addition to the unreliability percentages, it was determined that the QA/QC manager of this project had more insight in to the nonconformities than the risk manager. The information that was documented of the nonconformities was less than the information available in the QA/QC managers mind. This can also result in a lower reliability because both persons are in fact not provided with the same information.

5.2.3. *Discussion*

The unreliability of the first step is due to the different definition of probability of the QA/QC manager. A better explanation of the first step can help to lower the unreliability.

Concerning the impact it is possible that comparable nonconformities are classified as risk and no risk on different projects. However, because the impact of these nonconformities is low, no large risks will be overlooked. In addition, these impact differences can be lowered by improving the description in a way that only the nonconformities are classified that have a direct impact on the project objectives. That impact includes rework, but not work that was already planned.

During the interviews the influenceability and frequency differences could not be explained. However, these differences can be explained by a poor documentation of the nonconformities. The QA/QC manager has more knowledge of the nonconformities than documented in the nonconformity register. The risk manager does not have this information which could have caused the reliability differences.

In addition, it was noticed that the risk manager and QA/QC manager changed classifications during the interview. This can indicate that in first instance the procedure was not performed sufficiently.

5.3. Cross case results

Table 5 shows the cross case results. A positive percentage indicates a higher reliability at project two. Only positive results were expected after the changes that were implemented because of the first reliability test.

Step 1.1 – 1.3 show a higher reliability for project two than project one, step 1.4 shows a lower reliability for the second project. This is remarkable, especially because it shows a large difference: 17%.

Table 5 Cross case results

Step	*Unreliability project 1 – Unreliability Project 2*
1.1. Nonconformity or choice	10%
1.2. Influenceability	2%
1.3. Impact	13%
1.4. Frequency	-17%

5.3.1. Discussion

A high reliability indicates that the procedure provides comparable results when performed on several projects by several users. This section includes a discussion on the cross case results of the reliability tests performed.

It can be argued whether the reliability is high enough at all. While looking at the results of the second project, of three steps (1.1, 1.3 and 1,4) the unreliability is higher than the 15% that was prescribed as sufficient in the method section. This shows that if the procedure is performed at different projects, the results will not be comparable. This low reliability can be explained by the poor documentation of nonconformities in combination with the extra data available in the mind of the QA/QC manager. The nonconformities were often documented poorly, this documentation leaves space for interpretation of the description. The QA/QC manager is involved with nonconformities during his daily work. A result of the interviews was that the QA/QC manager has more specific background information than is documented in the nonconformity register. The risk manager who did not have this information, could have therefore classified the nonconformities differently.

The unreliability decreased of step 1.1, 1.2 and 1.3 as showed in the results section, this is expected since after the first test adjustments were made in order to improve the reliability. Although improvements were expected, the reliability of step 1.4 even decreased. The frequency step requires improvement since it is the most important step to distinguish between risk and non-risk. The unexpected higher unreliability can be caused by the low quality of the data used. As discussed in the previous paragraph the QA/QC manager has more information of the nonconformities than is documented within the register. Moreover, while looking at the frequency step, the unexpected results can be due to the description of the step itself.

The frequency step is described as standard for the organisation or for the project. The word "standard" leaves room for interpretation, what is considered to be standard is subjective, is a process standard when it is performed five, ten or fifty times on a project? Moreover, special conditions can make a standard process not standard, for instance drilling sheet piles next to a high voltage cable is can be a not-frequent, while drilling sheet piles in normal soft soil is frequent. Therefore, more research is necessary concerning the frequency step of the procedure. It should focus on amplifying the description of the frequency step, and can be performed by interviewing risk and QA/QC managers about nonconformities with a varying frequency. This can provide insight in when a nonconformity is due to standard process and when it is a risk.

The reliability can also increase if the procedure is performed directly after the nonconformity occurs. During the reliability tests, nonconformities were used that were documented in the past. Thus for the risk manager only the documented information was available. If the procedure is performed directly after the nonconformity occurs, the risk manager is able to contact responsible persons for additional information. Which will increase the reliability.

This can be tested during a pilot study. During this pilot, the QA/QC manager and the risk manager of a project can classify the nonconformities directly after they are documented. The reliability results are then expected to be higher.

5.4. Conclusion reliability

Within this section the following research question is answered: *What is the reliability of the procedure?* The reliability tests were performed in order to answer that question.

It can be concluded that the reliability of the procedure is low. The unreliability of the procedure as a result of the second test ranges between 10% and 35%. This indicates that the procedure does not provide comparable results when performed at different projects. The low reliability can be caused by the poor documentation of nonconformities. This poor documentation could have introduced ambiguity for either the risk or the QA/QC manager.

Therefore a pilot study is recommended. During this pilot the nonconformities have to be classified directly after they occur. This study will also be performed by the risk and QA/QC manager.

More research into the frequency step is recommended as well. Since this step is the most distinguishing step to determine whether a nonconformity is a risk or not. More research into this step should focus on making the step less subjective. This can be performed by specifying the word standard, and taking into account special conditions of a nonconformity in the frequency step.

5.4.1. Limitations

Concerning the reliability tests also some limitations can be discussed. First of all, a small sample of 100 nonconformities was used to test the reliability. Second, the reliability was tested on two projects. Finally, the nonconformities that were used were documented in the past, which enabled ambiguity.

6. Results and validity

This chapter shows the results of performing the procedure on three projects. First the results of each project are given. After that, the cross case results of the three projects are given. With these results the validity of the procedure is discussed, it discusses whether the result (risks and non-risks), are the desired results. Finally the results will be discussed, it discusses what the results of the procedure tell about the nature of nonconformities within BAM.

Table 6 shows examples of classified nonconformities for each category. These nonconformities can have a positive or a negative impact on the project objectives.

Table 6 Examples of results of the procedure

Type	*Example*
1. Choice/ no impact	In accordance with the client it is decided to leave the non-functional pile in the soil, this is nonconforming with requirement no. xxx. (It was a choice of the organisation to leave the non-functional pile in the soil)
2. No risk, influenceable	Due to wrong reading of the drawing the sheet pile was driven at the wrong position. (Driving sheet piles is a frequent activity. Moreover, the cause, wrong reading the drawing is influenceable by the organisation for instance by introducing a second opinion)
3. No risk, not influenceable	Due to sickness of the person responsible for setting out the coordinates of driven piles, the coordinates are set-out wrongly (the cause of this nonconformity is not influenceable, that the person gets sick, however it can be calculated how often a person gets with sickness data of the whole organisation (frequent), therefore plans can be developed to be sure that if someone is sick a replacement is possible)
4. Risk, influenceable	Unless extensive contact with the client, planned works were not allowed because of frost, the regulations show that there is no reason not to allow it (the client can be partly influenced by the contractor, however, it is not standard for the organisation nor for the project and thus not frequent)
5. Risk, not influenceable	Tar containing asphalt was discovered during demolitions works (there is no influence on the cause of this nonconformity, finding tar, using historical data it cannot be calculated how often tar containing asphalt can be discovered, therefore it is not frequent).

6.1. *Results of project 1*

First the results of step one and two of the procedure will be given. After that the results of the third step of the procedure are elucidated.

6.1.1. Result of step one and two

Figure 22 shows the results of steps one and two. The largest part of the nonconformities (57,9%) are classified as choice , unknown, or were classified with no impact. 39,1% of the nonconformities are classified as no risk. These have an estimated impact of 84,8% of the total estimated impact. The 1,2% of the nonconformities that are risks are 15,2% of the total estimated impact.

The largest part of the nonconformities that are non-risk are influenceable, and these are 72,3% of the total estimated impact of the nonconformities. The not influenceable/no risks, are a small percentage of the total number of nonconformities (1,4%), but are 12,5% of the estimated total impact.

Most of the nonconformities that are risks are influenceable, these are also responsible for the largest part of the impact of the nonconformities that are risks. 1,0% of the total nonconformities are unidentified risks, these are responsible for 15% of the total impact of the nonconformities. In the next section is further elaborated on these unidentified risks.

6.1.2. Results of step three

Table 7 shows a summary of the results of the third step of the procedure (appendix 1 shows all results). All unidentified risks are influenceable. The risk manager would not document four of the eight unidentified risks in his project risk register. Three of the four risks that the risk manager would document in the risk register were explained as important risks (0944, 0964, 1124), and one (1167) was very specific according to the risk manager.

Three of the four risks that the risk manager would not document in the risk register are standard work according to the risk manager, and should be managed in standard processes (0882, 1050 and 0523). The last risk that the risk manager would not document in the risk register was not influenceable by the contractor (according to the risk manager) and has to be managed by the client (1082).

The question whether the unidentified risks were identified during risk identification sessions, but not documented in the project risk register is answered with no for all unidentified risks. According to the risk manager, all the risks could have been identified. Three reasons for non-identification were assigned, forgetting categories, mobilisation of knowledge, and complicatedness. The risk categories that were assigned to the risks were organisational, planning and surrounding.

The total estimated impact of the nonconformities that are risks was mainly caused by nonconformity 0882. The opened asphalt truck that hit the bat gantry resulted in severe delays and damage to the gantry.

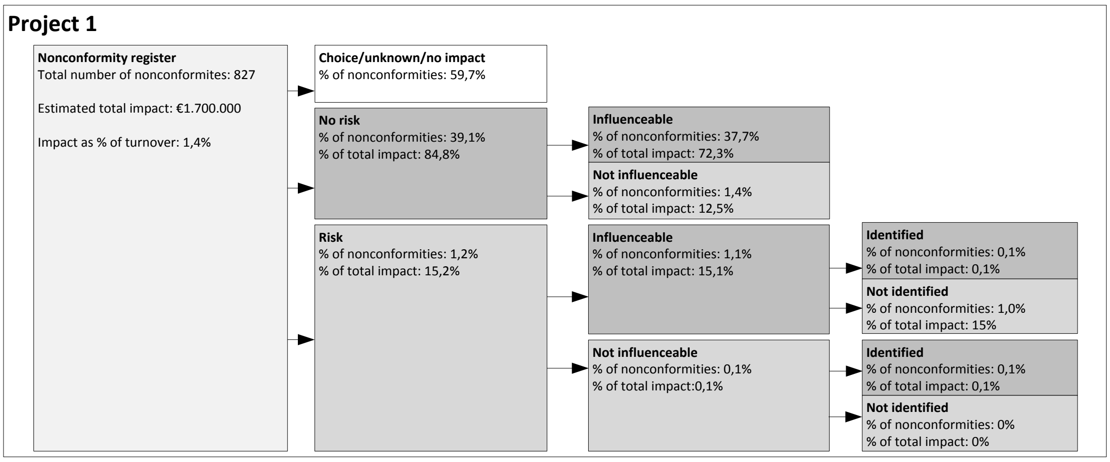

Figure 22 Results steps 1 and 2 of project 1

Table 7 Results of the interview with the risk manager

No.	Description	Record it in risk register?	identified but not recorded ?	Could it have been identified?	Reason for non-identification	Risk category:
0882	A bat gantry was hit by an opened asphalt truck, resulting that the gantry fell on an opened road.	No	No	Yes	Forgetting categories	Organisational
1167	Reprogramming of software is necessary because no attention was paid to a requirement.	Yes	Not specific	Yes	Mobilisation of knowledge	Organisational
0944	After road works, the road was opened later than planned due to several reasons.	Yes	No	Yes	Forgetting categories	Planning
1050	During asphalt works, asphalt is paved over and underground that was not compacted sufficiently	No	No	Yes	Forgetting categories	Organisational
0964	Several fauna tunnels that were constructed as part of the work are flooded due to unknown reasons	Yes	No	Yes	Mobilisation of knowledge	Organisational
0523	Asbestos tubes lay uncovered in open air and it is unknown how to deal with them.	No	No	Yes	Forgetting categories	Organisational
1124	After cameras are placed and tested, the stakeholder concludes that the view of the camera is insufficient.	Yes	Not specific	Yes	Complicatedness	Surrounding
1082	The software of swing gates to close the road is insufficient due to different interpretation of the requirements.	No	No	Yes	Forgetting categories	Surrounding

6.2. Results of project 3

First the results of step one and two of the procedure will be given. After that the results of the third step of the procedure are elucidated.

6.2.1. Results of step 1 and 2

Figure 23 shows the results of steps one and two. The largest part of the nonconformities (63,0%) are classified as choice , unknown, or were classified with no impact. 33,0% of the nonconformities are classified as no risk, these have an estimated impact of 79,9% of the total estimated impact. The 4,0% of the nonconformities that are risks are 20,1% of the total estimated impact.

The largest part of the nonconformities that are non-risks are influenceable, and these are 65,4% of the total estimated impact of the nonconformities. The not influenceable no risks are a small percentage of the total number of nonconformities (4,3%), but are 14,5% of the estimated total impact.

Most of the nonconformities that are risks are influenceable; these are also responsible for the largest part of the impact of the nonconformities that are risks. 2,6% of the total nonconformities are unidentified risks, these are 11,1% of the total estimated impact of the nonconformities. Next section elaborates more on the nonconformities that are unidentified risks.

6.2.2. Result of step three

Table 8 shows a summary of the results of step 3, the i or ni after the number of the nonconformity indicates that it was classified as influenceable (i) or not influenceable (ni).

The results are further elucidated in appendix 7. The risk manager who was interviewed, was only involved during a few stages of the project; therefore not all questions were answered.

The risk manager would not document one of the risks in the risk register (507). The question whether the unidentified risks were identified during risk identification sessions, but not documented in the project risk register is answered with no for all unidentified risks. According to the risk manager, two of the unidentified risks could not have been identified (316, 507). The reasons for non-identification that were assigned are project pathologies (786, 784 and 796) and risk awareness (781, 191, 023 and 052). The risk categories that were assigned are organisational (786, 784, 781, 191, 052, 796), technical (781, 052) and surrounding (023).

One of the risks (672) was explained as standard risk and should be incorporated into the standard work plans according to the risk manager.

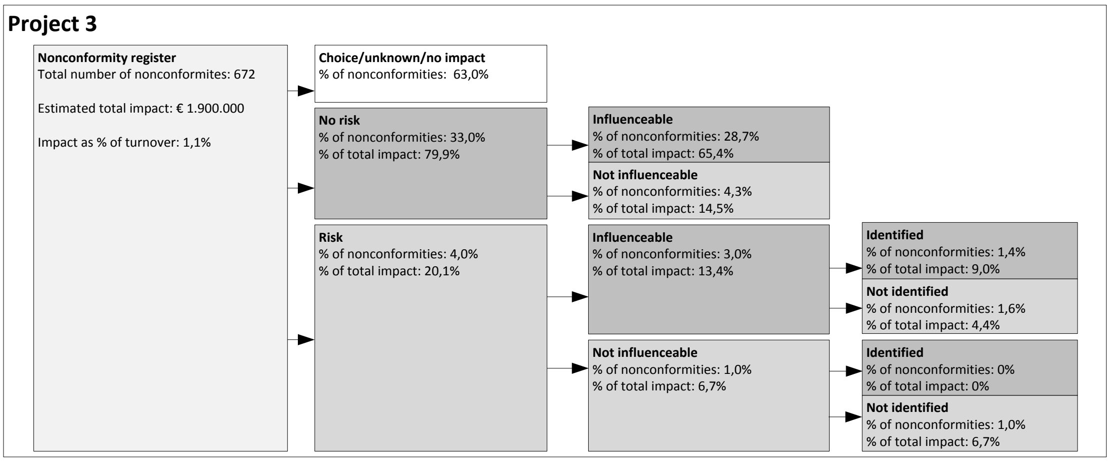

Figure 23 Results steps 1 and 2 of project 3

Table 8 Results of the interview with the risk manager

No.	Description	Record it in risk register?	identified but not recorded?	Could it have been identified?	Reason of non-identification	Risk category:
507 i	The gates that were designed cannot be executed on site	No	No	No	-	-
672 i	During driving in a sheet pile, a water pipe and a data cable were damaged. These were not shown on the drawing and the sheet pile was bent.	Yes	-	-	-	-
316 i	During drilling pipes, the deformation of a water pipe was higher than its maximum value. This was due to an unknown reason.	Yes	-	No	-	-
786 i/ 462 i	Construction was executed 1 mm outside the tolerated value, due to an unknown reason.	Yes	-	Yes	Project pathologies	Organisational
770 i	Several gaps are observed between a prefabricated beam and its bearing block, because the temporary supports broke.	Yes	No	-	-	-
132 i	Despite extensive contact with the client, planned works were not allowed because of frost; however regulations showed that there is no reason for not to allowing it.	-	-	-	-	-
784 i	The temporary sheet piles that were driven according to the design, blocked the rail	Yes	-	Yes	Project pathologies	Organisational

	inspection path.					
781 i	A sheet pile was driven 102 mm outside its tolerance and has to be replaced.	Yes	-	Yes	Risk awareness	Organisation al/ technical
191 i	Software to change the sound volume of railway station speakers is not compatible with the BAM computer.	Yes	-	Yes	Risk awareness	Organisation al
052 i	The location of the temporary cycling path is located too close to a gas pipe. During making the drawings no attention was paid to this. Therefore excavation of the pipe will result in deformation of the path.	Yes	-	Yes	Risk awareness	Organisation al/technical
126 ni	The soil parameters are different than expected during design.	Yes	No	Yes	-	-
290 ni	Unknown wooden piles were discovered during inspection of the underwater site, these resulted in problems during driving piles.	Yes	No	Yes	-	-
796 ni	Due to sickness of the person responsible for setting out, piles were driven outside their tolerances.	No	No	No	Project pathologies	Organisation al
485 ni	During the excavation, a unknown wooden sheet pile resulted in delay.	Yes	No	Yes	-	-
050 ni	Due to external circumstances, the planning could not be delivered on time.	No	No	No	-	-
023 ni	It was expected that the roads did not contain tar, however it turned out it did. Resulting in extra cost.	Yes	No	Yes	Risk awareness	Surrounding

6.3. Results of project 4

First the results of step one and two of the procedure will be given. After that the results of the third step of the procedure are elucidated.

6.3.1. Results of steps one and two

Figure 24 shows the results of steps one and two. The majority of the nonconformities (54,7%) are classified as choice , unknown, or were classified with no impact. 42,9% of the nonconformities are classified as no risk, these have an estimated impact of 90,4% of the total estimated impact. The 2,4% of the nonconformities that are risks are 9,6% of the total estimated impact.

The largest part of the nonconformities that are no risks are influenceable, and these are 71,7% of the total estimated impact of the nonconformities. The not influenceable no risks are a small percentage of the total number of nonconformities (4,0%), but are responsible for 18,7% of the estimated total impact. The nonconformity that the workplace (which was located in the river forelands) flooded during the execution of the work was mainly responsible for this impact. This nonconformity is frequent because the chance that a river floods can be calculated using historical data.

Most of the nonconformities that are risks are influenceable; these are also responsible for the largest part of the estimated impact of the nonconformities that are risks. 1,5% of the total nonconformities are unidentified risks, these are responsible for 3,0% of the total impact of the nonconformities.

6.3.2. Results of sub step three

Table 9 shows a summary of the results of step 3, the “i” or “ni” after the number of the nonconformity indicates what was classified as influenceable (i) or not influenceable (ni). The results are further elucidated in appendix 0.

It is remarkable that the risk manager would not document six unidentified occurred risks as risk in his risk register. Four of these risks were classified by the risk manager as identified risk but not included in the risk register.

The two unidentified risks that the risk manager would document in his risk register could have been identified. The reasons for non-identification that were assigned to these two risks (024 and 638) are risk awareness and complexity and the technical risk category was assigned to these risks.

The two not-influenceable risks both have a positive impact (034 and 153) because they resulted in an assignment from the client, from which profit can be made.

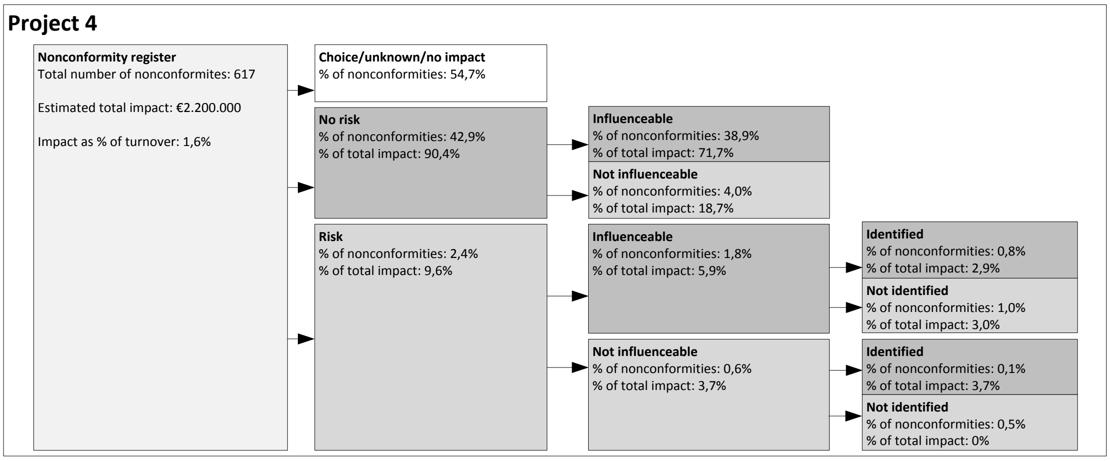

Figure 24 Results of steps 1 and 2 of project 4

Table 9 Results of the interview with the risk manager

No.	Description	Record it in risk register?	identified but not recorded ?	Could it have been identified	Reason of non-identification	Risk category:
024i	During driving a sheet pile a road deformed over a length of 25 m and additional asphalt is necessary to solve this deformation	Yes	No	Yes	Risk awareness	Technical
638i	Due to unknown reasons water drained out from a place of the construction that was not predicted, the drainage system does not work sufficiently.	Yes	No	Yes	Complexity	Technical
656i	Cracks in a concrete barrier occurred due to an unknown reason.	No	Yes	No	-	-
657i	A water draining crack was discovered in a bridge deck.	No	Yes	-	-	-
123i	The sufficient quality of concrete of a with concrete poured drilled pile is situated at a too low level.	No	Yes	-	-	-
456i	The architect proposed a different design that leads to a higher quality.	No	No	No	-	-
034ni	The client requests a different position of a camera.	No	No			
153 ni	Tar containing asphalt was discovered during demolition works.	No	Yes			

6.4. *Cross case results*

This section describes the cross case results. First the cross case results of steps one and two of the procedure are described, followed by results of step three.

6.4.1. Steps one and two

The cross case results of step one and two are showed by average percentages of the amount of nonconformities in a group and the average percentages of the impact of the nonconformities in a group. Next to the averages also a standard deviation is given. It is assumed that the nonconformities are normally distributed, which indicates that there is a 95% chance between the average plus and minus two times the standard deviation.

Figure 25 shows the cross case results of the three projects. The first number shows the standard deviation, the second number between parentheses shows the average percentage of the three projects.

Overall, the standard deviation compared to the average gets larger when the results get more detailed. The standard deviation of the impact of the no risk nonconformities is 5,3% with an average of 85%. Comparing this to the unidentified influenceable risks that have a standard deviation of 6,6% and an average of 7,5%, the average is almost the size of the standard deviation.

The total estimated impact as a percentage of the turnover is on average 1,4%, with a standard deviation of 0,2%. This means that there is a probability of 95% that the impact of the nonconformities of a multidisciplinary project is between 1% and 1,8% of the total turnover.

While looking at the second column of the figure. It is remarkable that an average of 59% of the nonconformities are classified as “choice /unknown/no impact”. In addition, 38,3% of the nonconformities are classified as no risk, and these nonconformities have an average of 85% of the total impact.

When looking at the third column of the figure, the average impact of the influenceable no risks is 69,8% of the total impact and is an average of 35,1% of the total nonconformities. There is a probability of 95% that the impact of the influenceable no risks is between 62,2% and 77,4% of the total impact.

This group, influenceable non-risks contains nonconformities that are the result of wrong execution of standard work. For instance paving asphalt, pouring concrete, but also many nonconformities of designs that cannot be executed on site.

Only a small percentage of the nonconformities are risks, on average 2,5%, and the standard deviation is 1,4%, which indicates that between 0% and 5,3% of the nonconformities of a project are risks. The impact of the risks is on average 15% of the total impact. There is a 95% probability that the nonconformities that are risks of a multidisciplinary project have an impact between 4,4% and 25,6% of the total impact.

Concerning the efficiency of the procedure, some remarks can be made. Performing the procedure is time consuming, approximately four hours for one hundred nonconformities for step one. The results show that the amount of no-impact nonconformities is high (Table 10). The impact is step 1.3, and before it is determined whether the nonconformity has an impact, two other questions need to be answered. This is inefficient because the answer “no impact” is enough to conclude that the nonconformity can be attributed to the category (choice, no impact, unknown).

Table 10 Amounts of no impact and no frequent nonconformities

	Project 1	*Project 3*	*Project 4*
Total amount of nonconformities:	827	672	617
Nonconformities with no impact:	243(29%)	257(38%)	199 (32%)

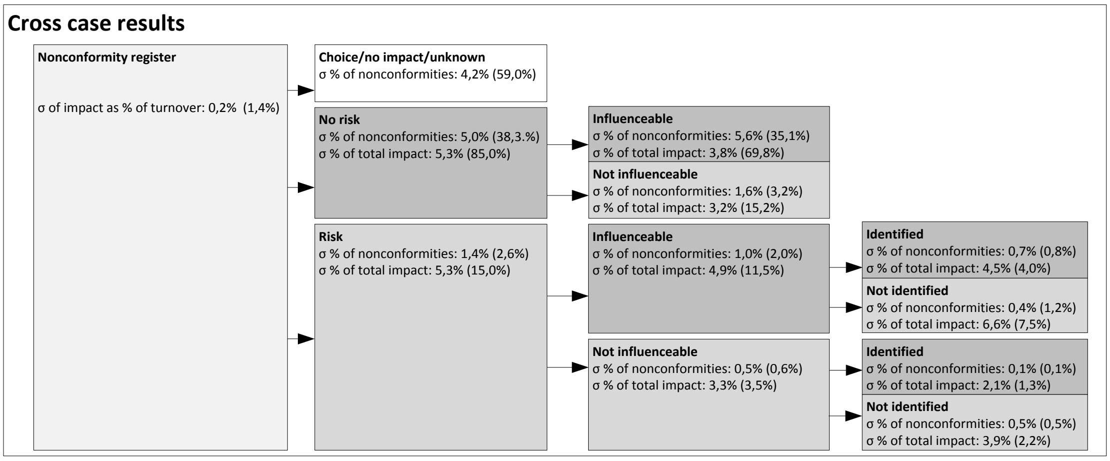

Figure 25 Cross case results of step 1 and 2

6.4.2. Step three

Concerning the reasons for non-identification, no patterns were found between the three projects. It could not be concluded that there was one reason for non-identification that was assigned often to all projects.

The risk managers would document 54% of the nonconformities that were classified as risk in their risk register. Approximately 23% of the nonconformities that were classified as risk, were explained as generic risks for the organisation and should not be managed using risk management. The other 23% of the nonconformities that were classified as risk were concluded by the risk managers as too specific.

While looking at the unidentified risks of all projects, four types of unidentified risks occurred multiple times (cameras, software, geotechnical, tar). At least two of the three projects contain unidentified risks that cover these areas. The first area is cameras: at projects one and four, the client or another stakeholder requested a different position of a camera than was designed. The other area is software, at project one and three, unidentified software risks occurred. The largest area is geotechnical, eight of the unidentified risks were assigned to this area. The last category is tar, at project three and four tar was found in an asphalt road that had to be demolished. High costs are involved with eliminating tar, because it can have an effect on the health of the employees, and it is chemical waste.

6.5. Validity discussion and conclusion

Using the results of the procedure the validity of the procedure can be discussed. If the procedure is valid, it indicates that it measures what it is intended to measure. This means that the nonconformities that are classified as risks are in fact risks, and the nonconformities that are classified as non-risks are in fact non-risks.

While looking at the results, it can be seen that on average 0,9% of the nonconformities were identified risks, these risks were identified as risk in the risk register of the project. This is a first indication that the procedure is valid, because it indicates that the risks are in fact risks.

As discussed in the cross case results section, a contribution to the validity of the procedure is the fact that the risk managers would document 54% of the nonconformities as risk in their risk register. Half of the risks that the risk managers would not document in their register, were classified by the risk managers as generic risks, the other half was classified as too specific to document in the project risk register. That the risk managers would classify a large percentage of the risks in their project risk register and that a large percentage, was classified as too specific to document in the project risk register. Indicates that the procedure classifies nonconformities into risks.

Concerning the non-risks, no tests were performed to determine whether the non-risks were in fact non-risks. The largest percentage of nonconformity was classified as non-risk. Therefore it is difficult to determine whether all these nonconformities are in fact non-risks. A possibility to perform this validation is to interview the project risk manager about a sample of nonconformities that were classified as non-risk. During this interview can be asked whether the risk manager would document these as risk in their risk register. If the answer is no for a majority of the nonconformities (for instance 90%) it indicates that the procedure is valid.

6.5.1. Validity conclusion

In this section the validity of the procedure is concluded. The research question concerning the validity was: *What is the validity of the procedure?* This question is answered using the results and the discussion of the validity.

Based on the validity tests it can be concluded that the procedure is valid. This indicates that the results of the procedure are the desired results. Hence, this conclusion is only based on the fact that the nonconformities that were classified as risks were in fact risks.

6.5.2. Limitation

The main limitation of this part of the research is that the validity of the non-risks was not tested. As described in the discussion section, further research can indicate whether the non-risks are in fact non-risks.

6.6. Discussion and conclusion of the results of the procedure

Within this section the cross case results of the procedure are discussed. After the discussion the results will be concluded. Finally, the limitations of the results are given.

6.6.1. Discussion of the results

Within this section the results of the procedure are discussed. First the results of step one and two are discussed, which is the classification of nonconformities into risk and non-risks. After that, the results of step three are discussed, step three is a determination of reasons for non-identification of the unidentified risks.

Results of step one and two

As discussed in the results section, there is a probability of 95% that the impact of the influenceable non-risk nonconformities of a multidisciplinary construction project at BAM is at least 62,2% of the total estimated impact of the nonconformities. For these nonconformities standard processes can be developed to manage them. Because BAM has influence on the cause of these nonconformities, they can be prevented from occurrence. Because the average total estimated impact of the nonconformities is 1,4% of the project revenue. The influenceable non-risks nonconformities are approximately (0,622*1,4=0,8) 0,8% of the project revenue. This indicates that there is a potential cost reduction of 0,8% of the total project revenue.

These nonconformities are nonconformities of standard processes. These standard processes are already defined within the organisation. However, it can be argued if these are managed sufficiently while looking at the total impact of the nonconformities. Much improvement is possible.

A possible improvement is to strengthen the QA/QC management, the influenceable nonconformities are the result of the execution of standard process which are the responsibility of the QA/QC manager. QA/QC means Quality assurance and Quality control. During quality assurance the standard process are developed, and during quality control these processed are checked to determine whether these processes are performed as designed and how they can be improved. It was determined that within BAM the QA/QC managers do not have the power to stop and improve the standard processes when they are not performed sufficiently. Strengthening the QA/QC management can therefore lower probably lower these costs. An important remark that should be made it that strengthening the QA/QC management will result in extra expenses and therefore all costs cannot be eliminated.

While reflecting the above percentage of 1,4% on rework costs in the construction industry which are estimated as 11% of the project revenue some interesting remarks can be made (USP, 2010):

First of all, the average estimated impact of 1,4% of the project revenue is only a small amount of the estimated total rework costs on construction projects of 11%. This research considered the nonconformities, which only consider the requirements. Clients of infrastructure projects do not specify requirements for the costs the contractor may make to construct the project. Before the projects starts is often agreed on a price that is paid by the client. Moreover, it is up to the contractor how much resources he uses to construct the work. The nonconformities therefore only consider a small part of the projects' rework.

In addition, the nonconformities that are documented are only a small part of the actual nonconformities. During the interviews it was obtained that nonconformities are often directly corrected after they occur without documenting it. Therefore the amount of actual nonconformities can be expected to be larger, and the total impact of the nonconformities is expect to be higher than 1,4% as well.

Results of step three

No patterns we indicated concerning the unidentified risks. There was not one reason for non-identification that was assigned mostly to all nonconformities. While looking at the assigned risk categories no patterns were indicated as well. Therefore no improvements can be suggested for the risk identification process. This is the result of the little nonconformities that were classified as unidentified risks, only 32 nonconformities were classified as unidentified risks. In order to be able to conclude about the unidentified risks, more projects can be analysed, which will result in more unidentified risks. An analysis of very risky projects can contribute to identify more unidentified risks.

While reflecting the unidentified risks to the identified risks some interesting remarks can be made. The number of unidentified risks is low when compared to the total amount of risks that were identified on the projects. For example, project four has a total number of 300 identified risks and 8 nonconformities were classified as unidentified risks. Therefore, it cannot be concluded that the risk identification is performed poorly.

It can also be argued what the value of the unidentified risks is to include them in a risk database. While comparing the impact of the unidentified occurred risk with the risk identification impact categories some interesting remarks can be made. The lowest risk identification impact category within the organisation is determined as 0,05% of the total contract value. For project one this will mean: €120.000.000*0,05%=€60.000. Reflecting this on the occurred risks of project one which have an average impact of (15,2%*1.700.000)/(827*1,2%)=€26.000 the risks have a lower impact than the lowest risk identification category. Therefore the added value of the unidentified risks of the three analysed projects is small. Including these risks in a risk database, will not result in a high added value. If other types of projects or more projects are analysed it can result in more unidentified risks, with a higher added value.

The fact that not many unidentified risks were identified does not indicate that the risk management is performed sufficiently. Risk management considers more than the requirements (and a nonconformity is a non-compliance to a requirement), it also considers for instance the planning and the costs. Therefore it cannot be concluded that the risk management is performed sufficiently.

In order to be able to conclude whether the risk management is performed sufficiently other ways to identify unidentified risks can be explored. These can focus on other aspects than the nonconformities. As discussed in the theoretical background, almost all risks results in a financial impact. Therefore an analysis on the projects' finance can be used to identify these risks.

6.6.2. Conclusion

Within this section is concluded on the research question: *What are the results of the procedure?* This question is answered using the above discussion of the results.

It can be concluded that within BAM as construction company the majority of the nonconformities are frequent and influenceable. These nonconformities are the result of standard processes that were performed during projects. BAM has influence on these processes. In order to eliminate these nonconformities BAM should focus on better performing these standard processes, for instance by strengthening the QA/QC management.

In addition, not many unidentified risks were identified from the nonconformities, no patterns could have been identified of these unidentified risks. It can also not be concluded that there are shortcomings to the risk identification process.

While looking at the three analysed projects, the added value of unidentified risks for BAM is low. The identified risks of the three projects are not of a size that including them in a risk database will result in added value for future projects. Further research on more and more risky projects can increase this added value.

6.6.3. Limitations

The two limitations about the results are:

First of all, the nonconformities were classified by the author and compared with a sample of 10% performed by the project risk manager. This was performed due to the time consumption of performing the procedure of all nonconformities. If the procedure is implemented within the organisation, the nonconformities can best be classified directly after they occur, the time consumption is than spread over the whole project instead of all in once.

Another limitation is that only three projects were analysed. Although these three projects were representative for the organisation (as discussed in the method section), no conclusions can be drawn about the unidentified risks.

7. Discussion

In the previous sections all sub-questions were discussed and answered. In this section will be reflected on the main research question. The main research question is: *What procedure can be developed that classifies nonconformities into risk and no-risk?*

First, the answers of the sub sub-questions will shortly be given, these answers together should answer the main research question. After that will be reflected on the contribution of this research to the research problem as defined in the method section. Finally, the efficiency of the procedure will be discussed.

7.1. Reflection on the main research question

In this section is reflected on the main research question. First the answers of the sub-questions are given. With these answers the main research question is reflected.

The answers of the first two sub-questions result in a theoretical procedure that is empirically tested. This procedure can be used to classify nonconformities into risks and non-risks by answering four questions of each nonconformity. After these four questions are answered, the risks can be selected. A comparison with the risk register leads to unidentified risks. The project risk manager will be interviewed about these unidentified risks to determine why these risk were unidentified. This can lead to improvements of the risk identification process.

The reliability of the procedure is concluded to be low. It is expected that this is caused by the fact that many nonconformities are documented poorly. The reliability of the frequency step is very low, and since it is the most important step to determine whether a nonconformity is a risk, more research concerning the reliability of the procedure is necessary.

The procedure is valid. This is based on the facts that identified risks were also identified and that the unidentified risks were classified as risk by the project risk manager. Whether the non-risks are in fact non-risks is not tested.

The results of the procedure show that the majority (38.3%) of the nonconformities of the three analysed projects are influenceable non-risks, while 59% of the nonconformities were classified as choice/unknown/no impact. BAM as a construction company has influence on the occurrence of these nonconformities and they are the result of the execution of standard work. The unidentified occurred risks as a result of the three analysed projects have a low added value. No shortcomings in the risk identification of the organisation can be concluded.

The above answers on the sub-questions can be used to reflect on the main research question. *What procedure can be developed that classifies nonconformities into risk and no-risk?* The procedure that is developed provides expected results; it classifies nonconformities into risks and non-risks. However, the results of the analyses can have been influenced by the loss of information between what was actually happened and what was documented. The analyses of the three projects were performed with the documented information of nonconformities. Due to the poor documentation of nonconformities it is possible that nonconformities that are in fact risks are classified by the risk manager and the author as non-risks. The validity tests do not provide from this outcome because they only consider the documented information and not what actually happened. As discussed before, during further research more projects can be analysed, and the nonconformities can directly be classified after they occur.

7.2. Contribution to the research problem

The results of this research can also be used to discuss the contribution to the research problem. The research problem is: *As a construction company, BAM does not know what* *unidentified risks occur during construction projects and there is little or no insight in the nature of the nonconformities that are documented during construction projects.*

The research problem consists of two parts, the first part is that BAM does not know what unidentified risks occur during construction projects. While reflecting on this first part it can be stated that the results of this procedure provide insight in what unidentified risks occur. However, as discussed in section 6.1.1, it does not identify all unidentified occurred risks. More research can be performed to identify unidentified risks, for instance by analysing the financial records of projects.

While reflecting on the second part of the research problem it can be argued whether the procedure provides insight in the nature of the nonconformities that are documented at construction projects. The nonconformities of three construction projects were analysed using the developed procedure. The results of these three analysed projects provide insight in the nature of the nonconformities at BAM. On average 38,3% of the nonconformities are influenceable non-risk. While 59% of the nonconformities are a choice, have no impact, or are unknown. The impact of the influenceable non-risks is in average 69% of the total impact of the nonconformities. The nature of nonconformities can thus be concluded to be influenceable non-risks.

7.3. Efficiency of the procedure

In this section the efficiency of the procedure is discussed. The efficiency is important when the procedure is implemented within an organisation. During the research is was obtained that the efficiency of the procedure can be improved by changing the sequence of the procedure.

A nonconformity that has no impact is not a risk. However, the impact is determined within step 1.3 of the procedure, and thus information is already collected that will not be used. In addition, as showed in the results section (§6.4.1), at least 29% of the nonconformities of each project have no impact. Therefore, the procedure can probably be made more efficient when the impact step becomes the first step. The procedure can end if the nonconformity has no impact.

Within this research, the procedure was applied after all nonconformities were documented. This is inefficient because only the documented information can be used. If the procedure is implemented, it can be more efficient to perform step one of the procedure during the project as part of the documentation of nonconformities. If the documented data does not contain enough information to classify the nonconformities the responsible person can be contacted in order to obtain this information. This can lead to less time consumption and a higher efficiency. In addition, the work load of classifying nonconformities will be spread more equally over the project.

8. Conclusion

The conclusion can be given by answering the main research question of this research: *What procedure can be developed to classify nonconformities into risks and non-risks?* This question was answered by answering the sub-questions of this research.

The procedure that was developed can be used to classify nonconformities into risks and non-risks. This procedure consists of three steps. Within the first step nonconformities are classified. The second step determines whether the nonconformities are risks. Within the third step reasons for non-identification are identified to determine improvement possibilities for the risk identification. Appendix 1 shows the final procedure, the sequence changes that were proposed in the discussion section are incorporated in this procedure.

The reliability of this procedure is low. This may be caused by the poor documentation of nonconformities within the organisation which created ambiguity by the two respondents of the reliability tests.

The procedure is considered to be valid. This is based on tests of the procedure on three multidisciplinary construction projects. This validity tests show that most (54%) of the nonconformities that are classified as risks are in fact risks. It was not tested whether the nonconformities that were classified as non-risks are in fact non-risks.

The procedure was performed on three multidisciplinary construction projects. On average 59% of the nonconformities can be assigned to the category: no impact, choice, unknown. Which indicates that the nonconformity was either a choice of the organisation, that the nonconformity had no impact, or that not enough data was documented to classify a nonconformity. An average of 35% of the nonconformities were assigned to the category, frequent, influenceable. These nonconformities are responsible for 70% of the estimated impact of the nonconformity. These nonconformities can be managed by improving standard processes that are defined within the organisation.

31 unidentified risks were identified using the procedure and reasons for non-identification were assigned to these risks. Using these results no improvements for the risk identification can be suggested. More data is necessary to be able to conclude improvements.

8.1. Theoretical relevance

This research proposes a new approach of classifying nonconformities. Much research has been performed concerning nonconformities, their costs and their causes much has been written about the causes and the cost of nonconformities (Abdul-Rahman et al., 1996; Burati Jr et al., 1992; Love & Li, 2000; Love et al., 1999). However, nonconformities have not often been related to risk. For instance, Josephson and Hammarlund (1999) determine risk as one of the causes of nonconformities. The procedure presented in this research, is a new approach of classifying nonconformities. It classifies nonconformities into risks and non-risks and shows whether a contractor can influence these nonconformities.

8.2. Practical relevance

The results of this research have several contributions to the construction practice:

First, the developed procedure can be used by contractors in the whole construction industry to determine whether the nonconformities that were documented are risks or non-risks. When implemented in an organisation the results of the procedure provide insight in the nature of nonconformities to be able to eliminate them. It can be used as part of a trend analysis of the nonconformities that are occurring within construction projects. Because it shows whether the nonconformities are risks or non-risks and whether these are influenceable or not, it can provide insight in which nonconformities the contractor should focus on. By performing the procedure during the project it can even be used by the project management during the project as a management tool to provide insight in which nonconformities can be eliminated.

Moreover, the procedure can also be used by contractors to identify unidentified risks. These unidentified risks can be included in a database and used as input for future projects. Moreover, it can also provide from improvement suggestions for the risk identification.

Specifically for BAM the nonconformities that are non-risk can be included in the “verbeterdatabase” (improvement database). This database which BAM is developing uses nonconformities of construction projects to improve the execution of standard processes. The nonconformities that are classified as non-risks can be included in this database.

For BAM as organisation this research created awareness of the relation between nonconformities and risks. In advance of this research nonconformities were specifically part of the work of the QA/QC manager. The many interviews performed during this research provided awareness within the organisation that nonconformities contain valuable information that can be used to improve the execution of standard work and risk management. Next to that, it especially provided insight within the organisation that the standard operating processes are not sufficient.

8.3. Limitations

Within this research there were several limitations that could have affected the results. First the main limitations of this research are given, after that the limitations of the reliability and validity tests are shortly summarised.

The analyses of the projects were performed by the author and verified by the risk manager of the project for a sample of 10% of the nonconformities. This could have had its effect on the results of the analyses. For instance, the impact of the nonconformities was estimated by the risks manager and by the author, which are both no cost experts.

The procedure was tested on a limited amount of projects. The reliability was tested on two projects, while the validity was tested on three projects. Due to the limited time available for this research only a limited amount of projects could be analysed. However, the projects that were analysed can be considered as representative for the organisation.

The procedure uses documented information of nonconformities. This information is not always complete what could have affected the results.

Reliability

- A small sample of 100 nonconformities was used to test the reliability.

Validity

The validity of the non-risks was not tested, due to the limited time available for this research.

9. Recommendations

Based on the discussion and conclusion of this research several recommendations can be formulated. These recommendations are split into recommendations for further research and recommendations for the organisation.

9.1. Recommendations for further research

Pilot test the reliability: In order to further test the reliability, a pilot study is recommended. During this pilot the nonconformities of a project have to be classified directly after they occur by two persons independently. It is recommended that the QA/QC and risk manager classify 200 nonconformities of a construction project directly after they occur. A comparison of the results will show the reliability.

More research into the frequency step: The frequency step (1.4) was the most unreliable step of the procedure. It is recommended to perform more research concerning this step. That research should focus on amplifying the description of the frequency step, and can be performed by interviewing risk and QA/QC managers about nonconformities with a varying frequency. This can provide insight in when a nonconformity is due to a standard process and when it is a risk.

More research into the validity of non-risks: It is recommended to perform more research into the validity of the non-risks. Due to the limited time it was not tested whether the nonconformities that were classified as non-risks are in fact non-risks. A possibility to perform this validation is to interview the project risk manager about a sample of nonconformities that were classified as non-risk. During this interview can be asked whether the risk manager would document these as risk in the risk register. If the answer is no for a large percentage of the nonconformities (for instance 90%) it indicates that the procedure is valid.

More and different projects and organisations: The procedure was tested on three multidisciplinary projects of one contractor. It is recommended to test the procedure on more organisations and on different types of construction projects. When analysing different organisations, it can be determined if the pattern that was found within BAM, (the largest amount of nonconformities are non-risks) is normal for the construction industry. In addition, applying the procedure to very risky projects would be interesting because on those projects it is expected that a higher percentage of the nonconformities are risks.

Different sectors: Finally it is recommended to test the procedure within different sectors. This research applied the procedure on the construction industry. It is possible that the procedure can also be applied in other sectors such as the oil and gas or offshore industry. Within these industries the margins are often higher than in the construction industry, which allows less attention to nonconformities.

9.2. Recommendations for the organisation

For BAM as organisation several recommendations were formulated:

Improve execution of standard processes: First, it is recommended for BAM to focus on a better performance of the standard process. 70% of the estimated impact of the nonconformities is caused by the (wrong) execution of standard processes. In order to improve the execution of standard process it is recommended to focus on improving the QA/QC management within BAM. This can be performed by an in depth analysis of frequent, non-risk nonconformities. Important is that these nonconformities are not documented a long time ago, background information can then be obtained by the responsible persons.

Focus on correct documenting nonconformities: In order be able to perform the procedure, it is recommended to improve the way nonconformities are documented. One of the results of the reliability tests was that ambiguity was created due to the way nonconformities are documented. Clear unambiguous descriptions can improve the reliability.

Stimulate documenting nonconformities: It is recommended to stimulate the documentation of nonconformities. During the interviews it was determined that many nonconformities are corrected directly after they occur and not documented as nonconformity. Stimulating the documentation of nonconformities can provide more insight in the total amount of nonconformities. These can then be analysed using the procedure providing more insight in the nature and costs of nonconformities.

Analyse the projects' finance: If BAM strives to identify all unidentified occurred risks, it is recommended for BAM to analyse the financial results of projects. Nonconformities consider the non-compliances to requirements, while risks can also be related to time or finance, if no requirements are specified for time or financial aspects of the project, no nonconformities will be documented of these aspects. As determined during the literature study, risks have a financial impact. While looking at the cost overruns, other unidentified risks can be identified, then by analysing nonconformities.

Implement the procedure within the organisation: Implementing it will provide BAM from useful information on how the nonconformities can be eliminated. If the procedure is implemented within the organisation, and the results are mapped during the time it can give an indication of the progress BAM is making to improve the execution of standard work. If at all projects less nonconformities of the category frequent, influenceable are documented during the time it can indicate an improvement. Table 11 shows the four extra fields that should be filled in of each nonconformity to enable using the procedure, appendix 1 shows more information.

Document step one directly after occurrence: If the procedure is implemented, it is recommended to perform the first step of the procedure directly after the nonconformity has occurred. In case the nonconformity is not documented clearly, responsible persons can be asked.

Use the risk database and the "verbeterdatabase" (improvement database): The implementation of the procedure will be most successful when it is supported by the use of the risk database and the "verbeterdatabase" (improvement database). The output of the procedure can be used as input of these both databases. The risks can be included in the risk database and the non-risks can be included in the "verbeterdatabase". Using both databases can improve the risk management and the execution of standard processes.

Table 11 Information to document of each nonconformity

Step name	Short description
1.1. Impact	Estimate the impact
1.2. Choice	Determine whether the nonconformity was a choice of BAM
1.3. Influenceability	Determine the influenceability of the cause of the nonconformity by BAM
1.4. Frequency	Determine whether the probability of occurrence could have been calculated, or whether it is the result of a standard process or not.

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Appendices

1. Overview procedure
2. Analysis of 200 nonconformities
3. Search terms in Scopus
4. List of interviewed persons
5. Question list and focus group discussion
6. Nonconformities that are unidentified occurred risks of project 1
7. Nonconformities that are unidentified occurred risks of project 3
8. Nonconformities that are unidentified occurred risks of project 4

1. Overview procedure