The risk management process for bridges

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Graduation project

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Summary

Many bridges in the Netherlands suffer from overdue maintenance. The overdue maintenance increases risks and these risks are not managed properly by the owner (Rijkswaterstaat, Provinces, Prorail). But what are the risks? What is the condition of the bridge? And how should a risk be managed?

Before going into the risk management process, it is important to understand what risk is and how risk can be managed. A risk is ''An uncertain event that is affecting on a positive or negative way''. In this research, the focus is on internal risk, risks that are initiated inside the project. Risk management is defined as the process to identify, and assess risks and to apply methods to reduce risks to an acceptable extent. Risk management consist of five steps:

1. risk planning;
2. risk identification;
3. risk analysis;
4. risk response;
5. risk monitoring and control.

To make risk management function effectively and efficiently, it is necessary to have a proper and systematic methodology in place to periodically perform a risk analysis. But what is the method behind risk management? A review of the literature has shown that there are at least 36 different techniques available to identify and analyze risks. However, only a handful of these is used in practice. The methods that are used do not stimulate that risks, problems, remedial measures and lessons learned from previous projects be captured and reused when developing new projects. There is at this moment no perfect risk management method. The main challenge that Movares faces is the reuse of the knowledge and lessons stored within the documents. Knowledge management and document management has become a crucial issue in modern construction projects and maintenance.

The aim of this research for Movares is to find an efficient risk management process. In this research, the central research question was: *How can risk management at Movares for bridges be improved?* This research aims to give a solution to performance problems, which requires solution-oriented research. To structure the research the regulatory cycle is used. The regulatory cycle is a common, practice-oriented research method that focuses on decision making. The regulatory cycle consists of five phases,1) Problem definition 2) Diagnosis 3) Design 4) Implementation 5) Evaluation. The first four phases will be considered in this research.

For an efficient risk management process, it is important to start by laying down the current process: what it looks like, how it functions and if there are any problems. The current risk management process has a basic process that has two kinds of optional activity. The basic process starts with the assignment of the project, creates an FMECA and ends with a report of the findings. The first optional activity is to perform a fault tree analysis and the second optional activity is to perform an inspection. The current process has two large bottlenecks, the first one is Excel. Excel is not a user-friendly application to work with. If you want to use a specific part again through cut and paste, formulas in Excel can easily get broken.

Reuse of lines and tables is difficult. It is also not feasible to do adjustments on location during the inspection. Another point is that Excel is error sensitive in the sense that replacing a formula with a number, may cause the calculation to no longer be correct when other changes occur. The final thing about Excel that the experts mentioned is that the risk analysis table is too big, so there is no clear overview. The second category is having a database. There is no database available with information for reuse. The experts must search every time again for the information. There also is no standard list of risks controlling measures.

To get a complete overview of what a risk management process look like, requirements in four categories are prepared. The four categories are requirements from literature, Movares requirements, Customer requirements, and user requirements. Out of the results, the conclusion can be drawn that the current risk management process at Movares does not meet the requirements. The current risk management process steps are lacking with respect to several requirements. With respect to the requirements from literature, knowledge management is not adequately implemented. The current process lacks a database and communication storage, and with this, the possibility for reusing lessons learned aside from the knowledge in consultants' heads. In addition, with respect to the Movares requirements, the process lacks (1) standardization, and with this adaptability, (2) the link with Redesign and Relations, (3) the possibility for 3D visualization, and (4) an efficient way to insert inspection results. For Customer requirements, the current process meets the requirements. With respect to the user requirements, the process lacks (1) a clear overview of the risk table and a professional appearance, and (2) a user-friendly application for performing the risk analysis since Excel does not meet the requirements. Out of the subsequent analysis, it followed that the most obvious aspects to improve are:

- Standardization;
- Database;
- Connection with Redesign;
- Interface for risk analysis;
- Lessons learned.

To improve the risk management process, a database library with standard risks and risk measures as well as a new FMECA application is needed. After analyzing 20 different FMECA's the conclusion is that there is much variation in the resulting data in the FMECA. This is often the case because different terms are used for the same information. In addition to this, there are spelling mistakes, cryptic descriptions, and information ending up in the wrong cell. But the conclusion is also that it is possible to standardize the decomposition and some of the columns that describe the function and possible failures. With a database library containing these standardized FMECA parts, two steps in the risk management process can be improved, namely the decomposition step and the desk study step. This yields more consistent products, higher quality and increased working speed. But the database does not ensure that all the requirements are met. To ensure that more requirements are met a better version of the risk analysis application is needed. Out of the research, Relatics emerged as the best option. With Relatics many quality improvements will be done, it will save time and there are more possibilities for new technologies in the future. To come back to the research question, the risk management process can be improved to create a database and to switch from Excel to Relatics. With these improvements, most of the requirements will be met.

Samenvatting

Veel bruggen in Nederland hebben last van achterstallig onderhoud. Het achterstallig onderhoud verhoogt de risico's en deze risico's worden niet goed beheerd door de eigenaren (Rijkswaterstaat, Provincies, Prorail). Maar wat zijn de risico's? Wat is de toestand van de brug? En hoe moet een risico worden beheerd? Voordat we ingaan op het risicomanagementproces, is het belangrijk om te begrijpen wat het risico is en hoe het risico kan worden beheerd. Een risico is '' Een onzekere gebeurtenis die van invloed is op een positieve of een negatieve manier ''. In dit onderzoek ligt de focus op interne risico's, risico's die binnen het project worden geïnitieerd. Risicomanagement is gedefinieerd als het proces om risico's te identificeren en te beoordelen en om methoden toe te passen om risico's tot een aanvaardbare mate te beperken. Risicomanagement bestaat uit vijf stappen:

1. Risico planning;
2. Risico identificatie;
3. Risicoanalyse;
4. Risicoreactie;
5. Risicobewaking en -controle.

Om risicomanagement effectief en efficiënt te laten functioneren, is het noodzakelijk om een goede en systematische methodologie te hebben om periodiek een risicoanalyse uit te voeren. Maar wat is de methode achter risicomanagement? Een literatuuronderzoek heeft aangetoond dat er ten minste 36 verschillende technieken beschikbaar zijn om risico's te identificeren en te analyseren. Echter wordt slechts een handvol hiervan in de praktijk gebruikt. De gebruikte methoden stimuleren niet dat risico's, problemen, corrigerende maatregelen en lessen die zijn getrokken uit eerdere projecten worden vastgelegd en hergebruikt bij het ontwikkelen van nieuwe projecten. De grootste uitdaging voor Movares is het hergebruik van de kennis en lessen die in de documenten zijn opgeslagen. Kennisbeheer en documentbeheer is een cruciale kwestie geworden in moderne bouwprojecten en onderhoud.

Het doel van dit onderzoek voor Movares is om een efficiënt risicomanagementproces te vinden. In dit onderzoek was de centrale onderzoeksvraag: Hoe kan het risicomanagementproces bij Movares voor bruggen worden verbeterd? Dit onderzoek wil een oplossing bieden voor prestatieproblemen, waarvoor oplossingsgericht onderzoek vereist is. Voor het structureren van het onderzoek wordt de reguleringscyclus gebruikt. De reguleringscyclus is een gebruikelijke, praktijkgerichte onderzoeksmethode die zich richt op besluitvorming. De reguleringscyclus bestaat uit vijf fasen, 1) Probleemstelling 2) Diagnose 3) Ontwerp 4) Implementatie 5) Evaluatie. De eerste vier fasen worden in dit onderzoek behandeld.

Voor een efficiënt risicobeheerproces is het belangrijk om te beginnen met het vastleggen van het huidige proces: hoe het eruit ziet, hoe het werkt en of er problemen zijn. Het huidige risicobeheerproces heeft een basisproces dat twee mogelijke soorten optionele activiteiten heeft. Het basisproces begint met de toewijzing van het project, het maken van een FMECA en eindigt met een rapport van de bevindingen. De eerste optionele activiteit is om een foutboomanalyse uit te voeren en de tweede optionele activiteit is om een inspectie uit te voeren.

Het huidige proces kent twee grote knelpunten, de eerste is Excel. Excel is geen gebruiksvriendelijke applicatie om mee te werken. Wanneer er een specifiek onderdeel opnieuw gebruikt dient te worden via knippen en plakken, kunnen formules in Excel gemakkelijk worden verbroken. Hergebruik van lijnen en tabellen is moeilijk. Het is ook niet mogelijk om tijdens de inspectie op locatie aanpassingen te doen. Een ander punt is dat Excel foutgevoelig is, in die zin dat het vervangen van een formule door een getal ervoor kan zorgen dat de berekening niet meer correct. Het laatste punt van Excel dat de experts noemden, is dat de tabel met risicoanalyses te groot is, dus er is geen duidelijk overzicht. De tweede categorie is het hebben van een database. Er is geen databases beschikbaar met informatie voor hergebruik. De experts moeten telkens opnieuw zoeken naar de informatie. Er is ook geen standaardlijst met risicobeheersingsmaatregelen.

Om een volledig overzicht te krijgen van hoe een risicomanagementproces eruitziet, worden vier categorieën eisen gezocht waaraan het proces moet voldoen. De vier categorieën zijn vereisten uit de literatuur, vereisten van Movares, eisen van de klant en gebruikersvereisten. Uit de resultaten kan de conclusie worden getrokken dat het huidige risicomanagementproces bij Movares niet aan de vereisten voldoet. De huidige risicobeheerprocesstappen ontbreken met betrekking tot verschillende vereisten. Met betrekking tot de eisen uit de literatuur is kennismanagement niet adequaat geïmplementeerd. Het huidige proces mist een database- en communicatieopslag, en daarmee de mogelijkheid om lessen te hergebruiken die zijn opgedaan naast de kennis in de hoofden van consultants. Met betrekking tot de vereisten van Movares ontbreekt het proces bovendien (1) standaardisatie en met dit aanpassingsvermogen, (2) de link met Redesign en Relatics, (3) de mogelijkheid voor 3D-visualisatie en (4) een efficiënte manier om inspectieresultaten in te voegen. Voor klantvereisten voldoet het huidige proces aan de vereisten. Met betrekking tot de gebruikersvereisten mist het proces (1) een duidelijk overzicht van de risicotabel en een professionele uitstraling, en (2) een gebruiksvriendelijke toepassing voor het uitvoeren van de risicoanalyse aangezien Excel niet voldoet aan de vereisten. Uit de daaropvolgende analyse volgde dat de meest voor de hand liggende aspecten om te verbeteren zijn:

- Standaardisatie;
- Database;
- Verbinding met Redesign;
- Interface voor risicoanalyse;
- Toepassen van de geleerde lessen.

Om het risicobeheerproces te verbeteren, is een databasebibliotheek met standaardrisico's en risicomaatregelen en een nieuwe FMECA-toepassing nodig. Na de analyse van 20 verschillende FMECA's is de conclusie dat er veel variatie is in de ingevoerde gegevens in de FMECA. Dit is vaak het geval omdat voor dezelfde informatie verschillende termen worden gebruikt. Daarnaast zijn er spelfouten, cryptische beschrijvingen en is er informatie die in de verkeerde cel terechtkomt. De conclusie is ook dat het mogelijk is om de decompositie en een aantal kolommen die de functie en het mogelijke falen beschrijven, te standaardiseren.

Met een databasebibliotheek die deze gestandaardiseerde FMECA-onderdelen bevat, kunnen twee stappen in het risicomanagementproces worden verbeterd, namelijk de decompositie en de stap van de bureaustudie. Dit levert meer consistente producten, hogere kwaliteit en een hogere werksnelheid op. Maar de database garandeert niet dat aan alle vereisten wordt voldaan. Om ervoor te zorgen dat aan meer eisen wordt voldaan, is een betere versie van de applicatie voor risicoanalyse nodig. Uit het onderzoek kwam Relatics naar voren als de beste optie voor een nieuwe applicatie. Met Relatics zullen veel kwaliteitsverbeteringen worden gedaan, het zal tijd besparen en er zijn in de toekomst meer mogelijkheden voor nieuwe technologieën. Om terug te komen op de onderzoeksvraag het risicomanagementproces kan worden verbeterd door een database te maken en van Excel naar Relatics te schakelen. Met deze verbeteringen zal aan de meeste eisen worden voldaan.

Abstract

Many bridges in the Netherlands suffer from overdue maintenance. The overdue maintenance increases risks and these risks are not managed properly by the owner. But how should a risk be managed? To make risk management function effectively and efficiently, it is necessary to have a proper and systematic methodology in place to periodically perform a risk analysis. A review of the literature has shown that there are at least 36 different techniques available to identify and analyze risks. However, only a handful of these is used in practice. The methods that are used do not stimulate that risks, problems, remedial measures and lessons learned from previous projects be captured and reused when developing new projects. The aim of this research is to find an efficient risk management process. In this research, the central research question was: *How can risk management at Movares for bridges be improved?* This research aims to give a solution to performance problems, which requires solution-oriented research. To structure the research the regulatory cycle is used. The regulatory cycle consists of five phases,1) Problem definition 2) Diagnosis 3) Design 4) Implementation 5) Evaluation. The first four phases will be considered in this research. Out of the results, the conclusion can be drawn that the current risk management process at Movares does not meet the requirements. The current risk management process steps are lacking with respect to several requirements. To improve the risk management process, a database library with standard risks and risk measures as well as a new FMECA application is needed. After analyzing 20 different FMECA's the conclusion is that there is much variation in the resulting data in the FMECA and that it is possible to standardize the decomposition and some of the columns that describe the function and possible failures. The database does not ensure that all the requirements are met. To ensure that more requirements are met a better version of the risk analysis application is needed. Out of the research, Relatics emerged as the best option. With Relatics many quality improvements will be done, it will save time and there are more possibilities for new technologies in the future. To come back to the research question, the risk management process can be improved to create a database and to switch from Excel to Relatics. With these improvements, most of the requirements will be met.

1. Introduction

The research in this thesis has been done in collaboration with Movares, one of the leading Dutch consulting engineers which employ over 1000 highly qualified engineering professionals. Movares stems from the rich tradition since 1839 of Dutch railroad design. In 1990, railroad design got its own engineering department within NS. Because of European regulations, in 1995, this engineering department became a legally independent company under the name Holland Railconsult. This was also the time of the mega projects such as the *Hogesnelheidslijn* and the *Betuweroute* to which Holland Railconsult made an important contribution. In 2001 the company was sold by NS and a management buyout followed. Holland Railconsult developed from a niche player in the field of rail to a consultancy and engineering firm with a much broader scope. Although rail is still an important focus for the company, the name Holland Railconsult no longer fit. Since May 1, 2006, the company operates under the name Movares Nederland BV.

In recent years Movares has expanded from traditional railway engineering to a leading agency of designers for an accessible and livable environment. Their motto is: We connect. Movares is currently active in eight different fields, to know: rail, light rail, infrastructure, public transport, mobility, power, water, and urban development. The RAMS and risk management department of Movares initiated this research. This group cooperates with Movares colleagues from everywhere in the organization.

The fields in which Movares is active, are mirrored in the organizational structure of Movares with different groups representing the corresponding themes. The groups are organized in departments and the department heads report directly to the Movares management board, which consist of a CEO and a CFO. The management board reports to the supervisory board.

The customers of Movares can be divided into eight groups, varying from organizations such as ProRail and Rijkswaterstaat to contractors and energy suppliers. In figure one, the customers and the groups are shown.

Figure 1 Customers of Movares

Two points make that Movares is different than other engineering companies. Firstly they see their employees as their partners. More than half of the employees own 70% of the shares. Secondly the sustainable business. They have the lowest CO2 footprint of all engineering companies, for example, all their offices are walking distance from train stations. What ensures that there is only a small lease car park required. The offices themselves are certified as BREEAM Very Good.

The projects of Movares are large and there are always hard deadlines, a small time frame, large amounts of money involved, attention for safety and sustainability and public attention. What is built must function properly with the least possible failure costs, and consequential damage, with low maintenance and long service life. Moreover, it must be demonstrably safe. Movares organizes the development process in such a way that the result effectively and demonstrably meets all safety and availability requirements. Such a development process requires a form of risk management. This risk management is provided by group RAMS and risk management. A natural question to ask is 'How does Movares manage the risks in large projects?' Examples of large projects in which safety and availability risk analysis are performed are dedicated assignments such as RINK and IAK2020 for Rijkswaterstaat, the Dutch government body that manages the infrastructure of roads, waterways. Here, Movares advises Rijkswaterstaat on long term maintenance of assets such as bridges, water locks, etc. The risk analysis is performed in the Rijkswaterstaat FMECA format, and the project requires much interaction with the Rijkswaterstaat organization in order to verify the input and maximize the utilization of the resulting advice. Similar activities are performed for regional government bodies such as the Province of South Holland.

1.1 Problem analysis

Figure 2 Genoa bridge collapse (Chryssanthopoulos, 2018)

Infrastructure projects are robust projects and go well in most cases, although unfortunately, incidents sometimes occur. On August 14, 2018, during lunch hour the Ponte Morandi in Genoa collapsed. More than 100 meters of the multi-span, cable-stayed suspension bridge, completed just over 50 years ago (Chryssanthopoulos, 2018) came down and killed 43 people. How was this possible? This example was in Italy, but it is not impossible in the Netherlands either, recently the Dutch media published several new items about the condition of the bridges in the Netherlands. EenVandaag published an item about the analysis of maintenance reports for bridges and overpasses in North-Holland. The analysis stated that dozens of bridges and viaducts in the province of North-Holland show such serious problems due to overdue maintenance, that there is an unacceptable risk of collapse (Edelenbosch, Lammers, & Spit, 2018). The NOS published an item about the maintenance of bridges as well. They stated that billions of euros are needed for the maintenance of bridges and overpasses (NOS, 2019). NOS also published an article about the Merwedebrug 'Merwedebrug almost collapsed, the Netherlands escaped a disaster' (NOS, 2019).

From such news items, one can conclude that many bridges in the Netherlands suffer from overdue maintenance. The overdue maintenance increases risks and these risks are not managed properly by the owner (Rijkswaterstaat, Provinces, ProRail). But what are the risks and what is the condition of the bridge? All of this is a reason for Movares to critically review whether their risk management for bridges is in order.

Risk management has two functions. The first is to avoid problems and enhance the success of an activity, process or project. The second one is it provide or deliver ideas or indication for the improvement of systems or processes.

A review of the literature (see chapter two) shows that there are at least 36 different techniques available to identify and analyze risks. However, numerous studies have shown that only a handful of these are used in practice. According to (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011) in construction projects, classical quantitative methods for risk assessment are used. According to (Serpell, Ferrada, Rubio, & Arauzo, 2015) and (Dikmen, Birgonul, Anac, Tah, & Aouad, 2008), the classical methods do not stimulate to record data such as risks, issues, actions taken to resolve them as well as lessons learned. If such data is recorded It can be used for the development of new projects. A change is necessary in risk management philosophy from “management of adverse “effects” to “learning from risks to eliminate risks at the first place” (Dikmen, Birgonul, Anac, Tah, & Aouad, 2008).

Atkinson et al. argue that readily available repositories of risk data from past projects are fundamental to the quality of estimates. Learning from risks may lead to a construction of more realistic risk models and better-informed guesses about the future. Before, during and after a project analysis can be carried out to understand risk impacts and identify the reasons for success and failure. Thus, it is believed that a focus on “learning from risks” may enhance the risk management process. Learning from risk events that have occurred can be facilitated by a risk memory in which risk-related information is stored and updated throughout a project's life cycle. One of the common developments addresses the risk management function from a knowledge-based perspective and may be based in a web application that can then be made available through the whole organization (Serpell, Ferrada, Rubio, & Arauzo, 2015).

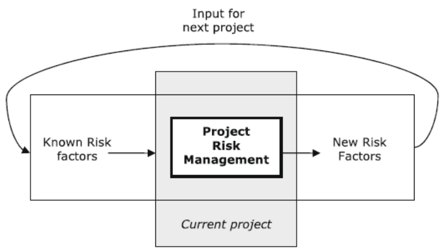

Figure 3 the evaluation approach to project risk management

However, at Movares the full deployment of risk management seems to be hampered. The problem that prevails at Movares is that the risks for their clients are managed in large Excel files. These Excel files are different since, for almost every new project, a new file format is developed to fit the requirements of the client. This way of doing risk analysis has a few benefits. The first benefit is that it gives freedom for changes. The second benefit is that it stimulates careful thinking. And the last benefit is that it ensures customization. There are also disadvantages. The first disadvantage is that at this moment risk management is time-consuming since the consultants of Movares develop a new file format for nearly every project. The second disadvantage is that there are no standard work methods and there is no list with standard risks or the most common risks for example bridges.

The time required for creating a new working file (for example Excel) and filling in the standard/most common risk leaves less time to find the risks that are unique in the project. The third disadvantage is that the current method does not stimulate to learn from previous projects. At this moment there are no facilities to enable this. There is, for example, no central data bank with previous projects. Through those disadvantages, information services are not adequate and more importantly potential work is missed.

1.2 Research aim, objectives and research questions

The aim of this research is to find an efficient risk management process that does not depend on Excel, that can be shared broadly within the company and that is in line with the innovation plans of Movares Redesign (a department that focuses on new developments inside Movares).

As explained earlier, many bridges in the Netherlands are old and ready for an update or transformation. Also, there is a lot of data available at Movares from risk management for bridges. Those two reasons in combination with the short time frame ensure that I have chosen to focus on risk management for bridges.

These research problems lead to the formulation of the following research question and the sub-questions:

How can risk management at Movares for bridges be improved?

1. What risk management process does Movares currently use for building and maintaining bridges?
2. Which requirements must be met to make risk management for bridges at Movares more aligned with current and future situations and conditions?
3. At what points does the existing risk management process deviate from the requirements?
4. How can the Movares risk management process be improved, such that it meets the requirements?

4.1 Can this be demonstrated with a prototype?

5. How to implement the improvements in the risk management process in the Movares organization?

Risks for bridges are already being managed. However, the current risk management process is not sufficient as discussed above. This research has five objectives to make the risk management process sufficient again. The first objective is to redevelop the risk management process to a time efficient process. The second objective is to create a standard way of working for the consultants of Movares. The third objective is to create a nicer way of doing a risk analysis. The fourth objective is to make sure there is a better foundation risk analysis through lessons learned from previous projects. The last objective is to redevelop the risk management process to generate more profit.

1.3 Reading guide

This research consists of six different chapters. In chapter two the literature review is discussed. The literature review gives insight in what risk management is and why it is so important, it also explains the importance of knowledge management and the link between risk and knowledge management and how to implement changes in an organization.

The third chapter explains how this research is structured and what methods are used to answer the research questions.

The fourth chapter gives insight into the current risk management process at Movares and how risk analysis is done. It shows bottlenecks and possible improvements. It also shows the requirements that the process should meet. The chapter ends with a conclusion about whether the process met all the requirements at this moment.

The fifth chapter shows which improvement options for the risk management process are available and concludes what the best option for Movares should be. It also shows the new risk management process and how to implement it.

The sixth chapter contains the conclusion of this research.

2. Literature review

The literature review is done to achieve insight into the research and find leads for answering the research sub-questions. The review has yielded a number of important findings which are used in the remainder of this thesis.

From section 2.1 till 2.3, the definitions of risk, risk management and methods for risk identification and analysis are prerequisite to lay down the Movares risk management process and the requirements.

Section 2.4 about knowledge management has yielded a few requirements and is used in the improvement proposals as well as their implementation. Section 2.5 underlines the importance of knowledge management.

Section 2.6 has crucial information on organization change and is therefore at the heart of the advice for implementing the proposed improvements to risk management.

2.1 Risk concept and definition

The concept of risk became popular in economics during the 1920s. Since then, it has been successfully used in theories of decision making in economics, finance, and decision science (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011). According to (Forbes, Smith, & Horner, 2008) risks and uncertainty are inherent in everything which is done. But what is a risk? In theory, there are many different definitions of the term risks. The project management body of knowledge (PMBOK® Guide[1]) defines project risk as “an uncertain event or condition that, if it occurs, has a positive or negative effect on at least one project objective” (Banaitiene & Banaitis, 2012). According to (Forbes, Smith, & Horner, 2014) risk can be defined as exposure to a decision which has an uncertain outcome. The outcome and consequence may be favorable or adverse. And Hillson (2013) defines risk as to the uncertainty that can be measured, and uncertainty is a risk that cannot be measured. The risk is the potential that a chosen action, activity or inaction will lead to an undesirable outcome, a chance, or a situation involving such a possibility (ECH 2011). Lastly, (Howard & Serpell, 2012) say that risk is a multifaceted concept, which is defined as the probability of a damaging event occurring within a project, affecting its objectives, however, it is not always associated with negative results. In case of positive results, risks may also represent opportunities. Usually, risks have so many negative results that people tend to only consider the negative side. Summarizing all the different definitions out of the literature risk can be defined as:

‘’ An uncertain event that is affecting on a positive or negative way’’

[1] PMBOK Guide is a ANSI norm for project management. Its developed in 1987 by the American Project Management Institute

The risk in the construction industry can be categorized in different ways. A couple of examples are categorization based on the source of risk, based on the impact of a risk or based on the project phase. In most cases, risks are categorized according to their source, into internal and external risks. Internal risks are initiated inside the project while external risks originate due to the project environment (KarimiAzari, Mousavi, Mousavi & Hosseini, 2011) (Serpell, Ferrada, Rubio & Arauzo, 2015). According to (El-Sayegh, 2008) internal risks are project related and usually fall under the control of the project management team. External risks are beyond the control of the project management team. In figure 4 a categorization between internal and external risks is shown.

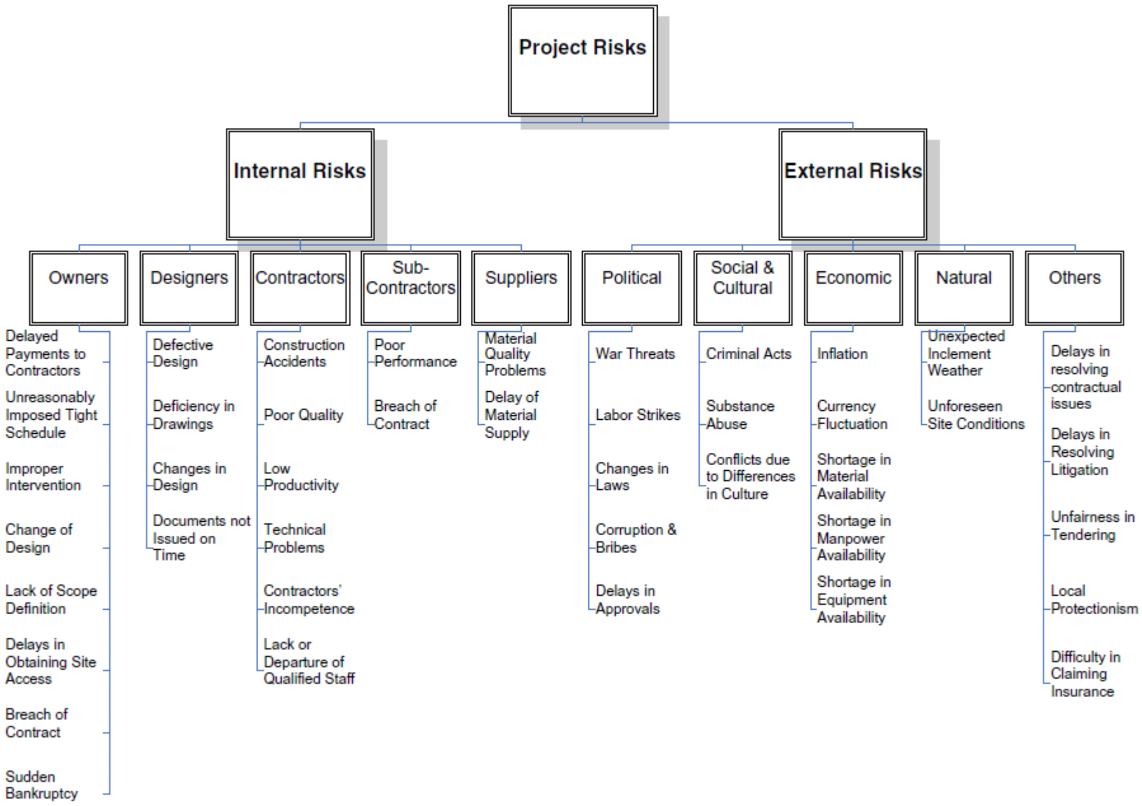

Figure 4 Risk breakdown structure (El-Sayegh, 2008)

2.2 Risk management process

In the past four decades, research on risk management has grown considerably in the construction industry. It has grown because the construction industry is permanently exposed to risks and is perceived to have greater inherent risk due to the involvement of many stakeholders (Serpell, Ferrada, Rubio, & Arauzo, 2015). As this industry is plagued by risk, risk management is an important part of the decision-making process of these companies. (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011) But what is risk management? According to (Howard & Serpell, 2012) risk management is defined as the process to identify, and assess risks and to apply methods to reduce these to an acceptable extent.

Since trying to eliminate all risks in the construction industry is impossible, there is a need for a risk management process to manage all types of risks. There is a strong belief that risk management provides the adequate tool for balancing the conflicts inherent in exploring opportunities on the one hand, and avoiding losses, accidents, and disasters, on the other (Aven, 2011). So risk management can be a key in a management stream which allows the team to achieve project objectives in terms of time, cost, quality, safety, and environmental sustainability. (Sommerville, Craig, & Chomicka, 2012)

Different standards and frameworks have been developed to effectively perform risk management. In the Netherlands three standards are often used, the AS/NZS 4360 Risk Management Standard, the ISO 31000 standard on risk management and the ISO 55001 standard on asset management (Aven, 2011). The first two provide a basic vocabulary for developing a common understanding of risk assessment and risk management concepts and terms among organizations and functions, and across different application areas. The ISO 5001 describes the requirements for an asset management system and can be used as a basis for certification. It is a practical tool to manage assets in an efficient, sustainable and cost-effective way.

To make risk management function effectively and efficiently, it is necessary to have a proper and systematic methodology (Serpell, Ferrada, Rubio, & Arauzo, 2015). In the literature, there is a dichotomy in the methodology for risk management. Project risk management consist of five steps (Howard & Serpell, 2012) (Serpella, Ferrada, Howard, & Rubio, 2014) (Banaitiene & Banaitis, 2012) (Kutsch & Hall, 2010):

1. risk planning;
2. risk identification;
3. risk analysis;
4. risk response;
5. risk monitoring and control.

According to Zhang & Fan, 2014; El-Sayegh, 2008;Forbes, Smith, & Horner, 2008 project risk management consist of three steps:

1. risk identification;
2. risk assessment;
3. risk response.

In the Netherlands, the RISMAN (RISk MANagement) approach has been developed since 1995. This project risk management approach has been applied to many construction projects (Van Staveren, 2006). The RISMAN approach includes five generic steps:

1. Setting the objectives of the risk analysis in the context of the project;
2. Identifying risk from several different perspectives;
3. Classifying these risks;
4. Identifying and executing risk remediation measures;
5. Updating of the risk analysis for the next project phase.

For this research, the model with five steps will be kept. The five steps give a complete overview of the process. The five steps are explained below.

1) Risk Planning: in project risk planning, one defines how to carry out the activities of project risk management. The risk planning process should result in a feasible and efficient plan for minimizing risk occurrence rate and exploiting available opportunities (MYMG, 2011).
2) Risk Identification: Risk identification is an important step in the risk management process since one attempts to identify the source and type of risks. It includes the recognition of potential risky event conditions in the construction project and the clarification of risk responsibilities among project stakeholders. Risk identification develops the basis for the next steps: analysis and control of risk management. Carbone and Tippett state that the identification and mitigation of project risks are crucial steps in managing successful projects. (Banaitiene & Banaitis, 2012) (Karimi Azari, Mousavi, Mousavi, & Hosseini, 2011).
3) Risk assessment: Risk assessment refers to examining the identified risks, refining the description of the risks, and estimating the risk by identifying the undesired event, the likelihood of occurrence of the unwanted event, and the consequence of such an event (Zhang` & Fan, 2014) (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011) (Kutsch & Hall, 2010).
4) Risk response: Risk response refers to identifying, evaluating, selecting, and implementing actions to reduce the likelihood of occurrence of risk events and/or lower the negative or positive impact of those risks (Zhang` & Fan, 2014).
5)Risk monitoring: Once risk mitigation measures have been selected, these must be regularly evaluated and possibly redefined. This approach transforms a rather static risk analysis to dynamic and cyclic risk management (Howard & Serpell, 2012) (Serpella, Ferrada, Howard, & Rubio, 2014) (Banaitiene & Banaitis, 2012) (Kutsch & Hall, 2010).

According to (Marelino-Sádaba, Pérez-Ezcurdia, Echeverría Lazcano, & Villanueva, 2014; ;Howard & Serpell, 2012; Banaitiene & Banaitis, 2012; Zhang` & Fan, 2014; El-Sayegh, 2008; Kutsch & Hall, 2010) risk analysis should not only be performed at the beginning of the project, but also during the project. It is recommended to periodically perform a risk analysis so that changes and new risks will be noted and obtain the optimum degree of risk elimination.

2.3 Risk management methods

An effective and efficient risk management approach requires a proper and systematic methodology and, more importantly, knowledge and experience in risk management (Serpella, Ferrada, Howard, & Rubio, 2014). Nowadays risk managers try to utilize previous knowledge through lessons learned, case studies and best practices in their memory to choose the right strategies from a pool of potential risk response strategies. However, managers often fail to do this because they are short of quantitative models as a reference for evaluating and selecting risk response strategies (Jaafari, 2001) to achieve the project objectives in cost, schedule, quality, etc. (Zhang` & Fan, 2014). A good model or method can help project managers select risk response strategies by maximizing risk response effects of implementing the strategies while considering project cost of performing the strategies, project schedule and project quality (Zhang` & Fan, 2014). A review of the literature has shown that there are at least 36 different techniques available to identify and analyze risks. However, numerous studies have shown that only a handful of these is used in practice. In construction projects, classical quantitative and semi-quantitative methods for risk assessment are used. The most common are:

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

Those commonly used methods differ in a variety of ways and they have their own advantages and disadvantages. According to (Lichtenstein, 1996) an ideal risk assessment method that suits all organizations does not exist, as each of the organizations and projects possesses has its own unique characteristics. Therefore, an organization and project management team need to select the most appropriate methodology (KarimiAzari, Mousavi, Mousavi, & Hosseini, 2011). According to (Forbes, Smith, & Horner, 2014) one of the reasons for the fact that in construction projects only a few methods are used could be that there is a lack of knowledge and understanding of when a technique can be applied. Another reason could be that currently, project management teams have more options from which to choose. Risk assessment methods have ranged from simple classical methods to fuzzy approach mathematical models. Acknowledging this situation, Forbes et al (2008) developed a matrix for selecting appropriate risk management techniques in the built environment for each stage of risk management. These techniques include artificial intelligence, decomposition, probabilistic analysis, sensitivity analysis, and decision trees, among others. (Serpella, Ferrada, Howard, & Rubio, 2014) Most of the literature turns out to focus on quantitative risk analysis. But according to several pieces of research, these techniques do not stimulate that risks, problems, remedial measures and lessons learned from previous projects be captured and reused when developing new projects (Tah and Carr, 2001).

2.4 Knowledge management

The construction industry is suffering under the ever-growing pressure from clients to deliver high-quality facilities on time and on budget. To meet their requirements new forms of innovative project management, supported by IT, are coming up and information is becoming more and more important. As a consequence of the construction domain becoming highly information intensive, a new activity emerged from the process of managing projects and established itself as a discipline in its own right: that is the one of information and **'Knowledge Management'** (Wetherill, Rezgui, Lima, & Zarli, 2002). If managed effectively, knowledge can be used to reduce project time, cost, and improve quality and, therefore, **improve project success** (Farooqui, Ahmed, & Saqib). We can conclude that knowledge is a vital resource in the construction industry. According to (Wetherill, Rezgui, Lima, & Zarli, 2002) an organization's competitive advantage lies in its ability **to learn faster** than its competitors to produce world-class construction. Construction organizations must integrate learning within day-to-day work processes, in such a way that they not only share knowledge and continuously improve, but also, operate efficiently and effectively in response to their changing environment (Wetherill, Rezgui, Lima, & Zarli, 2002).

According to (Rezgui, 2001) & (Wetherill, Rezgui, Lima, & Zarli, 2002) knowledge in the construction domain can be classified into the three following categories:

- **Domain knowledge**. Domain knowledge is understanding, ability, and information that applies to a specific topic, profession or activity. The term is commonly used to describe the knowledge of experts in a particular area (Spacey, 2016). According to (Spacey, 2016) in many cases, domain knowledge is highly specific such as the details of proprietary technology. And domain knowledge is valuable in specific situations but is relatively useless outside of its domain.
- **Organizational knowledge**. This is company specific. It resides both formally in company records and informally through the skilled processes of the firm. It also comprises knowledge about the personal skills, project experience of the employees and cross-organizational knowledge. The latter covers knowledge involved in business relationships with other partners, including clients, architects, engineering companies and contractors. Organizational knowledge can be categorized into several dimensions according to (Robinson, Carrillo, Anumba, & Al-Ghassani, 2006). There is individual and group knowledge, internal and external knowledge, and tacit and explicit knowledge. Tacit knowledge can be explained as it is stored in the heads of individuals and is difficult to communicate externally or to share. Explicit knowledge is captured or stored in an organization's manuals, procedures, information systems, and is easily communicated or shared with other people or parts of an organization
- **Project knowledge**. This is the potential for re-usable knowledge. It comprises knowledge each company has about the project as well as the knowledge that is created by the interaction between firms. It is usually not held in a form that promotes reuse (e.g. solutions to technical problems, or for avoiding repeated mistakes), thus companies and partnerships are generally unable to capitalize on this potential for creating knowledge. It includes both project records and the recorded and unrecorded memory of processes, problems, and solutions. (Rezgui, 2001)

Knowledge management by many leading companies, the discipline is still in its infancy. Many practitioners and researchers have acknowledged the limitations of current approaches to managing the information and knowledge relating to and arising from a project (Rezgui, 2001). According to (Rezgui, 2001) & (Wetherill, Rezgui, Lima, & Zarli, 2002) the key reasons for these limitations are:

- Much construction knowledge, of necessity, resides in the minds of the individuals working within the domain;
- The intent behind decisions is often not recorded or documented. It requires complex processes to track and record the thousands of ad hoc messages, phone calls, memos, and conversations that comprise much project-related information;
- People responsible for collecting and archiving project data may not necessarily understand the specific needs of the actors who will use it, such as those involved in the maintenance of the building(s);
- The data is usually not managed while it is created but is instead captured and archived at the end of the construction stage. People who have knowledge about the project are likely to have left for another project by this time their input is not captured;
- Lessons learned are not well organized and are buried in detail. It is difficult to compile and disseminate useful knowledge to other projects;
- Many companies maintain historical reports of their projects. Since people always move from one company to another, it is difficult to reach the original report authors who understand the hidden meaning of historical project data. This historical data should include a rich representation of data context so that it can be used with minimum (or no) consultation;
- New approaches to the management of knowledge within and between firms imply major changes in individual roles and organizational processes. While potential gains are desired, the necessary changes are resisted.

The challenge that the construction industry is facing today is the reuse of the knowledge and lessons stored within these documents (Rezgui, 2001). Document management has become a crucial issue in modern construction companies. According to (Rezgui, 2001) & (Farooqui, Ahmed, & Saqib) technologies can provide potential solutions to managing information and the different forms of knowledge in the construction industry. Already electronic document management, product data technology, groupware systems, advanced information-management systems, decision-support systems, and data-warehousing solutions are gaining wide acceptance in the construction industry (Rezgui, 2001).

The various solutions proposed by some software vendors have been revealed to be unsatisfactory. The current technology solutions present one or more of the following characteristics and problems:

- Lack of Homogeneity. Despite recent evolutions, mainly due to the impact of the Internet, existing solutions are still often fixed and not open, with a lack of support for legacy, as well as new, upcoming systems in terms of hardware, software, databases, and networks;
- High entry level. IT solutions are still often expensive to buy for SMEs. More entry levels should be provided, e.g. from personal (low-cost) to enterprise (high-cost) editions;
- Lack of scalability. Most available proprietary and commercial solutions offer limited growth path in terms of hardware and software;
- Application-centric and lacking support for business processes. There is often a requirement to organize the enterprise around the adopted IT solution;
- The balance between security and operation. It is not as easy to implement as for printed documents; EDM systems require improved user authentication and document protection (Rezgui, 2001).

Given that the current technologies and strategies do not fulfill this need, it is useful to know what is important when companies want to implement knowledge management. (Robinson, Carrillo, Anumba, & Al-Ghassani, 2006) conducted research on this topic. The following factors when implementing knowledge management should be considered:

- The need to develop a strategy which clearly defines the objectives of knowledge management implementation;
- Resources, including a budget and management support, are essential for knowledge management implementation success;
- Recognition that necessary reform such as organizational culture needs to be addressed to facilitate knowledge management implementation;
- Knowledge management strategy needs to be supported by both IT and non-IT tools to be successful. IT tools address the explicit knowledge component whereas non-IT tools address the tacit knowledge component;
- It is important to link knowledge management to existing performance measures;
- There is a need for a knowledge management maturity scale to enable organizations to objectively benchmark their knowledge management implementation efforts (Robinson, Carrillo, Anumba, & Al-Ghassani, 2006).

Since knowledge management is not easy to implement in construction companies (Robinson, Carrillo, Anumba, & Al-Ghassani, 2006) came up with a maturity ladder to measure how well knowledge is managed by an organization. The maturity ladder gives a clear overview of the different stages and how to reach the next stage.

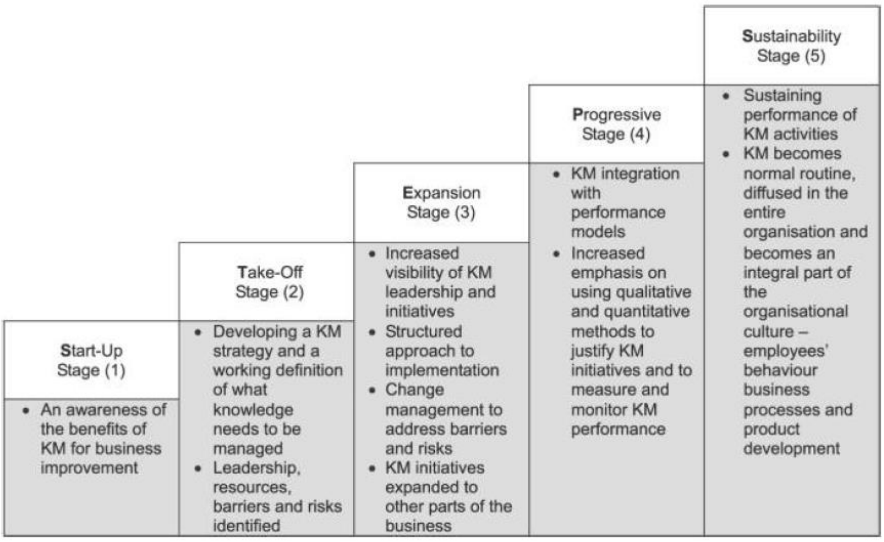

Figure 5 Maturity ladder (Robinson, Carrillo, Anumba, & Al-Ghassani, 2006)

2.5 Change management in Construction Projects

Client dissatisfaction is due to the fact that over 50% of construction projects suffer from delays and overspending and more than 30% of the completed projects have quality defects (Sun, Senaratne, El-Hamalawi, & Chung, 2014). Project delays and overspending are not always the fault of the project team. In fact, in many cases, delays are caused by client requirement changes that result in different specification of work. At the start of construction projects, many decisions must be made under uncertain conditions. Designers, engineers and other professionals must make assumptions based on existing available information and their previous experience. If any assumption is later proven incorrect, some decisions must be revised and change made on certain aspects of the work that has already been done. Change management has emerged as a method to deal with change.

The aim of project change management is not to seek the elimination of all project changes, but to minimize the negative impact of necessary changes and to avoid unnecessary ones. At present, in practice, there is a lack of industrial standards for project change management procedures and methods. This often results in changes being poorly managed, on an ad hoc basis, by project teams during individual projects (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006).

There are according to (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006) three ways of classifying types of change.
The first one is to classify a change that occurs during a project as a 'gradual change' or a 'radical change', depending on the degree of severity. A gradual change, also known as an incremental change, happens slowly over a prolonged period and its intensity is usually low. A radical change is sudden, dramatic and has a marked effect. Gradual changes often occur during the design development stage, where many decisions are fine-tuned and refined progressively. Radical changes occur more often at post-design development and on-site phases.
The second one is to classify project changes as 'anticipated changes' or 'emergent changes'. Anticipated changes are those discovered during the project and before they occur. They nevertheless also cause changes to the original plan and affect other parts of the project. On the other hand, emergent changes arise spontaneously and are not anticipated or intended.
The third way to classify project changes is through their necessity. From this perspective, project changes can be classified as 'elective changes' and 'required changes'. An elective change is where one may choose whether or not to implement it, and a required change is where there is no option but to make the change. Changes, during the design stage and before the final design becomes fixed, are less disruptive to the project development. Therefore, project changes can be classified as design development changes and construction changes (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006).

Changes are caused by different things. According to (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006) the causes of project change may originate from either external or internal pressures that are being applied to a project. External causes may be the result of technological changes, changes in customers' expectations and tastes, changes in competitors' activities, changes in government policies, or changes in macro as well as microeconomic conditions. Internal causes may result from changes in company management policy, changes in organizational objectives and changes in the long-term survival strategy of the organizations involved (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006).

Project changes can result in some indirect effects, which will ultimately have a negative impact on project cost and schedule. Indirect effects include disputes and blame among project partners; loss of productivity as a result of reprogramming; loss of rhythm; changes in cash flow; financial costs; loss of earnings; increased risk of coordination failures and errors; (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006). To reduce the negative effects of the project change, it is important to identify, as early as possible, causes that are likely to lead to changes and to establish the possible effects in the event that a change occurs (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006).

Managing change in construction projects is a collective problem-solving process. It requires the sharing of tacit (personalized) and explicit (codified) Knowledge between the project team and appropriate application of the knowledge (Sun, Fleming, Senaratne, Motawa, & Yeoh, 2006). But this is also the point where there are problems. According to (Senaratne & Sexton, 2008) most of the knowledge created remains within the heads of individual project participants. Change experience is simply absorbed by the team members and not subjected to deep reflection and experimentation afterward. Also, the research findings of (Senaratne & Sexton, 2008) revealed, the project documentation that codified the change event generally included details of the final change decisions, but not the details of the whole change experience. So far, there is a lack of suitable tools to help construction practitioners with managing changes during projects. According to my opinion, there is not an answer about how to connect knowledge management and change management in the construction industry. I would recommend that there is more research needed for the combination of the two topics in the construction industry.

2.6 Organization change management

In the previous paragraph changes inside a construction project is discussed. In this paragraph, the reason why changes are that difficult will be described as well as important matters that help to change your organization successfully.

A quick search on bol.com reveals that there are 8.069 books available within the title the words ‘change management’. A literature study reveals that there are different ways of changing your organization successfully. But two out of every three transformation programs fail (Sirkin, Keenan, & Jackson, 2007). Why is change so hard? According to (Garvin & Roberto, 2007) most people are reluctant to alter their habits. What worked in the past is good enough; in the absence of a dire threat, employees will keep doing what they’ve always done. And when an organization has had a succession of leaders, resistance to change is even stronger. A legacy of disappointment and distrust creates an environment in which employees automatically condemn the next turnaround champion to failure, assuming that he or she is “just like all the others”. According to (Garvin & Roberto, 2007), without a doubt, the toughest challenge faced by leaders during a turnaround is to avoid backsliding into dysfunctional routine, habitual patterns of negative behavior by individuals and groups that are triggered automatically and unconsciously by familiar circumstances or stimuli.

According to (Gill, 2002) change programs often fail because of poor management: poor planning, monitoring and control, lack of resources and know-how, and incompatible corporate policies and practices. (Gill, 2002) says that it also may fail because of a lack of communication or inconsistent messages. The resulting misunderstanding of the aims and process of change lead to rumors that demoralize people and to a lack of commitment to change.

(Kotter, 2007) maintains that too many managers do not realize transformation is a process, not an event. It advances through stages that build on each other. And it takes years. Pressured to accelerate the process, managers skip stages. But short cuts never work. After helping a lot of companies and researching their transforming (Kotter, 2007) found out that there are eight common mistakes. Those mistakes or errors lead to failing the transformation of the organization. The eight errors are:

1. Not establishing a great enough sense of urgency;
2. Not creating a powerful enough guiding coalition;
3. Lacking a Vision;
4. Under communicating the vision by a factor of ten;
5. Not removing obstacles to the new vision;
6. Not systematically planning for, and creating short term wins;
7. Declaring victory too soon;
8. Not anchoring changes in the corporations' culture.

2.6.1 Successful organization change

According to Sirkin, Keenan, & Jackson, 2007 companies overemphasize the soft side of change. In recent years, many change management gurus have focused on soft issues, such as leadership style, corporate culture, employee motivation. Such elements are important for success, but managing these aspects alone isn't sufficient to implement transformation projects. Their research shows that change projects fail to get off the ground when companies neglect the hard factors. That doesn't mean that executives can ignore the soft elements; that would be a grave mistake. However, if companies do not pay attention to the hard issues first, transformation programs will break down before the soft elements come into play.
According to Sirkin, Keenan, & Jackson, 2007, the hard elements are DICE:
D. The **duration** of time until the change program is completed if it has a short life span; if not short, the amount of time between reviews of milestones.
I. The project team's performance **integrity**; that is, its ability to complete the initiative on time. That depends on the members' skills and traits relative to the project's requirements.
C. The **commitment** to change. Companies must boost the commitment of two different groups of people if they want to change projects to take root: They must get visible backing from the most influential executives (what we call C1), who are not necessarily those with the top titles. And they must consider the enthusiasm or often, lack thereof of the people who must deal with the new systems, processes, or ways of working (C2).
E. Effort: the extra work employees must do to adopt new processes. The less, the better.

Just as people are creatures of habit, organizations thrive on routines. (Garvin & Roberto, 2007) found out that for change to stick, leaders must design and run an effective persuasion campaign, one that begins weeks or months before the actual turnaround plan is set in concrete. They also conduct a four-persuasion campaign:

1. Prepare your organization's cultural "soil" months before setting your turnaround plan in concrete by convincing employees that your company can survive only through a radical change.
2. Present your plan, explaining in detail its purpose and expected impact.
3. After executing the plan, manage employees' emotions by acknowledging the pain of change, while keeping people focused on the hard work ahead.
4. As the turnaround starts generating results, reinforce desired behavioral changes to prevent backsliding.

According to (Gill, 2002) an integrative model of leadership for successful change needs to explain the following elements of effective leadership practice: vision, values, strategy, empowerment and motivation and inspiration. According to (Beer, Eisenstat, & Spector, 2007) general managers at the business unit or plant level can achieve task alignment through a sequence of six overlapping but distinctive steps, the *critical path*. This path develops a self-reinforcing cycle of commitment, coordination, and competence. The sequence of steps is important because activities appropriate at one time are often counterproductive if started too early. Timing is everything in the management of change. The six steps are:

1. Mobilize commitment to change through joint diagnosis of business problems.
2. Develop a shared vision of how to organize and manage for competitiveness
3. Foster consensus for the new vision, competence to enact it, and cohesion to move it along.
4. Spread revitalization to all departments without pushing it from the top.
5. Institutionalize revitalization through formal policies, systems, and structures.
6. Monitor and adjust strategies in response to problems in the revitalization process.

According to (Kotter, 2007), in almost every case, the basic goal has been the same: to make fundamental changes in how business is conducted to help cope with a new, more challenging market environment. The most general lesson to be learned from the more successful cases is that the change process goes through a series of phases that, in total, usually require a considerable length of time. Skipping steps creates only the illusion of speed and never produces a satisfying result. A second very general lesson is that critical mistakes in any of the phases can have a devastating impact, slowing momentum and negating hard-won gains. (Kotter, 2007) developed an 8-step model for transforming your organization. In figure six the steps are explained. The 8 step model is the most complete model when comparing the previous researches.

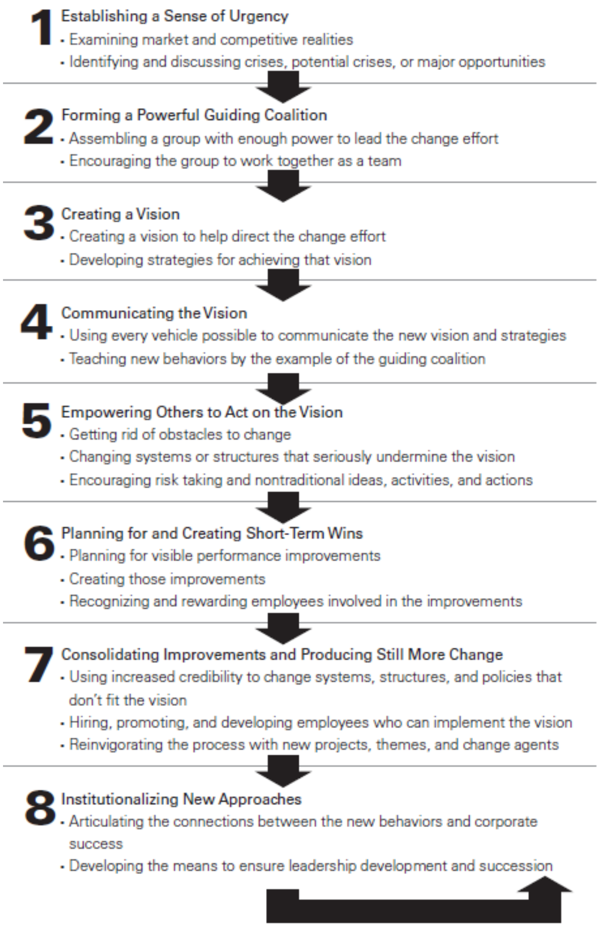

Figure 6 Eight steps to transforming your organization by (Kotter, 2007)

2.6.2 Conclusion organization change

The studies mentioned before have a few things in common. The first one is 'without vision, a people perish', one is told in the Bible (Proverbs 29:18 King James Version (KJV)), and so does an organization. To succeed in a successful change a **vision** is important. But not only have a clear vision, but also the communication to the employees is lifesaving. If there is understanding what the content of the change is and why it is necessary employees are more willing. (Kotter, 2007) makes the point that, for organizational change, only an approach based on vision works in the long term. He says a shared vision clarifies the direction of change and ensures that everything that is done (new product development, acquisitions, recruitment campaigns) is in line with it. Motivates people to act in the right direction, even though the initial steps in the change process may be painful to some individuals. And it helps to align individuals and coordinate their actions efficiently (Gill, 2002). The second thing that the studies have in common is **empowerment**. They all mentioned that you need employees who lead the organization through the change. Those employees must be the most influential executives, who are not necessarily those with the top titles.

2.7 Wrap up

Before going into the risk management process it is important to understand what risk is and how risk can be managed. A risk is ''An uncertain event that is affecting on a positive or negative way''. In this research, the focus is on internal risk, risks that are initiated inside the project. Risk management is defined as the process to identify, and assess risks and to apply methods to reduce risks to an acceptable extent. Risk management consist of five steps:

1. risk planning
2. risk identification
3. risk analysis
4. risk response
5. risk monitoring and control.

To make risk management function effectively and efficiently, it is necessary to have a proper and systematic methodology in place to periodically perform a risk analysis. But what is the method behind risk management? A review of the literature has shown that there are at least 36 different techniques available to identify and analyze risks. However, only a handful of these is used in practice. The methods that are used do not stimulate that risks, problems, remedial measures and lessons learned from previous projects be captured and reused when developing new projects. There is at this moment no perfect risk management method.

The main challenge that Movares faces is the reuse of the knowledge and lessons stored within the documents. Knowledge management and document management has become a crucial issue in modern construction projects and maintenance.

3. Methodology

The way Movares works at the moment does not work, it has performance problems. This research aims to give a solution to performance problems, which requires solution-oriented research. To structure the research the regulatory cycle is used. The regulatory cycle is a common, practice-oriented research method that focuses on decision making. The regulatory cycle consists of five phases (Eijnatten, Buyse, Hendriks , & Desmares, 1989):

1. Problem definition
2. Diagnosis
3. Design
4. Implementation
5. Evaluation

1. Problem definition:

In this phase, either the observation that something is wrong or a question or complaint from a client is the reason to formulate a global scientific problem statement. In this report, the problem definition is given in chapter 1.

2. Diagnosis

In this phase, the problem situation will be investigated and an attempt is made to uncover the causes. An analysis will be made from the initial situation. After this diagnosis, the causes of the problem should be clear and a suitable design can be made. In this research, several methods are used to investigating the problem situation. The leading method is Six Sigma and interviews with experts are held for information.

3. Design

In this phase, the advice will be prepared and concrete solutions for improvement will be introduced. In this research, expert meetings, brainstorm sessions, and data analyses will be used to create advice.

4. Implementation

In this phase, the proposed plan will be implemented. In this research, the plan is not implemented but advice on how to implement the proposed plan is written. The advice is based on the eight implementation steps from Kotter.

5. Evaluation

In this phase, it will be examined whether the initial problem has been solved by the proposed plan, whether the problem has been tackled effectively and if the correct solution has been chosen. In addition, the solution is also examined to determine whether it may have cost too much money. In this research, there is no evaluation, since the plan is not fully implemented.

For the first two phases, theoretical knowledge and insights are the most important tools for the successful completion. A focused model-based and substantive analysis plays an important role here (Eijnatten, Buyse, Hendriks , & Desmares, 1989).

For phase three and four, change management, and the corresponding recipes and skills are the most important tools for successful completion. Advice and planned intervention require a tailor-made approach. Literature can provide support on a theoretic level (Eijnatten, Buyse, Hendriks , & Desmares, 1989).

To answer the research question and achieve the research objectives, this research makes use of the above-introduced research methods. Knowledge of the current risk management process should be obtained, risk management requirements should be collected, and expert interviews are needed to get the underlying causes for the problems and obtain insight into the possible improvements.

Six Sigma

For the visualization of the risk management process, a literature study was done to find a method that ensures the right visualization. The research has shown that Six Sigma gives the best result. Six Sigma is a smarter way to manage a business, it dictates the use of information and statistical analysis to measure and improve an organizations performance. With Six Sigma defects or inconsistencies in a process can be measured to deliver perfect products and services. Within Six Sigma, process engineers use two sub-methodologies, DMAIC for improving existing processes and DMADV for creating new processes. For this research, DMAIC will be used since it is an existing process (Williams, 2017). DMAIC is a 5-step method (a direct descendant of the Deming Plan-Do-Check-Act Cycle) that is used to improve current processes (Athuraliya, 2018). DMAIC stands for (Williams, 2017):

- **Define** the opportunity for improvement (project goal);
- **Measure** the performance of your existing process;
- **Analyze** the process to find any defects and their root causes;
- **Improve** the process by addressing the root causes found;
- **Control** the improved process and future process performance to correct any deviations before they result in defects.

For efficient risk management process, it is important to know what the process looks like at this moment, how it functions and if there are any problems. In this research, the project goal is to improve the risk management process for the maintenance of bridges. Here we look at the efficiency, the fun factor, duration, standardization, and the cost.

Expert interviews

The first two steps (define, measure) of Six Sigma has been performed on a process diagram of the risk management process. The information that is needed is collected by interviews with experts. Five experts who are doing on a weekly basis risk management were chosen for the interviews. The interviews have been organized in a semi-structured way. The same question is the basis for all the interviews, and they are complemented by information gathered from the interviews. A semi-structured interview gives also the possibility to react to answers. The interviews are held at the office and took around one hour each.

During the interviews the experts answered two categories of questions, the first one is about the process, what it looks like and how much time it takes. The second one is about the details of the process. During the interviews, an outline of the process is made and verified with the expert. After the sketch of the process, the process itself is discussed. The interview is recorded, and notes are written down. After the interview, I made a summary for myself and I use the recorded conversation to look for clarifications in parts when I hesitate about the respondents abstract. With the five sketches of the process, one process is created and designed in a process diagram.

For the third step in Six Sigma (analyze) the second category of questions is used. The second one is about the details of the process. Example questions are: What are your favorite activities? and What could be improved in the process? With the answers, an image can be created in the process. What are the things that people like the most? Are there any defects and what are their root causes?

Expert meetings

Expert meetings have been done a few times during the research. During the meetings, questions are asked or improvements will be discussed. On this way, the opinion of the experts get a value in the research and the solution will satisfy the requirements of the experts.

Brainstorm session

There will be two brainstorm sessions. The first one is with the department manager to think about the requirements from Movares for the risk management process. During the session the question 'What are the requirements that Movares expect from the risk management process?' is central. The second brainstorm session is to find out how the Relatics interface must look like to satisfy the needs of the consultants. In this session, two consultants and the Relatics programmer will be asked to draw an overview of the ideal situation.

Data analyses

The data analyses will be done through primary data collection. Primary data is specifically gathered for this research. The data that will be used are 20 FMECA's which have been created by different consultants for different clients and different projects. Since the data consists of different Excel formats and different risk descriptions, there isn't a program that can be used for finding similarities. The data will be checked by hand to find similarities and common risks and to identify clusters and find out which criticality values are most common.

4. Results

In this chapter, the results from the research for answering the first three research questions will be discussed. As mentioned in chapter three the information for answering research questions comes from the literature review, the interviews that were held and the meetings with experts.

4.1 Risk management process

In this paragraph, the results are discussed of the research for question 1: *What risk management process does Movares currently use for building and maintaining bridges?*

For an efficient risk management process, it is important to start by laying down the current process: what it looks like, how it functions and if there are any problems. For measuring the performance of the existing process, five interviews with experts have been held. The detailed versions of the interviews can be found in Appendix 1. Out of these five interviews, five different schemes of the process emerged. After analyzing these five schemes on similarities and logic, the conclusion is that there is one basic process that has two kinds of optional activity.

The **basic process** starts with the assignment of the project and ends with a report of the findings. In figure seven this process is drawn. During the interviews, the experts were asked how much time each step in the process takes. On average the basic process has a duration of 8 workdays. Note that during these 8 days, the number of people involved in the process can vary.

The **first optional activity** is to perform a fault tree analysis. Between the expert meeting and the report, a review of the FMECA and the creation of a step is added for the fault tree analysis. The extended process has a duration of 12 workdays.

The **second optional activity** is to perform an inspection. After the expert meeting, the consultant visits the object to inspect the current condition of the object. After the inspection the results are processed, the risks revalued and new risk controlling measures are created. After those steps, the report is written in the same way as in the basic process. The extended process has a duration of 12 workdays. In figure seven both extended versions of the process are shown.

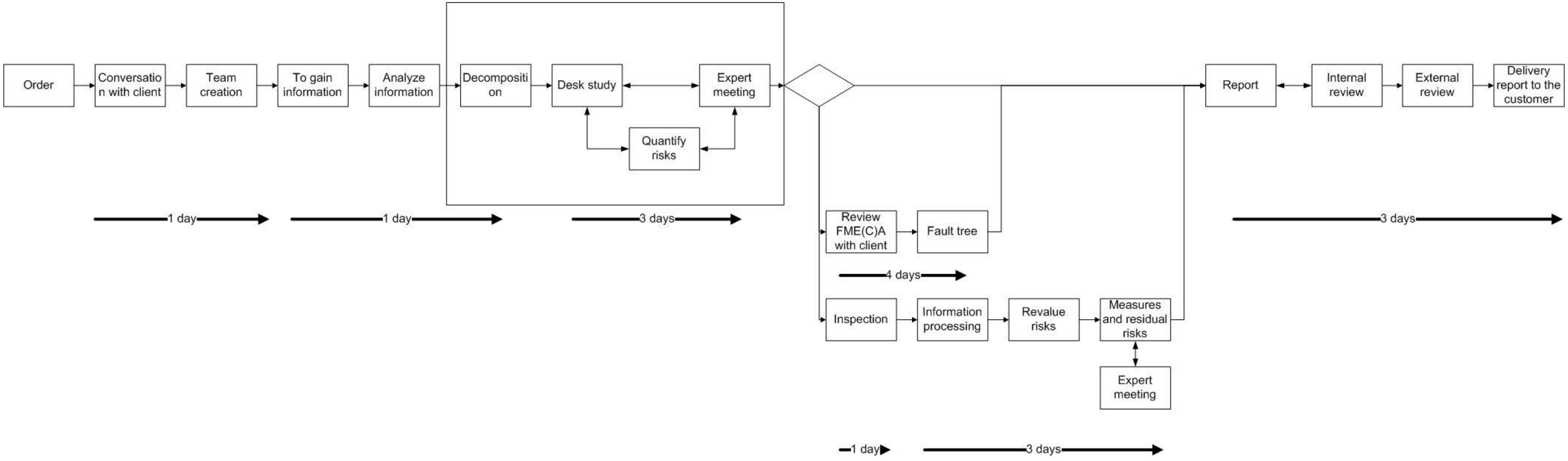

Figure 7 Process of risk analyze

4.2 Risk management process bottlenecks/improvements

To be able to answer research question 2 Which requirements must be met to make risk management for bridges at Movares more aligned with current and future situations and conditions? information about what the consultants think about the process is needed. From this information, requirements can be extracted. To collect the information interviews with five experts

In the interviews, it became clear that all the experts like the fact that they are building bridges between the technical jargon and details on the one hand and the natural language that everybody understands on the other hand. Another part that they enjoy is doing research on possible risks and searching for the differences between the documents and the current situation. The last thing that they like is finding solutions for risk control measures.

The frustrations, bottlenecks, and possible improvements that the experts mentioned can be divided into two categories. The first one is the application that they work with: **Excel**. Excel is not a user-friendly application to work with. If you want to use a specific part again through cut and paste, formulas in Excel can easily get broken. Reuse of lines and tables is difficult. It is also not feasible to do adjustments on location during the inspection. Another point is that Excel is error sensitive in the sense that replacing a formula with a number, may cause the calculation to no longer be correct when other changes occur. The final thing about Excel that the experts mentioned is that the risk analysis table is too big, so there is no clear overview. The second category is having a **Database**. There is no database available with information for reuse. The experts must search every time again for the information. There also is no standard list of risks controlling measures.

4.3 Risk analyses

To be able to answer research question 2 (Which requirements must be met to make risk management for bridges at Movares more aligned with current and future situations and conditions ?) general information about the method for identifying and analyzing risks and the need of Movares clients is needed. From this information, specific requirements can be extracted.

An effective and efficient risk management approach requires a proper and systematic methodology and, more importantly, knowledge and experience in risk management (Serpella, Ferrada, Howard, & Rubio, 2014). A review of the literature has shown that there are 36 different techniques available to identify and analyze risks. However, numerous studies have shown that only a handful of these is used in practice. In construction projects, classical quantitative and semi-quantitative methods for risk assessment are used.

The clients of Movares usually determine the method for identifying and analyzing risks. For Rijkswaterstaat, the required method depends on the type of object. For bridges, they demand an FMECA or FMEA. Rijkswaterstaat has a practical instruction guide on how to do an FME(C)A. They have a standard template for an FME(C)A, they demand RAMSHE€P as risk indicator method and they have a standard risk matrix. ProRail demands a risk analysis and they demand RAMS as risk indicator method. The municipalities and/or provinces demand an FME(C)A, usually with their own risk matrix.

The explanation of the different FME(C)A templates is given in the remainder of this paragraph because it is helpful for getting the requirements right, for properly understanding the consultant feedback and for proposing appropriate improvements. An FME(C)A consist of two axes, a vertical and a horizontal axis. On the vertical axis the decomposition is shown, see figure eight for an example. It has elements of the object as the highest level of hierarchy and components of the elements in the next layer. The decomposition varies with the type of object. For example, a movable bridge has a different decomposition than a tunnel or a fixed bridge. In an FME(C)A, the vertical axis always shows the decomposition.

Figure 8 FMECA vertical axis

The horizontal axis is the one that varies depending on the client. The first part of the horizontal axis is the initial risk analysis. This part is something that is been done for all clients. It discusses the function of the elements/components, the possible failures, their cause and consequences and the risk scoring for probability and effect. For Rijkswaterstaat, the second part contains the maintenance strategy, the third part has the desired risk image, and the fourth part gives the current risk profile. In figure nine the horizontal axis from Rijkswaterstaat is shown among each other. For ProRail, the horizontal axis looks a bit different. The first part is based on genetic analysis, the second part is a specific analysis based on a desk study, the third part contains they analysis after inspection, the fourth part is the analysis of proposed risk control measures. In figure ten the horizontal axis from ProRail is shown among each other.

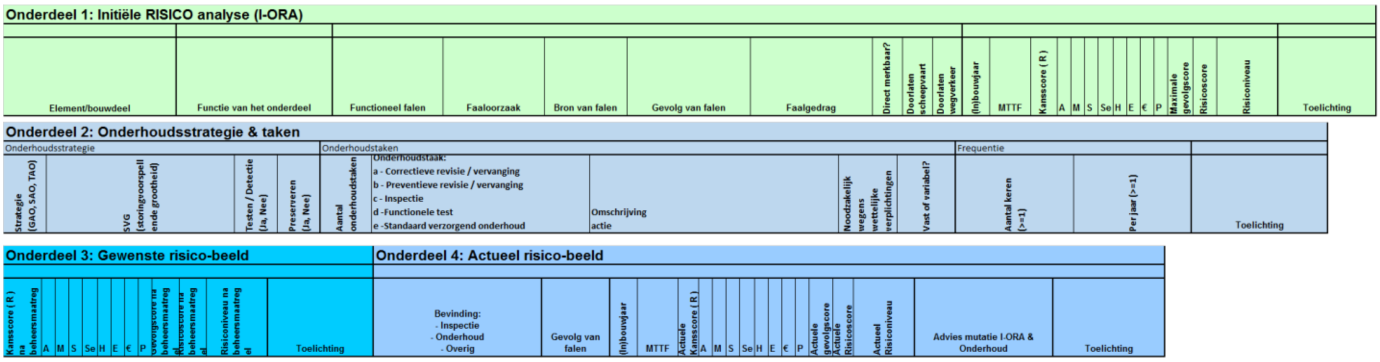

Figure 9 Rijkswaterstaat horizontal axis FMECA 2019

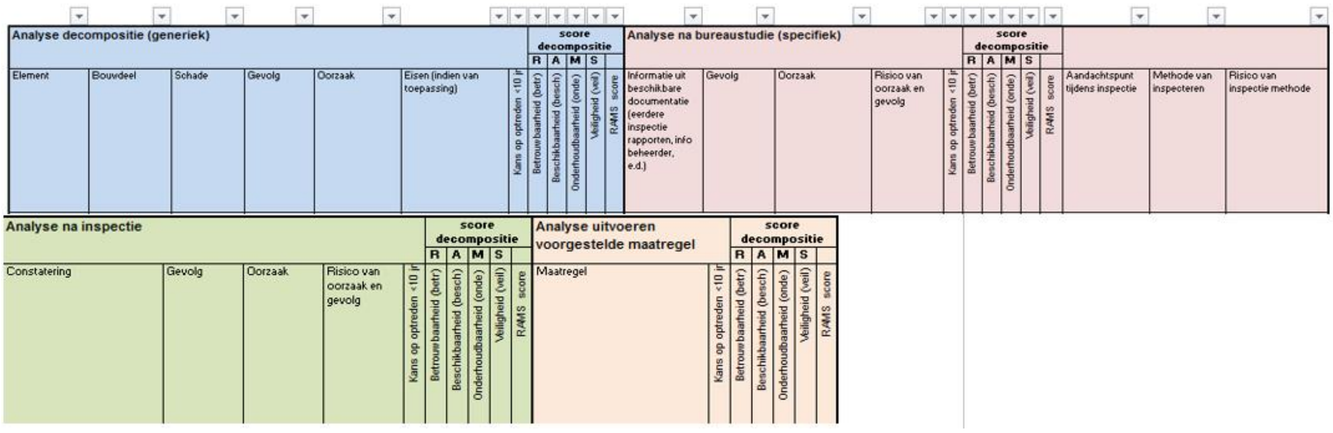

Figure 10 ProRail horizontal axis FMECA 2019

4.4 Risk management process requirements

In the previous paragraphs, the research findings on the risk management process have been described. Out of the five interviews, the process itself, as well as the problems and suggestions for possible improvements, came forward. Also, information was discussed from the different clients about the demanded methods for identifying and analyzing risks. Out of the literature and the previous paragraphs, the requirements are now extracted to answer research question 2: *Which requirements must be met to make risk management for bridges at Movares more aligned with current and future situations and conditions?*

To get a complete overview of the requirements four categories are created: requirements from literature, Movares requirements, Customer requirements, and user requirements.
Requirements from literature: are the requirements that emerged from the literature review. Most importantly, the analysis must fit into the whole life cycle process and it should be done systematically and periodically. Also, researchers say that it is crucial to store all the knowledge and learn from previous projects.
Movares requirements: are the requirements that the Movares organization demands. Most importantly, it must be linked to the plans of Redesign (a Movares innovation spin-off), it must be generically usable for multiple customers and the ratio of reusability should be roughly 80% standard to 20% customization.
Customer requirements: are the requirements that the customers demand. There is a difference between ProRail, Rijkswaterstaat and the municipalities/provinces. For Rijkswaterstaat it depends on the object what kind of risk method they use. For bridges, they demand an FMECA of FMEA performed according to their own practical instruction guide, in their standard template for an FME(C)A, with RAMSHE€P as risk indicator method and the given standard risk matrix. ProRail demands a risk analysis with RAMS as risk indicator method. The municipalities and/or provinces demand an FME(C)A, usually with their own standard risk matrix. The three clients have one thing in common and that is that they all demand NEN 2767 for the decomposition. Rijkswaterstaat has strict rules for risks analysis and the other clients give more leeway.
User requirements: are the requirements that the consultants of Movares mentioned in the interviews. The consultants want to have a clear overview of the analysis and more reusable standard information out of a database. The application must be user-friendly with a low error-sensitivity and it should provide a fun way of filling it in.

In figure 11 on page 40, the requirements are shown. The requirements are colored differently to indicate three types: requirements for the software/application (blue), requirements for the analysis (grey) and organizational requirements (green).

Requirements from literature

- Systematic methodology
- Risk life cycle process
- Periodically preform risk analyze

- Knowledge management
- Lessons learned
- Data base (with old risks)
- Electronic document management
- Communication storage

Movares requirements

- Generic usable for multiple customers
- Standardization
- 80% standard, 20% customization

- Adaptability
- Database
- Shielded (afgeschermd)
- Connection with other software
- Relatics
- 3D Visualization
- Insert inspection results
- Standard controls
- Meet the quality system

- Connect to Redesign
- No yearly program cost
- Can be recouped

Customer requirements

- RAMSSHE€P/RAMS
- Risk life cycle process
- FMEA / FMECA
- Risk matrix
- NEN 2767 for decomposition
- Risk control measures
- Provide insight in risk

User requirements

- Standard decomposition
- Clear table
- Standard risks and control measures
- Periodically perform risk analyze

- Lessons learned
- Database
- User-friendly
- Low error sensitivity
- Adjustable on location
- The possibility of reuse
- Professional appearance
- Fun way of filling in

Blue = requirements for the program
Grey = requirements for the analysis
Green = organizational requirements

Figure 11 Requirements results

4.5 Risk management process adequate

The previous paragraphs provide the input to answer question 3: *At what points does the existing risk management process deviate from the requirements?*

When comparing the process to the requirements, the process flow seems adequate but the process steps themselves not quite. Consultants do exactly what the customer asks but not in an efficient way. At this point, it is not optimal and there could be more pulled out of the process. The biggest gain in time and efficiency can be gained from in the process from the decomposition step up to the delivering of the report.

The current risk management process steps are lacking with respect to several requirements. In figure 12 the requirements that are satisfy have a green check mark. With respect to the requirements from literature knowledge management is not adequately implemented. Examples of this are found in the other, more specific requirements that are connected with knowledge management. For instance, the current process lacks a database and communication storage, and with this, the possibility for reusing lessons learned aside from the knowledge in consultants' heads. There is an electronic document management system which supports version management but does not facilitate straightforward spotting and reuse of earlier FMECA's.

In addition, with respect to the Movares requirements, the process lacks (1) standardization, and with this adaptability, (2) the link with Redesign and Relations, (3) the possibility for 3D visualization, and (4) an efficient way to insert inspection results. For Customer requirements, the current process meets the requirements. In addition to the points mentioned before, with respect to the user requirements, the process lacks (1) a clear overview of the risk table and a professional appearance, and (2) a user-friendly application for performing the risk analysis since Excel does not meet the requirements.

According to the type of the requirements, the conclusion can be drawn that almost all requirements for the analysis (grey) are met, apart from the lack of a clear overview and of standardization. The organizational requirements (green) are met, except for the connection to Redesign. Hardly any of requirements for the application (blue) are met.

Figure 12 Requirements

It seems that the most obvious aspects to improve are:

- Standardization
- Database
- Connection with Redesign
- Interface for risk analysis
- Lessons learned

The following chapter will introduce the improvement proposals based on this research.

5. End product

In this chapter, the results from the research for answering the last two research questions will be discussed. As mentioned before the information for answering research questions comes from the literature review, the interviews that were held, the studied FMECA's and the meetings with experts.

5.1 Risk analysis standardization

In this paragraph, the results are discussed of the research for question 4: *How can the Movares risk management process be improved,* such that it meets *the requirements?* To give an answer to this question 20 FMECA's, which have been created by different consultants for different clients and different projects have been studied.

At this moment the consultants of Movares create a new FMECA every time and make a new decomposition for every object. On the decomposition, they perform the desk study. Here, they have to fill in among others, the function of the element, possible failures, and the cause and consequences per failure. After analyzing the set of FMECA's I can conclude that there is much variation in the resulting data in the FMECA. Often, different terms are used for the same information. In addition to this, there are spelling mistakes, cryptic descriptions, and information ending up in the wrong cell. A solution for the consistency could be to apply more standardization. With limited choices, dropdown menus, and pre-filled information, the resulting FMECA's will become much more consistent.

Also after researching the set of FMECA's, I can conclude that it is possible to standardize the decomposition. All FMECA's have an overlap in the same elements and components. The decomposition is now made based on the consultants own experience, the question of the client and the NEN 2767 standard. Since the NEN 2767 is demanded by all the clients of Movares, the obvious improvement is to draw the standard decomposition from the NEN 2767. In order to implement this for movable bridges, the decomposition the NEN 2767 has been combed through. In the resulting Excel file, all the elements of a movable bridge are listed below each other. For every element, the corresponding components are added. In appendix 2 the total decomposition is shown. The standard decomposition is a starting point for new movable bridge FMECA's and can be adjusted to the specific object if necessary. The expectation is that the amount of adjusting will be fairly small, so in this aspect, the Movares requirement for a reuse ration of 80% standard versus 20% customization can be met.

All FMECA's in the research set were different in format and were filled in differently. Many times, two of the FMECA's in the set had a risk in common, but that did not give enough evidence to create a list with standard risks for a movable bridge. However, a few things can be standardized besides the decomposition, namely some of the columns that describe the function and possible failures. The first column that can be standardized is the function of the component since the function from the bridge to the bridge. The second column is the functional failure, in which the deviation from the function is described. This deviation is not always the same, but it must always start with a guide word. So the possible guide words can be standardized in, for example, a pulldown menu and from there supplemented. The third column that can be standardized is the cause. There are always 16 options for a cause, varying from 'corrosion' to 'fatigue'.

The fourth column that can be standardized is the source of failure. There are always five different options for the source of failure, varying from ‘design error’ to ‘nobody’s fault’. By applying the proposed standardization to these columns, the consistency will increase greatly. The effort spent on filling in this part of an FMECA may increase the first time around, but when doing this more often, the consultant becomes used to the standard possibilities and can work faster.

In the Excel file that contains the standard decomposition, the standardized four columns are included. For functional failure, cause and source of failure, drop down menus have been made. With experts from movable bridges, the Excel file can be filled in to obtain the first library. With this library, two steps in the risk management process can be improved, namely the decomposition step and the desk study step. This yields more consistent products, higher quality, increased working speed. The library can be found in Appendix 2.

5.2 Risk analysis application

The standardization from the previous chapter is already a huge step forward but does not tackle all the requirements from paragraph 4.4. This paragraph shows the next steps that Movares can take in optimizing their risk management process, besides, the paragraph discuss what is needed for these next steps.

From the previous paragraphs, it can be concluded that the current application is not functioning properly. In this paragraph, three options for improvement are discussed.

In the previous paragraph, a start is made with standardizing the risk analysis. If the standardized format will be made available in **Excel**, an improved version is already made. This will tackle the problem of consistency in the Excel file and it will reduce the error sensitivity. Also, it is the start of a database that could be a growth model. But the application is lacking on several points according to the requirements. With respect to the requirements from the literature, the current process lacks knowledge management in general. More specifically, the process lacks the possibility for profiting from lessons learned outside of the consultant’s head, as well as communication storage. There is an electronic document management system which supports version management but does not facilitate straightforward spotting and reuse of earlier FMECA’s. In addition, with respect to the Movares requirements, the process lacks (1) adaptability, (2) the link with Redesign and Relations, (3) the possibility for 3D visualization, and (4) an efficient way to insert inspection results. With respect to the user requirements, the process lacks (1) a clear overview of the risk table and a professional appearance, and (2) no possibility for lessons learned. Concluding is that an adjustment in Excel isn’t solving all the problems.

When thinking outside the box the idea arose for creating **a new application** for risk management. The huge benefit of creating a new application is that it could be developed according to all the wishes. A database could be built and the program could ensure standardization. It is also possible to think about knowledge and electronic document management and how to ensure that lessons learned are captured and reused. Such a new application satisfies all the requirements from literature, the user requirements, and the Customer requirements. But it does not yet meet all Movares requirements. There should be a connection with other software used at Movares and Relatics is one of these.

It is possible to develop the application in such a way that the output from the new application is fed into the other programs used at Movares. In order to connect with Redesign, the new application should be integrated with the current developments at Redesign, which is not straightforward. If all of these requirements are met, two requirements remain, namely to have no yearly program cost and the possibility of recouping the effort of the development. For developing a new application a lot of knowledge is needed. Besides, application development does have high investment costs, and the developing time can be long. This leads to a hard business case for recouping the investment cost. Also, the application will need yearly adjustments what is causing yearly program cost. To conclude, a new application can solve the problems, it will ensure that all the wishes and needs are taken into account. However, a new application development brings high investment costs, for example, it needs to be connected to the existing programs.

Both options, namely adjusting Excel or developing a new application turn out to be much less than ideal, so the search for another solution was continued. The starting point is that it must connect with the plans from Redesign. After several conversations with consultants from Redesign, their plans were clear and it also appeared that there was already for another department V&G in Movares something done for risk management. After talking to the consultants from the different department it became clear that they are doing risk management in a slightly different form, for a different kind of risks. They are focusing on safety and health risks for employees. But the program **Relatics** that they use could, with a few adjustments, also work for risk management for the maintenance of bridges. Relatics is a web-based cloud platform with the help of semantic technology and a requirement-centered approach, requirements, objects, spaces, activities, risks and verifications can be managed in a coherent network. As a result, information becomes fully traceable and projects remain fully under control. Relatics also supports the management and use of reference libraries (such as project staff or reference documents) and knowledge libraries (such as a requirement library or risk library). When combining the database from the previous paragraph and Relatics, a program that satisfies almost all the requirements arises. The benefits of Relatics are:

- Quality improvements
    - More consistent interpretation
    - More professional appearance
    - Higher quality
    - Less error sensitive
- It will be more fun to fill it in
- Ability to learn from previous projects
- More standardization leads to more room for customization, which leads to better quality and more satisfied clients, which lead to more work.

Out of the conversations with the consultants of Redesign and V&G, a few disadvantages came forward. The user interface is difficult: there are a lot of steps that have to be taken. Many columns next to each other do not give a clear overview. So only two of the requirements are not met, namely user-friendliness and having a clear table. But it is possible to redress this. In Redesign, it is possible to program and make a few adjustments. When comparing the three options and all their disadvantages and advantages, the third option, namely Relatics, is the most achievable.

5.3 Risk analyses in Relatics

In the previous paragraph, Relatics and the standard database came forward as an improvement for the risk management process. In this paragraph research question 4.1 Can this be demonstrated with a prototype? will be answered.

To see what the current state and the possibilities are for Relatics a conversation with a consultant from Redesign, a consultant from V&G and the person that programs Relatics is held. Out of that conversation came that risk management in Relatics is in its infancy. For V&G the basic is built in Relatics but they are still testing and append changes. They made already mistakes where could learn from for new developments. Since the basic is already in Relatics it is important to find out how to implement the current method FMECA into Relatics and what adjustments need to be made. Two consultants of risk management were invited to sketch the relations between the different columns in an FMECA. This gives the programmer a better picture of the situation and an estimation of the adjustments. In figure 13 the model that describes the structure of the FMECA on a conceptual level in the database is shown.

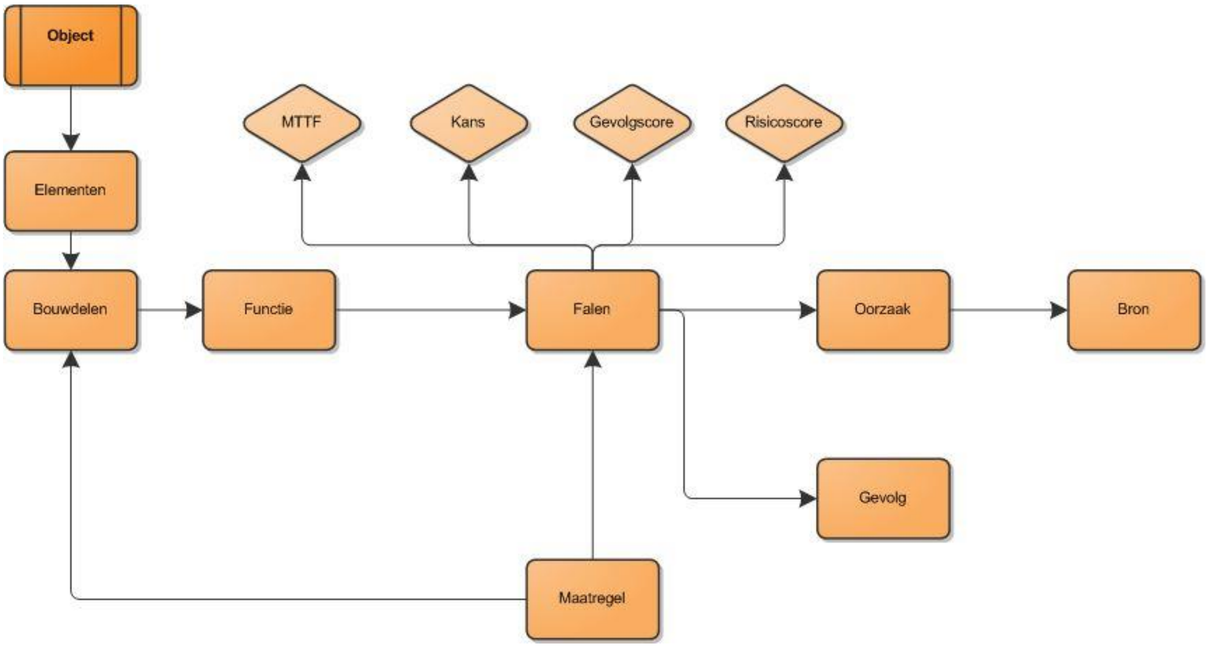

Figure 13 Conceptual model

According to the programmer, the data model and the output can be programmed in Relatics.

5.4 New Risk management process

In paragraph 4.1.1 the current risk management process is discussed. This paragraph discusses whether the improvements in the previous paragraphs have influences on the risk management process.

When changing from Excel to Relatics the process flow is not affected. All the process steps remain in the current order and they are all still necessary. The content of a few of the steps changes, for example, the creation of an FMECA will be done in Relatics instead of Excel.
The consultants have to select the decomposition instead of creating one themselves. In the desk study, their information is already available and input options are standardized. The huge difference will be in creating the FMECA.

In the previous paragraphs, the quality advantages have been discussed but besides the quality, there are more advantages. There are more possibilities for the future, for example, it will be possible to connect virtual reality with the risk analysis and it will be possible to see the risks when designing the new object. The other huge advantage is that it will save time.

Through the creation of a database, approximately 1 day will be spared.
Through the standardization and increased consistency, the ½ day will be spared.
Through the better possibility for adjustments on the inspection location, the ½ day will be spared.

At the beginning of 12 to 16 hours per project could be spared. But it is a growth model: the more projects are done in Relatics, the more extensive the library becomes, leading to fewer data to be filled in manually by the consultants, plus more consistency, all of which leads to more profit being made. In figure 14, the risk management process is shown including the time and in red the reduced time when Relatics is used.

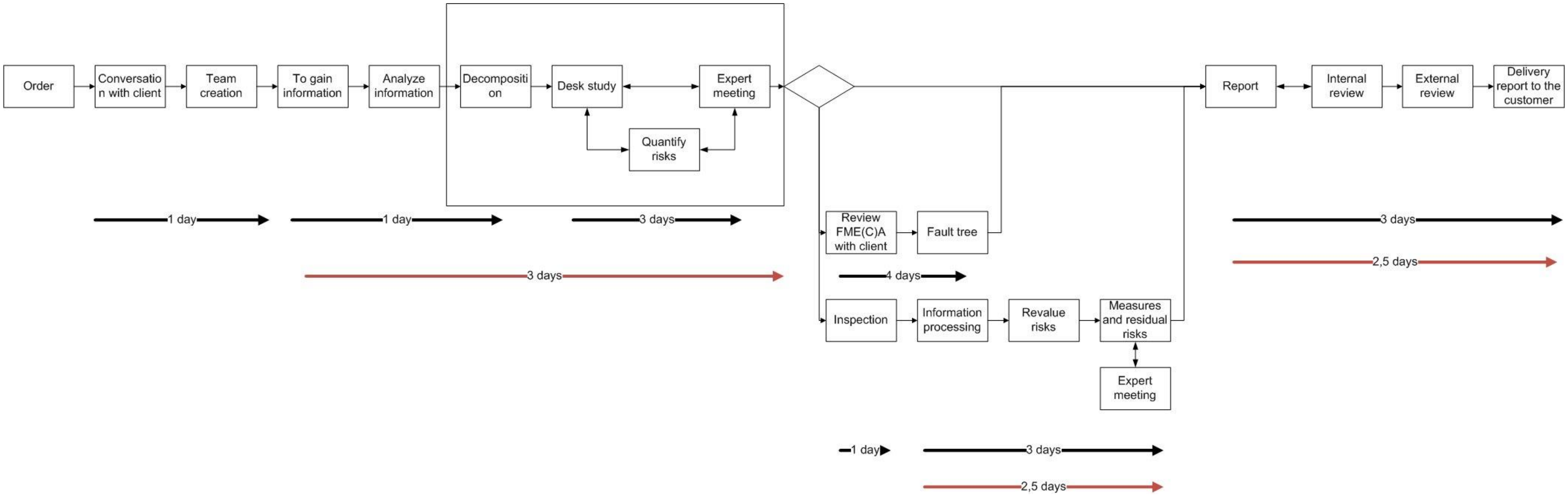

Figure 14 Riks management process including time

5.5 Implementation of the new Risk Management Process

The previous paragraphs have discussed the new improvements and how they influence the risk management process. This paragraph discusses research question five: *How to implement the risk management adjustments in the Movares organization?*

In the literature review, organization change management is extensively discussed. Kotter created eight steps to transform an organization. Here, based on those steps, we will look at how to implement risk management improvements.

The first step is to establish **a sense of urgency**. Among the consultants there is a feeling of frustration, coming from the use of the application Excel. Excel is not working the way they want it to work and they are willing to try another application. The managers see that they are missing assignments that are awarded based on the lowest price. The price of the consultants per hour is too high in combination with the hours of work so the combined price becomes higher than the price of competitors. Both managers and consultants experience a sense of urgency.

The second step is forming **a powerful guiding coalition**. The coalition needs to be powerful enough to lead the change. The coalition has to create a business case that must be approved by the division manager. In the business case, the sense of urgency must be expressed, as well as the advantages and disadvantages of the changes, the investment cost involved and the expected profit. The coalition must consist of at least a junior consultant and a senior consultant. The junior consultant is fresh and not prejudiced. The senior consultant can speak for the older generation. It is important that the senior is a proponent for new technologies.

After approving for the business case the third and fourth step is to create and share **a vision**. To succeed in a successful change a vision is important. Besides having a clear vision, also the communication to the employees is lifesaving. If there is understanding what the content of the change is and why it is necessary, employees are more willing. A shared vision clarifies the direction of change and ensures that everything that is done (new product development, acquisitions, recruitment campaigns) is in line with it. It motivates people to act in the right direction, even though the initial steps in the change process may be painful to some individuals. And it helps to align individuals and coordinate their actions efficiently.

The fifth step goes hand in hand with creating and sharing the vision. In the fifth step, the **empowerment** of others to act on the vision is central. Movares needs employees who lead the organization through the change and empower colleagues. Those employees should be the most influential executives, who are not necessarily those with the top titles. These employees must be unafraid to change systems or structures that undermine the vision and have to encourage risk-taking as well as nontraditional ideas, activities, and actions.

The sixth step is important to give employees the feeling that there is already something changing. In the sixth step, you plan and create **short term wins**. It is important to plan visible improvements and recognize and reward employees that are involved.

Step seven is to ensure that people do not stop changing. In this step **producing still more change** is important, for example by changing aspects that do not yet fit the envisaged change. Also, reinvigorating the process with new projects, themes, and change agents are in this step important.

The eighth and last step consists of **institutionalizing the new approach**. In this step, the new way of working will be experienced as the new normal and leadership will be adjusted to this.

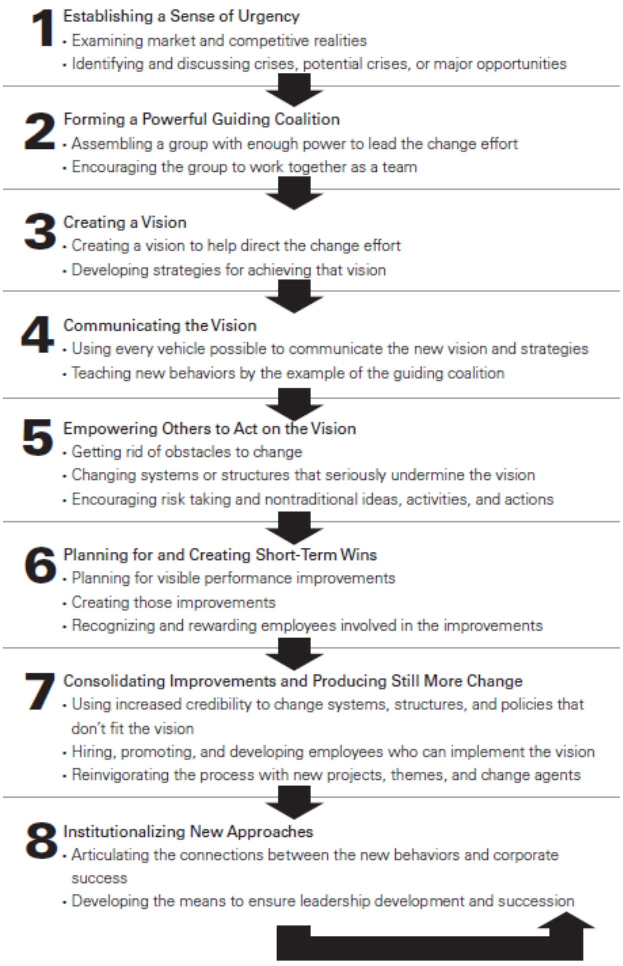

Figure 15 Eight steps from (Kotter, 2007)

In the previous paragraphs Relatics is discussed as a new application for risk management but what is the next step to make it concrete. After that, the business case is approved the first thing that needs to be done is that in Relatics adjustments need to be made to create the possibilities for risk management. The programmer in collaboration with consultants has to create the desired environment. When the basic environment is there, it needs to be evaluated. The first evaluation will be an alpha test. The main purpose of an alpha test is to discover software bugs that were not found before. At the stage of alpha testing, software behavior is verified under real-life conditions by imitating the end users' actions. After the alpha test, the programmer can adjust the mistakes that came forward. After the adjustments, a closed beta test will be done. Whereby a select group of consultants will test the environment and give their feedback on how it works. The programmer will make the potential changes that came back from the feedback in the Relatics environment. After that the last evaluation will be done, the gamma test. Gamma test is the final stage of the testing process conducted before software release. It makes sure that the product is ready for market release according to all the specified requirements. Gamma testing focuses on software security and functionality. During gamma testing, the software does not undergo any modifications unless the detected bug is of a high priority and severity

6. Conclusion

In this research, the central research question was: *How can risk management at Movares for bridges be improved?* Out of the results, the conclusion can be drawn that the current risk management process at Movares does not meet the requirements. The current risk management process steps are lacking with respect to several requirements. With respect to the requirements from literature, knowledge management is not adequately implemented. The current process lacks a database and communication storage, and with this, the possibility for reusing lessons learned aside from the knowledge in consultants' heads. In addition, with respect to the Movares requirements, the process lacks (1) standardization, and with this adaptability, (2) the link with Redesign and Relations, (3) the possibility for 3D visualization, and (4) an efficient way to insert inspection results. For Customer requirements, the current process meets the requirements. With respect to the user requirements, the process lacks (1) a clear overview of the risk table and a professional appearance, and (2) a user-friendly application for performing the risk analysis since Excel does not meet the requirements. According to the type of the requirements, the conclusion can be drawn that almost all requirements for the analysis are met, apart from the lack of a clear overview and of standardization. The organizational requirements are met, except for the connection to Redesign. Hardly any of requirements for the application are met. Out of the subsequent analysis, it followed that the most obvious aspects to improve are:

- Standardization
- Database
- Connection with Redesign
- Interface for risk analysis
- Lessons learned

To improve the risk management process, a database library with standard risks and risk measures as well as a new FMECA application is needed.
After analyzing 20 different FMECA's the conclusion is that there is much variation in the resulting data in the FMECA. This is often the case because different terms are used for the same information. In addition to this, there are spelling mistakes, cryptic descriptions, and information ending up in the wrong cell. But the conclusion is also that it is possible to standardize the decomposition and some of the columns that describe the function and possible failures. With a database library containing these standardized FMECA parts, two steps in the risk management process can be improved, namely the decomposition step and the desk study step. This yields more consistent products, higher quality and increased working speed. But the database does not ensure that all the requirements are met. To ensure that more requirements are met a better version of the risk analysis application is needed. Out of the research, Relatics emerged as the best option. With Relatics many quality improvements will be done, it will save time and there are more possibilities for new technologies in the future. To come back to the research question, the risk management process can be improved to create a database and to switch from Excel to Relatics. With these improvements, most of the requirements will be met.

The main challenge that Movares faces is the reuse of the knowledge and lessons stored within the documents. Knowledge management and document management have become crucial in modern construction projects and maintenance. With Relatics and a database, this becomes a more structured process but still, it remains a challenge.

The literature research made it clear that classical risk management methods do not stimulate to record data such as risks, issues, actions taken to resolve them as well as lessons learned. Moreover, readily available repositories of risk data from past projects are fundamental to the quality of estimates. Learning from risks may lead to more realistic risk modeling and better-informed guesses about the future. The literature research also showed that one of the common developments addresses the risk management function from a knowledge-based perspective and may be based in a web application that can then be made available through the whole organization. The suggested improvements in the shape of a database and Relatics both meet these points from the literature.

This research is conducted at Movares in a period of six months, which puts limitations on this research. In total there have been three limitations in this research, all of which have led to a demarcation of the research. The first limitation is the period of six months, in which only a limited amount of research could be done. The second limitation is the fact that the research was done with only data from Movares. This leads to the uncertainty of relevance outside Movares and it is unsure whether the outcomes from this research could be used by other companies. The last limitation is that this research only focuses on the maintenance of bridges. This is a specific part of a lifetime cycle for a specific type of infrastructure.

This research is new and relevant because it connects the literature with practice. It gives answers on how to create a new risk management application and it gives insight into all the possibilities.

To follow up on this research, I recommend that Movares invests in a study to find out how to design the Relatics environment. With very limited effort, a lot of profit can be realized and it lends itself well to a growth model, that can benefit from additions from the following projects. Aside from this, in my opinion, there is no answer yet for connecting knowledge management and change management in the construction industry. I recommend that more research is done into the combination of these two topics in the construction industry, by universities in collaboration with companies like Movares. My final recommendation is to research how knowledge management and change management can be improved in a web-based application.

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8. Appendix

1. Summary Interviews

Samenvatting Yue Xie

Bij ProRail krijg ik minder informatie vooraf dan bij Rijkswaterstaat. Bij ProRail gebruik ik meer brainstormsessies.

Wat ik het leukste vind is: hoe je het gaat oplossen dat er geen problemen/risico's meer zijn. Hierbij kan je veel leren. Het is uitdagend je moet echt opzoek naar oplossingen. Je moet kijken hoe je het probleem oplost binnen de onderhoudsstrategie en binnen de kostenanalyse. Communicatie vind ik het minst leuke. Het is namelijk moeilijk om dezelfde werkwijze te vinden. Het is lastig om met iedereen op dezelfde lijn te zitten.

Maybe its problem that is this project, but it is hard to in the first beginning that all the people from different disciplines must agree on 1 way of working. A corporation with other company they were always complaining about the process. Getting on the same line is the worst part. We do things in different ways.

Er zijn twee grote bottle necks. De eerste is de decompositie want heel de FMECA hangt er aan vast. Als daar een fout in staat heb je een probleem. De andere is het inspectierapport. Het rapport is verschrikkelijk omdat alles gebaseerd is op communicatie. Het is een drama om op een lijn te komen met alle mensen die eraan mee schrijven. Daarnaast is het programma disk waarin je vaak moet werken niet gebruiksvriendelijk. Die gebruik voor het inspectierapport.

Als ik iets zou kunnen aanpassen dan was het, het werken met Excel. Liever geen Excel! Daarnaast is de tabel te groot die we gebruiken. Het liefst heb ik een programma waarmee je ook ter plaatse (bij de inspectie) aanpassingen kan doen.

Maybe change the format not using Excel all the time maybe using a different platform. The table is too big and it is too terrible to see. It's better to have an easier like process that you can click and choose the risks. I also want to make it easier to change it on the side because somethings you can't change anything and must go back to the office and change it there. Something that you can do on a tablet that you can easily change on the side. Maybe it is also nice to have a digital platform what kind of risk and what kind of measurements must be taken to control or improve those kinds of risks. Data bank with most common risk and most common measurements makes it more efficient.

Automatisering zou een databank zijn. Met standaard risico's en maatregelen erin.Vaak krijg ik data die niet compleet is en niet met een bestandsnaam word aangeleverd. Er is geen lijst met data die je nodig hebt. Het is veel administratie. Feedback komt pas maanden later. 12 a 15 mensen bij een risico sessie.

Report: final inspection reports we fill in all the damages in the report and the reports takes so long. If you concentrate working on it, it will take 1 week but we have 3 disciplines and first, you must agree on 1 working why. And at Movares we don't have the possibility to work in the same document. Inspection is based on experience.

Samenvatting Axel

Wat vind je het leukste aan het proces:
Inspecteren, de check of het klopt. De bureau studie doen en dan lezen wat er wordt gedaan en dan het verschil zien tussen de documenten en buiten. De effecten zien.

Inspecteren zelf. Want dan ga je echt buiten kijken naar het gene wat op papier staat klopt dat nou is dat nou echt zo. Bureau studie vond ik interessant omdat je dan echt stukken gaat lezen. Als je dit een tijdje doet dan zie je al tijdens je bureau studie dat dit wat op papier staat buiten helemaal niet meer zo is. Of dat is veel erger of minder. Wat ook wel interessant was is vervolgens het zien (niet het invullen zelf dat is niet leuk) zien wat nou het verschil is wat is hetgeen dat ik buiten heb geconstateerd en wat is het effect op het risico dat ik had van tevoren gezegd. Welk risico blijft erover. Dus je gaat een toets doen op een ouder rapport.

Wat vind je het minst leuke?
Het invullen van alles. Het is enorm tijdrovend en foutgevoelig. Omdat in Excel je bepaalde dingen wilt wijzigen kan het flinke consequenties hebben omdat dan ineens formules weg zijn. Ik weet dat Rijkswaterstaat om die reden bezig is met een webapplicatie dat scheelt al een hele hoop. Iets in Excel wijzigen is een drama. Iets wat nu 4 dagen kost zou in 2 dagen kunnen als het systeem meewerkt. Dat je makkelijk regels ertussen kan voegen dat je dingen kunt verwijderen of toevoegen en dat niet het hele ding dan overhoopligt. Het is ook niet leuk om mee te werken. Niet gebruiksvriendelijk.

Waarom is dit het minst leuke?
De gebruiksvriendelijkheid is dramatisch.

Klanten noemen het een FMECA maar het is geen FMECA, vaak klopt de methode niet helemaal.

Alles automatiseren! Behalve de kwantificering en de bevindingen dat gaat niet maar de rest wel. Standaard decompositie, standaard risico's. Geen grote Excel maar in de stappen van de FMECA het proces doorlopen. Dan kan je ook niet dingen overslaan en ga je standaard te werk. Werken met sjablonen als je een brug pakt dat je de decompositie van een brug naast een andere brug legt zie je dat er veel overeenkomsten zijn .je kunt je decompositie dus redelijk standaard maken op basis daarvan kan je dus ook redelijk wat standaard risico's koppelen aan je bouwdelen. (Elementen). Krijg je uiteindelijk een sjabloon die helemaal gevuld is met je decompositie je risico's waarbij e vervolgens alleen nog je bureau studie en kwalificeren in hoeft te vullen en dan ga je weer naar de volgende stap en die stap krijg je een apart overzicht van zodat je niet meer zoals een groot Excel tabel. Hebt maar dat je echt richting gaat van nu moet je dit invullen en dat geeft denk i kook heel veel overzicht bij de mensen die dit moeten invullen.

Eindproduct is het instandhoudingsrapport de FMECA is een bijlage. Daarnaast zit er in disk data bij Rijkswaterstaat.

Er is feedback met de klant, evaluatie zo snel mogelijk.

Samenvatting Margreet

Wat vind je het leukst aan het proces?
Bureau studie! De nieuwsgierigheid het uitzoeken van de huidige stand van zaken. Checken of alles klopt wat er is gedaan.
Risico inventarisering. Nieuwsgierigheid hoe zit het in elkaar en zijn er dingen mee gebeurd.

Ik heb zo het gevoel dat het zinloos is. Vooral omdat er niets meer mee wordt gedaan je kan er nu mooi dingen mee in beeld brengen je kan zien wat de ernst van sommige dingen is.

De rest van de analyse vind ik zinloos want als je het eerste deel goed uitvoert ben je al heel ver. En daarnaast de volgende keer dat ze weer het gaan inspecteren moeten we weer van vooraf aan beginnen. En is het werk daarvoor voor niets geweest.

Het is een Excel dingentje dat is al een bron van narigheid kan gewoon heel makkelijk misgaan als je een keer iets misdoet met kopiëren of je hebt het niet in de gaten.
Excel is verschrikkelijk het is niet gebruiksvriendelijk. Het is een foute bron.
Wat fijn zou zijn is een databibliotheek met daarin alle data erin zodat je vanaf daar alles eruit kunt halen.

Bij opdrachtgevers moet het allemaal net iets anders telkens. Wij moeten ons elke keer aanpassen en het net anders doen.
Geen feedback. Alleen soms als je je stukken naar de klant stuurt krijg je reactie.

Samenvatting Judi
Leuk: klantgesprek vind ik altijd leuk. Je leert altijd wat en zij ook je probeert ze te helpen. Orde te scheppen in chaos. Foutenboom omdat je mag puzzelen. Rapport om uit te leggen wat & hoe in een taal die de klant begrijpt. Bruggen slaan tussen techniek en taal. Het leren en het andere mensen iets laten leren vind ik heel leuk.

Stom: offerte maken. Want je maakt een begroting met te weinig kennis dus je weet nooit of het klopt. (Niet gebaseerd geen feiten) Overgang tussen Excel en de foutenboom, 2 programma's die niet te combineren zijn.

Knelpunt: vullen van de tabel is handwerk bij de klant. Het hergebruiken van stukken in Excel is dramatisch. Het invullen van de Excel bij de klant is niet fijn. Groot onoverzichtelijk je bent snel de draad kwijt en het ziet er niet professioneel uit.

Verbeter: tijdens de sessie een leukere manier van invullen. Hergebruik vermakelijke. Excel gebruiksvriendelijker maken en een mooiere lay-out duidelijker. Met een VR-bril een risico sessie houden en dan kijken wat en hoe en waar iets roods komt op kunnen drukken en meteen zien wat het risico is.

Auto: hergebruik automatisch. Ander systeem en een systeem waarbij je een interface hebt met foutenboom. 3d omgeving van het object simuleren van wat de klant zegt. Bv-brug blijft open en dat je dan meteen dat in 3d ziet. Feedback: extern met de klant naderhand intern niet tenzij het uit de hand loopt.

Samenvatting Conny:
Rams is vaak te laat pas in het proces betrokken. Waardoor het vaak het geval is dat het object niet aan de gewenste kwaliteit doet of dat er maar 1 optie is en als we eerder waren aangehaakt waren er meerder opties.

Leukste: verschillende mensen leren kennen en alles van hun leren op hun vakgebied. Je leert alles over het object, het zien van het object, de techniek bespreken van het object. Analytisch en technisch. Vakkennis en het puzzelen van hoe het object in elkaar zit en hoe het werkt het beeld ervan in mijn hoofd krijgen. Puzzel compleet krijgen.

Ik vind het heel leuk om met verschillende mensen te praten en dat die dan het ontwerp uitleggen dat ik dan precies weet hoe zo object in elkaar zit . En als je nou echt spekkoper bent dan kan je met de beheerder praten en die zit al 30 jaar op het object en die weet alle bloopers en kan je soms het object nog bekijken dat is ook heel erg leuk om te zien hoe het werkt. De techniek te bespreken en dan weet je hoe zoiets in elkaar zit. En ik vind het ook heel leuk om het model dan te maken. De analytische technische kant en dan de ervaring en vakkennis van mensen te horen. Langzamerhand krijg ik het ontwerp in mijn hoofd van zo werkt het dus zo hebben ze het bedacht. Ik stel vragen om de puzzel in mijn hoofd compleet te maken.

Stom: opzoeken van faal frequenties

Geen knelpunten
Het zou fijn zijn als er een database is met faalfrequenties erin.
Feedback moet je zelf regelen.

2. Database

The database can be found in a separate excel file.