



**KTH Architecture and  
the Built Environment**

# Comparison of Risk Assessments for Underground Construction Projects

A study about distinctions and common features and  
suggestions for improvements

**Lisa Avestedt**

**Master of Science Thesis 11/07  
Division of Soil and Rock Mechanics  
Department of Civil and Architectural Engineering  
Royal Institute of Technology  
Stockholm 2012**

**© Lisa Avestedt  
Master of Science Thesis 11/07  
Division of Soil and Rock Mechanics  
Royal Institute of Technology  
Stockholm 2012  
ISSN 1652-599X**

## **PREFACE**

The work with this master thesis was carried out between December 2010 and February 2012 at the division of Soil and Rock Mechanics, Department of Civil and Architectural Engineering at the Royal Institute of Technology in Stockholm.

I thank my supervisor Staffan Hintze for guiding me thorough the writing process adamantly and providing the most useful feedback I could ever have received in preparing this thesis. Without Staffan there would be no thesis. Staffan Hinze is a professor at the Division of Rock and Soil Mechanics and also employed as technical expert by NCC Construction, Sweden.

My thanks also go to co-supervisor Joe O'Carroll my supervisor at Parsons Brinkerhoff USA, for first of all providing me with the splendid idea for the subject of this thesis and furthermore; useful material to study and other input and reflections on risk management in relation to this thesis. I also thank Joe for hiring me; it has been a pleasure working with you for the last four years at PB. Thanks also to Noel Berry for your guidance regarding literature to study and reflections on the subject.

Material studied in this thesis, in addition to what Staffan Hintze and Joe O'Carroll provided; was made available by several persons working in the Swedish construction business, thank you all very much for your kind participation.

Last but not least thanks Dennis for managing our two “hazards” while I studied.

Menlo Park, California, June 2012

Lisa Avestedt



## ABSTRACT

This master thesis is a study of risk assessment tools and other risk management documentation created by consultants and contractors in the US and Sweden for underground construction projects. Risk management as part of managing underground projects is common practice in both countries for underground construction projects. Depending on location and other parameters other types of risks than the geological ones need to be considered, for example of the settings of the project is an urban environment or if it is situated in a less densely populated area. Normally underground project also involves large investments and therefore managing cost is important. Risk management is a way of managing cost and other areas that may be of concern.

The main goals of this thesis are to:

- Identify a theoretical general approach to risk management and specifically risk assessments based on a literature study
- Identify similarities between risk management practices in the two countries
- Identify differences between risk management practices in the two countries
- Identify how risk management practices differ in the two countries from the theoretical approach established from the literature study

Apart from the study of theoretical literature 12 projects in total were studied; 5 Swedish projects and 7 projects from the USA. The conclusions of this thesis are generally not statistically significant nor do they indicate trends; they are purely observation on the specific documentation studied.

When comparing application in Sweden vs. application in the USA; main conclusions are:

- It is recognized that practices within risk management are generally the same in the two countries as established when studying theoretical literature on the subject. However categorization of risk parameters is normally less detailed in both countries' project specific documentation than found in theoretical literature.
- The US risk management as a rule includes a numerical simulation to determine contingency levels for cost and schedule high ranked risks but the simulations were not done in the Swedish project specific documents. However it must be remembered that the US-projects studied were provided from one source provider and is not in any way significant for this country but for the particular provider studied.
- Evaluating the risk registers of the projects studied there seem to be more concern for damages to third party in the US as compared to in Sweden. Also right-of-way, insurance and financial issues are of higher concern in the US projects studied as compared to the Swedish projects studied.
- The projects in Sweden put a slightly higher emphasis on space availability for construction than in the US projects.

For more detailed findings; please read on!



## SAMMANFATTNING

Detta examensarbete är en studie av verktyg för riskstyrning och riskhantering i undermarksprojekt i Sverige och USA. Studien har omfattat en sammanställning av dokumentation från riskanalyser som upprättats av konsulter och entreprenörer i USA och Sverige för undermarksprojekt.

Riskstyrning är en viktig del av projektstyrningen av undermarksprojekt och är vanligt förekommande i de båda länderna. Beroende på platsspecifika faktorer och andra faktorer än de geologiska förhållandena så måste exempel omgivningens förutsättningar beaktas. En viktig förutsättning är om det är stadsmiljö eller om det är ett mindre tätbefolkat område.

Normalt innebär undermarksprojekt stora ekonomiska investeringar och därför är hantering av kostnader i projektet viktigt. Riskstyrning och riskhantering är därför ett sätt att hantera kostnader och andra faktorer som är viktiga för att styra ett projekt till ett positivt resultat.

De viktigaste målen för denna studie är att:

- Genom en litteraturstudie identifiera ett allmänt tillvägagångssätt för riskstyrning och riskhantering för undermarksprojekt.
- Identifiera likheter och skillnader i riskstyrningsmetoder mellan Sverige och USA.
- Identifiera hur riskstyrningsmetoder i de två länderna skiljer sig åt från erfarenheterna från litteraturstudien.

Förutom studier av rapporter och material i litteraturen studerades totalt 12 st. verkliga undermarksprojekt, 5 st. från Sverige och 7 st. från USA.

Slutsatser från studien är inte statistiskt säkra och anger inte heller trender. Dessa ska endast ses som observationer från de 12 studerade projekten. När tillämpningen i Sverige jämförs med tillämpning i USA, och även teoretisk litteratur, är slutsatserna huvudsakligen följande:

- Tillämpning av riskstyrning i båda länderna följer generellt den teoretiska litteraturen som studerats. I båda länderna använder man praktiskt en mycket enklare uppdelning av riskparametrarna och mindre detaljerat än vad som beskrivits i litteraturen.
- Projektdokumentation från USA innehåller som regel en numerisk simulering för de högst rankade riskerna för kostnads- och tidsplanering. Simuleringar utförs vanligen inte i svenska projekt. De studerade projekten från USA kommer dock från samma konsult och man kan därför inte dra säkra slutsatser om hur det är generellt i USA.
- Analys av risk för påverkan på tredje man verkar vara en viktigare faktor i USA jämfört med Sverige. Statens rätt att använda mark för infrastrukturprojekt samt försäkrings- och finansiella frågor är också av högre vikt i de studerade projekten i USA jämfört med de Svenska.
- I de svenska projekten betonas vikten av tillgängligt utrymme för produktionen mer jämfört med projekten från USA.

För noggrann beskrivning av resultat och slutsatser rekommenderas att läsa examensarbetet.



## Table of Content

1. Introduction .....	11
1.1. Background and Motivation .....	11
1.2. Goals.....	11
1.3. Method.....	12
1.4. Selection of Projects .....	13
1.5. Projects Studied.....	13
1.6. Limitations and Possibilities.....	13
1.7. Objectives.....	14
1.8. Scope and Structure.....	15
1.9. Abbreviations .....	16
1.10. Definitions .....	16
2. Analysis.....	19
2.1. Theoretical Risk Assessment Procedures and Methodologies .....	19
2.1.1. Literature Review.....	19
2.1.2. Application in Sweden and USA.....	20
2.1.3. Conclusions .....	20
2.2. Risk Program Cycle.....	21
2.2.1. Literature Review.....	21
2.2.2. Application in Sweden.....	21
2.2.3. Application in USA .....	22
2.2.4. Conclusions .....	22
2.3. Fault Tree Analysis.....	23
2.3.1. Literature Studied.....	23
2.3.2. Application in Sweden.....	23
2.3.3. Application in USA .....	23
2.3.4. Conclusions .....	26
2.4. Risk Register Content.....	26
2.4.1. Literature Review.....	26
2.4.2. Application in Sweden.....	27
2.4.3. Application in USA .....	31
2.4.4. Some Statistics on the Risk Registers Studied .....	34
2.4.5. Conclusions .....	36
2.5. Risk Formula .....	39
2.5.1. Literature Review.....	39
2.5.2. Application in Sweden.....	39
2.5.3. Application in USA .....	39
2.5.4. Conclusions .....	40
2.6. Ranking and Terminology Used for Likelihood and Severity .....	40
2.6.1. Literature Review.....	40
2.6.2. Application in Sweden.....	41
2.6.3. Application in USA .....	43
2.6.4. Conclusions .....	45
2.7. Risk Matrix.....	46
2.7.1. Literature Review.....	46

## Table of Content

---

2.7.2.	Application in Sweden.....	47
2.7.3.	Application in USA .....	47
2.7.4.	Conclusions .....	48
2.8.	Numerical Methods versus Non-Numerical Method for Risk Analysis .....	49
2.8.1.	Literature Review.....	49
2.8.2.	Application in Sweden.....	49
2.8.3.	Application in USA .....	50
2.8.4.	Conclusions .....	50
2.9.	Detectability and Toll Gates.....	51
2.9.1.	Literature Review.....	51
2.9.2.	Application in Sweden.....	51
2.9.3.	Application in USA .....	52
2.9.4.	Conclusions .....	52
3.	<i>Discussions</i> .....	53
3.1.	Further Studies of Project Risk Documents .....	53
3.1.1.	Comparing US Documents Only.....	53
3.1.2.	Comparing Two Underground Projects in Metropolitan Areas .....	54
3.1.3.	Good Ideas and Concepts.....	56
3.2.	Need for Continuity .....	61
3.3.	Who Should Be Responsible for the Risk? .....	62
3.4.	Insurance .....	63
3.5.	Right-of-Way.....	63
3.6.	Risk Assessment Standard .....	64
4.	<i>General Conclusions</i> .....	65
4.1.	Literature Review .....	65
4.2.	Application in Sweden .....	65
4.3.	Application in USA .....	66
5.	<i>Proposal for Future Studies</i> .....	69
6.	<i>References</i> .....	71
	<i>Appendix A</i> .....	73
	<i>Appendix B</i> .....	75
	<i>Appendix C</i> .....	77

## **1. INTRODUCTION**

### **1.1. Background and Motivation**

There are many things that can go wrong in an underground construction project and negatively affect cost, schedule, the labor force, the environment etc.. In order to manage unforeseen events that have adverse impacts; most of the larger construction projects includes a risk management program in its management procedures and within that effort; risk assessments. The aim is to become more aware and better prepared for unwanted events and if possible steer clear of certain unwanted events and manage potential hazards as well as possible. Intuitively, the approach for how to manage risk could possibly be different depending on in what country or part of the world you are.

The background for this thesis is a discussion I had with Joe O'Carroll who leads the Tunnel Construction Engineering group at Parsons Brinckerhoff. Parsons Brinckerhoff is part of the construction company Balfour Beatty. Further on I had a similar talk with Staffan Hintze, professor at the Department of Rock and Soil Mechanics at the Royal Institute of Technology in Stockholm. We agreed that a comparison of risk management practices in the two countries would be worthwhile conducting. In this way I could report on difference and similarities between how risk management is carried out in the two countries.

A couple of motivation factors for choice of subject for my thesis are the large cost overruns in underground construction and that incidents with adverse affects do happen repeatedly in the underground construction business. There are many recent examples from across Europe as well as in the US of these undesirable facts.

Having had some limited insight into the subject before the start of the thesis my understanding was that the risk assessment processes were well established in the two countries for underground construction projects and well advanced. However I had not much detailed theoretical knowledge to know for sure how the approaches vary and coincide in the two countries.

### **1.2. Goals**

The objective of this thesis is to reach a deeper understanding of how standard underground risk assessments are performed and how risk program procedures are designed for underground construction works in Sweden and in the US. I aim to present how the studied project specific risk related documents differ from a general standard and how they differ from each other and where they are similar or same in approaching the subject if risk. Also if possible; a subjective appreciation and documentation of what is good practice within risk management seen in the project examples studied is sought.

## 1.3. Method

The analysis of the chosen project specific risk documentation will be made first and foremost by a qualitative study to obtain a comprehension of their intended use and their specific features. The analysis will be comparative to distinguish differences and similarities. A breakdown will be made of the sample project specific risk documents into elements/features which can be compared intermittently and also compare with general theory on the subject, described in the sub sections “Literature review”.

The project specific documentation was provided by Joe O’Carroll for the US and from Staffan Hintze and some of his professional contacts from Sweden.

Generally the literature sources are articles obtained from search online and articles recommended by the supervisors of the thesis, as well as course literature from universities in the US which teach risk theory.

The subsection “Risk Register” in chapter 2 requires its own description of method. See the following few paragraphs:

It was not always clear from the studied material which categories of risk the assessors thought were affected by each hazard therefore I decided to re-categorize. While categorizing the risks the descriptions from the studied risk registers in most cases lead to obvious categories whilst in some case there had to be a judgment call made. The categorization I have made does not include any evaluation of level for probability of occurrence, severity of impact and thereby not risk levels either.

A part from categorizing the hazards into risks I also tried to identify what was the cause of the hazard. In some cases this was already described in the project specific documents studied but in some case this had to be determined during the analysis. In many case the source was not explicitly spelled out. In those cases I have if I felt it was possible attributed the one source I subjectively think would apply. All hazards in the studied risk registers have at least one cause indicated

In cases where I could not attribute the hazard one single cause or source; I indicated several sources as being the possible candidate. For those cases it is important to explain that when several causes/sources are indicated it is not because all of them would be the cause jointly but because all of them could separately be the cause. A good example is when the cause could have been the workmanship but it could also be inadequate design or geological ground conditions differing from the expected. In those kinds of cases I indicated all three causes.

## **1.4. Selection of Projects**

In attaining material to compare from the US and the Sweden the supervisors of this thesis Joe O'Carroll and Staffan Hintze provided suitable documents to study. Staffan Hintze also provided names for contact persons whom could provide documents from further projects. Contact was made and further documents were provided from these persons. The choices were made based on the aspiration from the writer; Lisa Avestedt, and the supervisors, to get state of the art risk assessments from both regions to compare. As both Joe O'Carroll and Staffan Hintze are experts in the risk management and risk theory field, the material studied in this thesis should be very relevant and would represent good practice in respective country.

The references in this write-up to the different projects studied are made through use of letters representing each a project. For each project studied within this thesis one or more risk related document such as risk assessments, risk work shop reports, risk work guidelines or specifications has been available. The Swedish projects are often represented by several types of documentation either; owner, consultant and contractor generated. The US project all are represented by one document per project written by the consultant for the owner. For a tabular format description of each project and documents studied, see Appendix B.

## **1.5. Projects Studied**

This thesis will compare the state of the art risk analysis practice, specifically risk assessments, from Sweden and the United States of America. The projects considered are larger infrastructure projects, all including underground works to some extent, such as larger tunnels or underground stations or other major underground structures See project list in Appendix B. The values of the project studied ranges from approximately 50 to 3,000 million dollars. In the printed thesis this project list may have been excluded as some of the information in the project specific documentation studied could be confidential or of sensitive nature.

## **1.6. Limitations and Possibilities**

One limitation of this project is time available. The thesis is to be compiled during 20 weeks of full time studies. The results will correspond to what can be accomplished during the specified time available. Another limitation would be the requests from the contributors to handle the risk assessments provided with confidentiality. Therefore the thesis can probably not reveal some details of specific projects. However: this does hopefully not mean compromising the display of lessons learned.

The limits of this thesis are also the means of obtaining project specific material to study. I have decided to obtain information from a limited amount of sources. This choice was done based on current established contacts within those companies and agencies.

Having only one provider of risk assessments from the US makes the comparison focused on this core provider. This may limit the prospect of getting a diverse selection of approaches to compare between.

This thesis will not in depth describe the methods for probabilistic numerical risk analysis. Monte Carlo simulation method is only briefly mentioned with a short description. I do not discuss different distributions used in numerical simulations either, although I recognize that several exists and can be applied in risk analysis and Appendix C shows short descriptions for some distributions which have been used in the project specific documents studied within this thesis.

The comparison of risk assessment documents would probably have been more relevant if the cases studied were only by one type of provider, for example consultants for the owner of a project rather than a mix of assessments from a construction company and consultants for owners. Because the project specific documentation studied is not created by similar originators, and also not at the same phase of the projects lifecycle; the thesis do not always compare “apples with apples”. But at the same time, having both consultants’ and contractors’ documentation may result in a broader range of issues to study.

## 1.7. Objectives

The main objectives of this study are:

- To identify a general or standard approach to risk analysis through a literature review
- To study the risk analysis process in Sweden and USA through some underground construction projects
- To compare and discuss the differences of the risk analysis process in Sweden and USA
- To propose further studies in this area.

## 1.8. Scope and Structure

This study consists of 6 chapters briefly described here below:

**Chapter 1** gives an introduction to the area of research as well as the main objectives for this thesis. The chapter includes a scope and structure section as well as a list of abbreviations and further; a section about definitions within risk theory.

**Chapter 2** includes several sub chapters which each describes a features or components of risk management and risk assessments. The sub-chapters for each feature or component is generally further divided into “Literature Review” and then “Application in Sweden” followed by “Application in USA” The sub-chapters also each include “Conclusions”. The sub-chapter about Risk Registers also includes a sub-section dedicated to statistics, in addition to the breakdown described here above.

**Chapter 3** includes a few loosely structured subsections where I discuss ideas and findings I consider interesting and/or useful from one or a selected number of the projects studied not previously presented in the thesis. This chapter also presents some of the results in the chapter 2 analysis and discussion regarding those results.

**Chapter 4** presents general conclusions and includes findings regarding differences and similarities between theoretical literature, Swedish applications and US applications, based on the studies in chapter 2.

**Chapter 5** suggests ideas for further studies on the subject.

**Chapter 6** constitutes the reference list for the study.

## 1.9. Abbreviations

ALARP	As Low As Reasonably Practical
BOT	Build-Operate-Transfer
CM	Construction Management
FTA	Federal Transit Administration or Fault Tree Analysis
L	Magnitude of Potential Loss
P	Probability of Occurrence
RA	Risk Assessment
RAMP	Risk Analysis and Management of Projects
RP	Risk Process
S	Severity of Impact
UK	United Kingdom
US	United States of America

## 1.10. Definitions

Here follows a quite extensive list of expressions used in risk theory in general. Each expression is followed by a brief description. Unless otherwise noted, the above definitions are gathered mainly from Raschperger, 2011 and Reinschmidt, 2006 unless otherwise noted.

A ***hazard*** is defined as an event that has the potential to impact a project, which could result in a consequence that is deemed undesirable for any number of reasons.

***Likelihood / probability of occurrence*** is what ranking the hazard has of occurring. This parameter is normally expressed in percent or as a number on a predetermined scale.

***Severity of impact*** is what ranking a hazard has for how severe the consequence would be if the hazard occurs. This parameter is normally expressed in percent or as a number on a predetermined scale.

***Detectability*** is defined as how easy or hard a hazard about to happen is to detect.

***Risk program:*** a structured procedure which seeks to identify, quantify and mitigate risks associated with the project. It is the term used to signify the whole process within a project that involves efforts of dealing with risks. Ideally this program would carry from the initiation of the project by the owner throughout the design phases, construction phase and finally operations. The risk related efforts within a project is often divided into several steps, as shown in Figure 1.

***Risk management:*** phase of the risk program in which identified and specified risks are avoided or eliminated, transferred to other parties better positioned to manage them, mitigated or accepted and controlled by the project. Risk management is also

about establishing contingency plans to deal with risk if they should occur and defining needed recourses and secure a budget.

**Identification** of hazards would be identification at a specific point of the project, which does not mean that further hazards, or possibilities, cannot be identified in a later stage. The identified hazards are gathered in the risk register.

A **risk register** is a format for recording risk information using risk identification techniques. It records various data for each individual issue, including a description, causes, likelihood of occurrence, impact, mitigation, status and ownership. The risk register is a primary tool intended to be used to track risk exposure and monitor risk management throughout the project.

**Risk assessment:** identifies hazards to a project and assesses, in qualitative, and often also in quantitative terms, the likelihood of the hazard event and its consequences for the project. Risk assessment is a step in a risk program process. Risk assessment is the determination of quantitative or qualitative value of risk related to a concrete situation and a recognized threat, also called hazard.

**Risk analysis:** makes the identified hazards specific with regards to location responsible parties etc. and quantifies the likelihood and impact of the events.

**Qualitative risk assessment** is the identification, description, understanding and assessment of the impact of the hazard in qualitative terms such as very unlikely / possible / low impact etc. The qualitative assessment provides a basis for determining priorities for management attention.

A **quantitative risk assessment:** replaces the terminology of the qualitative assessment with numbers for purposes of modeling and / or quantification of a risk and thereby it's associated effect on the project cost and schedule, or other categories if interest. Quantitative risk assessment requires calculations or maybe better put; designation of two components of risk. These two components are the magnitude of the potential loss; L, and the probability; P, that the hazard will occur (Wikipedia, 2011). The magnitude of potential loss is also commonly referred to as severity of impact; S.

A **likelihood - impact matrix** is used to assess the relative importance and ranking of risks. This matrix is often also called probability-impact matrix. For each hazard an assessment of the likelihood of occurrence and the potential severity of impact is made, selected from a range of *High / Medium / Low* or similar categorization. The likelihood – impact matrix shows the risk value of the specific hazard as the product of the likelihood of occurrence and the severity of impact. The likelihood-impact matrix is also called **risk matrix**.

A **Fault Tree Analysis** is a top-down method that looks at what different hazards can lead to a specific event (Ericson, 1999). In mapping out the different hazards and attributing probability of occurrence for each of them. Another term for this type of analysis is **decision tree analysis**.

**Monte Carlo simulation** is a simulation technique where single value estimates (of duration, resource and cost in the case of risk assessments studied in this thesis) are

replaced by a distribution to reflect the perceived uncertainty in those estimates. A random number is generated and a corresponding value sampled from the distribution. Once a sample has been taken from all variables in the model, a single value is calculated for each target. A target could be a milestone, a total budget number, a project end date etc. The process is repeated a large number of times to give a distribution of possible outcomes. In short the likelihood in the analysis is switched out to a probability with an uncertainty described as a distribution function. The types of software used to perform this Monte Carol analysis for risk purposes in construction projects normally runs between 1,000-10,000 simulations to come up with a range of cost or schedule implication for a certain range of probability of occurrence and a thereby a range of impacts to cost and/or schedule. The information retrieved is then used to determine how much contingency should be applied to the project in terms of cost and schedule, in addition to the engineers estimated and schedule.

***Toll gates*** are actions that have to be taken before entering into a new phase of a project to ensure measures/procedures are followed to avoid hazards.

## 2. ANALYSIS

### 2.1. Theoretical Risk Assessment Procedures and Methodologies

#### 2.1.1. Literature Review

Traditional risk assessment for construction has been synonymous with probabilistic analysis. Such approaches require events to be mutually exclusive, exhaustive, and conditionally independent. However, construction involves many variables, and it is often difficult to determine causality, dependence and correlations. As a result, subjective analytical methods have been developed which rely on historical information and the experiences of individuals and companies have been used to assess the impact of construction risk and uncertainty (Bajaj 1997).

Looking at scientific papers and other theoretical literature, not related to the projects studied in this thesis, written on the subject of how to identify, evaluate, analyze and manage risk within construction and underground construction; I have found several suggested procedures and methodologies to follow. Reading about their specific features they all seem to be, as mentioned above; subjective analytical methods relying on the experience of the people and companies involved. They also have the common features of identifying hazards ranking risks and discussing ways to manage, eliminate or transfer the risks. Here below follows three approaches identified through literature study. They are all variations of the same general approach even if they have their distinctive finesses in terms of detail in the procedures or for example specification of using certain software or other:

- A general method developed in the UK is RAMP (RAMP 2005), applicable on all types of projects. RAMP stands for **Risk Analysis and Management of Projects**. The RAMP method is produced by the Institute of Civil Engineers and the Institute of Actuaries in the United Kingdom and it was first published in 1998. This method uses a project framework to identify and mitigate risk by using the accepted framework of risk identification and project controls by focusing on risks as they occur during the project life cycle. It requires users to follow a rational series of procedures and to undertake this analysis at scheduled intervals during the life cycle of a project. It is not clear from the literature study carried out for this thesis if RAMP was based on other commonly used methods at the time it was created or if it was very different and “ground breaking” from construction industry standard at the time.
- **Risk Assessment Methodology for Underground Construction Projects** (Choi 2004): This is a paper that presents a risk assessment methodology specifically for underground construction projects with a detailed case study from a subway project in Korea. The authors suggest specific software developed to assess and manage risk. The specific finesse with the suggested software tool is that it is designed to consider the uncertainty range that represents uncertainties in both probabilistic parameter estimates and subjective judgments. The method also suggests survey sheets to collect risk data and a detailed check sheet for identification and analysis of risk.

- **Guidelines for Tunneling Risk Management** (Eskesen 2004): These guidelines were prepared by Working Group 2, Research, of the International Tunneling Association. The paper was written to give guidance to all those who have the job of preparing the overall scheme for the identification and management of risks in tunneling and underground projects. The guidelines provide owners and consultants with what is modern-day industry practice for risk assessment, and describes the stages of risk management throughout the entire project implementation from concept to start of operation.

### ***2.1.2. Application in Sweden and USA***

For all the project I have studied within this thesis, the above statement made by Bajaj et al. is true; risk analysis are subjective analytical methods that do rely on the experience of the individuals and companies involved. It seems most project specific risk assessment documents studied are partly or entirely based on the knowledge of the participants of a risk workshop or similar event proceeding creation of the documents studied within this thesis.

For all of the studied projects, it seems the RAMP approach or similar approach is more or less used. The “Guidelines for Tunneling Risk Management” mentioned above is one similar method which discusses similar approaches as RAMP but adjusted for tunneling in particular. Without saying anything about if there is a worldwide standard it seems appropriate to say that there are similar standards for the risk assessments cycle in USA and Sweden in underground construction projects. On a side note; some of the reference material used for this thesis is from Brittan and without having studied project specific documentation from there, it is probably safe to say that the same type of standard approaches for risk work within construction is applied there too.

One single major difference however between the Swedish and US project studies is that the US projects generally includes a probabilistic simulation for major cost and schedule risks.

### ***2.1.3. Conclusions***

- There exist many suggested approaches for how to execute risk management in construction. Generally it seems there is similar approach to how to work with risk programs in construction projects; a subjective analysis is carried out relying on historical information and the experiences of participants.
- The projects studied from Sweden and USA follow the same standard approaches found in literature in regards to risk management.
- The US projects studied included probabilistic simulations in addition the subjective analytical method.

## 2.2. Risk Program Cycle

### 2.2.1. Literature Review

Figure 1 demonstrates the cycle of events that the risk program should include. It is important that the program is seen as a continuous process throughout the life cycle of the project and also stretching into the operations and maintenance phase.

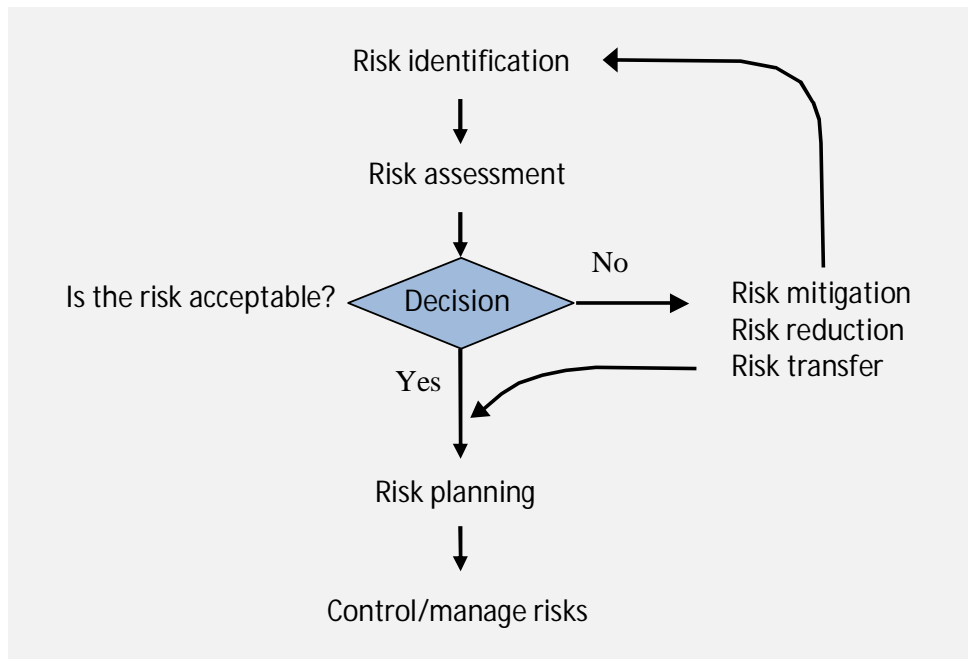


Figure 1: Main elements of risk program of a construction project

### 2.2.2. Application in Sweden

The most explicitly pronounced description of the risk program and management made in the Swedish project specific documentation was documented for Project A, in one of the contractor's bid proposal documents. The writer describes the extensive risk assessment effort that has taken place during the bid period and also continues describing how the contractor would expect to work on a risk management program throughout construction. The contractor here describes the main hazards identified during the bid-specific risk workshop the contractor has conducted. Also identified are ranking of the identified risks and suggested mitigation measures.

The risk management handbooks for projects A, D and E also describes the cycle, in a similar way to the above literature review example shown in Figure 1.

In project A's contractor bid-proposal it is pointed out that it is important to have a fully working continuous task for risk management throughout the project. Identification and analysis of new risk, revision if necessary of already identified risk,

reevaluation of mitigation measures and revision of action plans should constantly be carried out through all and any phase of the project. A close working relationship between contractor and client is brought forward as paramount as well as an open frank communication between the two without prestige.

In the documentation for Project D there was a description made by the client's consultant on how the risk program should be implemented for one of the railway stations that would be constructed as part of a new railway line under the city. The paper points out the procedures of the risk program process and highlights the importance of continuity and follow-up through the project. Similarly to what was mentioned in the above paragraph good communication is identified again as a very important building block for a working risk management; both communication between client and contractor but also between management and labor is highlighted.

### ***2.2.3. Application in USA***

In the risk management plan of Project I risk the similar description is made about importance of constant follow-up through reevaluation of known risks and development of new risk. However; it does not explicitly point to the importance of good communication between parties involved.

This continuity with constant follow up and adjustments has also been pointed out as important in conversations with Joe O'Carroll. Who in many cases has been one of the authors or reviewers of the US project specific documentation studied in this thesis.

### ***2.2.4. Conclusions***

- The Swedish project documentation brings up the importance of communications and transparency between parties involved in the projects; a thorough search was done in all the projects' documentation to see if this was a significant difference.
- None of the documentation from the US brings up open and good communication between parties in a project as important.
- Both countries project specific documentation emphasizes the importance of constant follow up, feedback and adjustments within the risk management process throughout the project.

## **2.3. Fault Tree Analysis**

### **2.3.1. Literature Studied**

In theoretical literature and case studies Fault Tree Analysis and fuzzy-FTA seem to be popular methods for analyzing hazards and reasons for how they occur. When searching for projects where FTA is normally used the general area of employment seems to be in aerospace industry, nuclear industry and electrical systems. FTA is a top-down method that looks at what different hazards can lead to a specific event (Ericson 1999). In mapping out the different hazards and attributing probability of occurrence for each of them, a system's resistance to the occurrences can be evaluated. Intuitively this method might not be that useful for risk assessments in the underground business. However for particular unique events it may be successfully employed, if a more detailed analysis is needed.

### **2.3.2. Application in Sweden**

The client's procedures for Project D include fault tree analysis as a mean to analyze risk. It is mentioned in a process description of the project "handbook" as a quantitative method for evaluating risk, among other methods. No project studied from Sweden explicitly uses the fault tree analysis within the risk work presented in the project specific documentation.

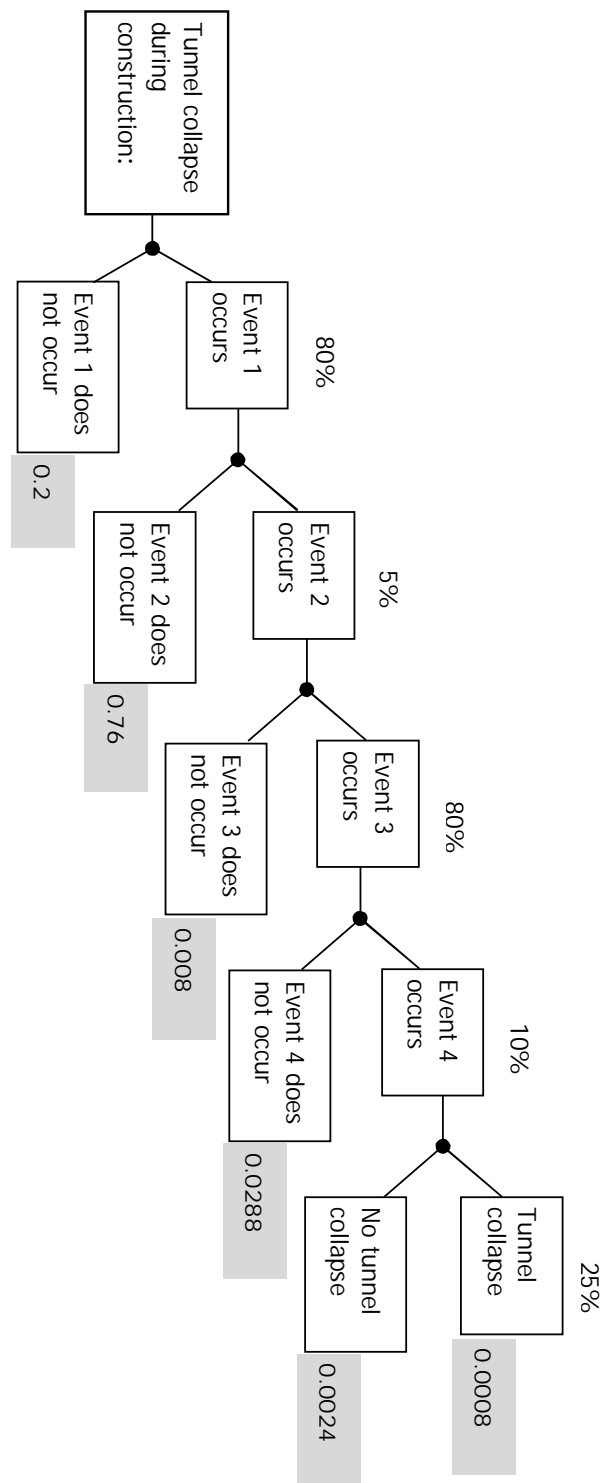
### **2.3.3. Application in USA**

Fault tree analysis has been explicitly applied on one of the projects, Project H. Mention of fault tree analysis does not occur in any other project specific documents studied for this thesis.

In Project H FTA is systematically used to come up with values for chains of events related to specific hazards, see Figure 2 for a generalized example taken from the project. The figure shows the estimated probability for each step of the chain of events leading to that one serious hazard occurs. For each step of the chosen path the estimated probability of occurrence is multiplied with the resulting estimated probability from the previous steps, and so on until the end state is reached and an estimated probability is determined for that end state.

In the document studied for Project H it is described that the decision tree analysis concentrates on the risk of structural failure of a sewer tunnel. A few of the identified hazards for which a structural collapse of the tunnel is a possible outcome are singled out and studied with this method. Based on all information available at the time of the analysis the estimated probabilities were determined by a risk workshop team who worked with the fault tree as a tool to reach conclusions on the resulting estimated probabilities of failure. In Figure 2 it should be noted that not all the branches lead to a failure condition; in this particular case failure of the tunnel liner. The probability of failure is represented by the number noted in the shaded box at the far most right of

the fault tree. You can also see that all the shaded numbers are the estimated probability for the particular path of event and all the shaded numbers added up together is 1, where 1 represents all possible outcomes added up together. The author of the document also points out that the resulting estimated probability of failure, attained by adding the shaded numbers for all hazards which could lead to structural failure, is probably lower than the actual resulting probability if failure. The reasoning given is that the risk assessment team may not have identified all possible hazards which could lead to a structural failure, thus; the resulting total estimated probability of failure is lower than if more hazards had been identified and analyzed.



**Figure 2: Example of fault tree analysis with a sequence of negative events occurring or not and the possibility for a serious resulting hazard to occur**

### **2.3.4. Conclusions**

- The client's "handbook" for Swedish Project D mentions fault tree analysis as one quantitative method of analyzing risk exposure.
- Project H from USA uses fault tree analysis for a selected number of risks related to collapse of the studied tunnel.

## **2.4. Risk Register Content**

### **2.4.1. Literature Review**

Any underground construction is considered to be of high risk to the environment (Moergeli 2004). There are several good reasons for this:

- The ground always remain unpredictable
- Unforeseen amounts of water present can be a major factor of concern
- Heavy weight and/or high energy transports activities
- Available space is very limited
- Darkness
- High construction noise
- High temperature, high moisture level
- Dealing with explosives and high voltage equipment
- Fresh air can be very limited

Work hours also need particular consideration as tunnel project normally run on an around-the-clock schedule. In addition an underground project is often a public project with a high publicity potential.

Risk registers normally consists of the identified hazards in a tabular format list, often divided into a number of risk categories. A common set of risk categories are (Hintze 2011):

- Working environment –work injury on person working on the project
- Third party –injury on person that is not engaged within the project
- Project property –damage to project property or property of participating parties in the project for example to permanent or temporary structures or equipment etc.
- Third party property –damage to property belonging to third party not engaged in the project
- Environment – damage to natural resources (ecosystems)
- Time – delay of activity activities that delays the project in relation to existing schedule
- Cost – ”damage” that pass on the necessity to use reserves and thereby a budget overrun
- Trust/Goodwill – occurrences that reduces the interested parties and/or stakeholders trust in the project organization, the contractor or the project

Depending on how far the risk assessment process for the project has progressed the risk register is expanded with information about rating for probability of occurrence and severity of impact as well as resulting risk evaluation. In addition, a risk register generally includes risk mitigation measures aiming to reduce or eliminate risks (O’Carroll 2011).

Depending on which categories of risk the assessors are interested in the evaluation for each of the desired risk categories to address is included too. As you can see in section 3.1.3.1 the risk register can be expanded to a matrix that holds all kinds of information, if so is desired.

## ***2.4.2. Application in Sweden***

The project for which risk registers have been studied for this theses are projects A, B, C, D, F, G, H, J, K and L. Out of which A, B, C and D are from Swedish projects. Here below follows a set of tables that display different findings of the Swedish risk registers studied in this thesis.

### **2.4.2.1. Risk Categories**

Table 1, Table 2, Table 3 and Table 4 show an assortment of information in terms of which risk categories would be affected by the identified hazard, resulting from the analysis of the risk registers from Sweden.

Project	A	B	C	D
Number of hazards	150	102	18	61
Number of risk	267	86	125	46

**Table 1: Summary of number of risks identified for the Swedish projects studied**

The Swedish projects included a number of risks which were grouped under a new category; "Quality of product", not included in the groups presented in the literature review. These hazards represented 6% of the Swedish hazards. Due to their nature, such as; deficient or wrong materials being or not properly carried out works leading to a product of less quality than intended it seemed appropriate to include this additional group.

Risk to cost is the one largest concern for all the Swedish projects. For projects A to C 2<sup>nd</sup> largest risk category is schedule, for project D the 2<sup>nd</sup> largest risk category is damages to the environment. When looking at the mean values for all projects A to D of one risk category the top 5 categories in descending order for the Swedish projects are:

1. Cost
2. Schedule
3. Damage to the environment
4. Quality of product
5. Damage to third party property

Risk type \ Project	A	B	C	D
Effect on working environment	6	7	1	8
Injury or impact to third person	2	6	1	9
Damage to property	4	12	0	11
Damage or other impact to third party property	12	13	0	9
Cost	99	36	12	42
Time/schedule	31	27	6	21
Trust/goodwill	3	2	0	10
Damage to the environment	24	11	1	22
Quality of product	17	3	1	10

**Table 2: Number of hits for respective risk category per Swedish project studied**

Risk Category \ Project	A [%]	B [%]	C [%]	D [%]
Effects on working environment	3	6	5	6
Injury or impact to third person	1	5	5	6
Damage to property	2	10	0	8
Damage or other impact to third party property	6	11	0	6
Cost	50	31	55	30
Time/schedule	16	23	27	15
Trust/goodwill	2	2	0	7
Damage to the environment	12	9	5	15
Quality of product	9	3	5	7

**Table 3: Percentage of allocation for specific risk category/type per Swedish project**

Risk Category \ Country	Swedish projects [%]
Effects on the working environment	5
Injury or impact to third person	4
Damage to property	5
Damage or other impact to third party property	6
Cost	41
Time/schedule	20
Trust/goodwill	3
Damage to the environment	10
Quality of product	6

**Table 4: Mean values of percentage for number of hits per risk category for the Swedish projects**

#### 2.4.2.2. Cause/Source of the Hazard

Apart from the risk categories which describe what areas of interest could be affected by an identified hazard, there is something that makes that hazard occur, a source or cause. Here below in Table 5 follows data from Sweden regarding sources of hazards following categorization made for this thesis.

Identified Cause/Source	Project A [%]	Project B [%]	Project C [%]	Project D [%]
Contract packaging, procurement and strategy	3	16	13	6
Regulatory requirements and permit issues	4	6	0	4
Caused by environmental issues in ground	1	2	0	1
Contractor's problems to carry out works	44	30	25	28
Geological / geotechnical conditions	16	9	25	24
Other ground conditions or other obstructions	7	2	6	0
ROW Legal, funding and insurance	1	2	0	0
Project reconfiguration or other scope change	2	5	6	13
Space issues or lack of available transportation means	3	13	6	1
Material delivery issues time and capacity	4	0	0	1
Inexperience or lack of resources	2	2	6	0
Inadequate planning such as design, survey etc.	5	3	0	20
Weather	2	1	0	0
Communication problems	3	2	0	0
Cost fluctuation for materials, equipment and or labor	1	2	13	0
Neglect in safety preparedness and execution	1	2	0	3
Third party impacts with work	1	4	0	0

**Table 5: Percentage of project total distributed per identified cause/source of the hazard occurring for Swedish projects**

The reason that projects B and C have very high percentages for “Contract packaging, procurement and strategy” is for project B that the PPP; partnering set up was used and the assessing party, in this case the contractor, was concerned about distribution of responsibilities between parties as these contracting form was not regularly used by this company. The high score on the same category for project C was related to that the assessed project was close to start construction and the assessors, also a contractor team, raised concerns about interfaces with other contracts.

The largest concerns in general in the Swedish projects’ risk registers in terms of sources for the hazards are the contractors encountering problems which makes it harder desired to carry out the works and in particular; differing ground conditions.

The top 5 causes/sources for hazards occurring in the studied projects from Sweden are:

1. Contractor's problems to carry out works
2. Geological / geotechnical conditions
3. Contract packaging, procurement and strategy
4. Inadequate planning such as design, survey etc
5. Space issues or lack of available transportation means

### 2.4.3. Application in USA

The project for which risk registers have been studied for this theses are projects A, B, C, D, F, G, H, J, K and L. Out of which F, G, H, J, K and L are from US projects. Here below follows a set of tables that display different findings of the US risk registers studied in this thesis.

#### 2.4.3.1. Risk Categories

Table 6, Table 7, Table 8 and Table 9 show various information in terms of which risk groups would be affected by the identified hazard, resulting from the analysis of the risk registers of the projects studied from USA.

Project	F	G	H	J	K	L
Number of hazards	118	53	31	44	105	78
Number of risk	102	89	142	22	119	199

**Table 6: Summary of number of risks identified for the US projects studied**

The projects from USA included risks which were grouped under the new category; “Quality of product”. For the American projects this category represented 1% of the total number of risks.

Risk to cost is the one largest concern for all the projects from USA. For projects F through J and project L the 2<sup>nd</sup> largest risk is schedule, for project K the 2<sup>nd</sup> largest risk is damages to the environment. When looking at the total number of risks from one category for all projects F to L of one category the top 5 risks in descending order for the American projects studied are:

1. Cost
2. Schedule
3. Damage to third party property
4. Damage to the environment
5. Damage to property

Project Risk type	F	G	H	J	K	L
Effects on the working environment	7	2	3	3	0	1
Injury or impact to third person	17	2	1	5	1	2
Damage to property	19	2	7	4	0	1
Damage or other impact to third party property	31	3	0	8	0	6
Cost	95	37	21	44	104	45
Time/schedule	70	25	11	13	5	42
Trust/goodwill	11	2	0	5	1	2
Damage to the environment	14	13	0	3	7	1
Quality of product	1	0	0	3	0	4

**Table 7: Number of hits for respective risk category per project from USA**

Project Risk Category	F [%]	G [%]	H [%]	J [%]	K [%]	L [%]
Effects on the working environment	3	2	7	3	0	1
Injury or impact to third person	6	2	2	6	1	2
Damage to property	7	2	16	5	0	1
Damage or other impact to third party property	12	3	0	9	0	6
Cost	36	43	49	50	88	43
Time/schedule	26	29	26	15	4	40
Trust/goodwill	4	2	0	6	1	2
Damage to the environment	5	15	0	3	6	1
Quality of product	0	0	0	3	0	4

**Table 8: Percentage of allocation for specific risk category/type per project from USA**

Country Risk Category	US Projects [%]
Effects on the working environment	3
Injury or impact to third person	3
Damage to property	5
Damage or other impact to third party property	5
Cost	52
Time/schedule	23
Trust/goodwill	2
Damage to the environment	5
Quality of product	1

**Table 9: Mean values of percentage for number of hits per risk category out of the total for the projects from USA**

### 2.4.3.2. Cause/Source of the Hazard

See below Table 10 for results of the effort to categorize the causes/sources of what would make the hazards occur for projects studied from USA.

One eye-catching number is the 50% of risks possibly caused by “Project reconfiguration or other scope change”. In reality it is not that chocking but rather logical because that particular project, Project K, was in a very early design phase when the this particular risk assessment was carried out and there were still quite a few uncertainties about increases to the program and how that would increase in particularly the cost and schedule of the project.

Project K always had cost as a risk category for every identified hazard. This was intentional as the cost was the main risk category which had to be studied at the time in order to determine the credibility of the contingencies included in the engineers estimate for the project.

Within the projects’ risk registers from USA the largest concerns in general are the contractors encountering problems which makes it harder than desired to carry out the works and in particular; differing ground conditions.

Identified Cause/Source \ Project	F [%]	G [%]	H [%]	J [%]	K [%]	L [%]
Contract packaging, procurement and strategy	5	7	6	0	1	4
Regulatory requirements and permit issues	5	9	3	0	3	13
Caused by environmental issues in ground	2	2	3	7	3	5
Contractor’s problems to carry out works	27	16	12	27	4	19
Geological / geotechnical conditions	19	9	18	50	6	21
Other ground conditions or other obstructions	5	2	6	3	15	4
ROW Legal, funding and insurance	5	7	3	0	16	15
Project reconfiguration or other scope change	10	11	0	0	51	1
Space issues or lack of available transportation means	4	2	0	0	0	0
Material delivery issues time and capacity	1	0	0	0	0	2
Inexperience or lack of resources	1	0	0	2	0	5
Inadequate planning such as design, survey etc.	7	13	12	7	0	1
Weather	2	4	18	2	0	1
Communication problems	1	0	0	0	0	1
Cost fluctuation for materials, equipment and or labor	2	13	12	0	0	2
Neglect in safety preparedness and execution	1	0	0	0	0	5
Third party impacts with work	3	5	6	3	2	0

**Table 10: Percentage of project total distributed per identified cause/source of the hazard occurring for the projects from USA**

The top 5 causes/sources for hazards occurring in the studied projects from USA are:

1. Contractor's problems to carry out work
2. Geological / geotechnical conditions
3. Project reconfiguration or other scope change
4. Inadequate planning such as design, survey etc
5. ROW, legal, funding and insurance

Inadequate planning such as design, survey etc. and ROW, legal, funding and insurance have the same amount of hits.

From the above results in there are some areas which seemed interesting to bring up as additional information that explains some of the variation between projects and how risk and causes/sources of risk are distributed in for the projects studied. For right-of-way and insurance issues see paragraphs 3.4 and 3.5 .

#### **2.4.4. Some Statistics on the Risk Registers Studied**

When looking at the risk registers analysis in the above sections; the step is not far to explore if the results are statistically interesting. Here follows a small section on that subject.

The correlation, described in the below function, is calculated for the US and Swedish projects to see how well they follow the same distribution between risk and causes of hazards.

$$Correl(X,Y) = \frac{\sum (x - \bar{x})(y - \bar{y})}{\sqrt{\sum (x - \bar{x})^2 \sum (y - \bar{y})^2}} \quad \text{Equation 1}$$

The resulting correlation for risk distribution is 0.98 and for the cause of hazard it is 0.88, where 1 would be completely correlated. However there were large fluctuations with in each country and if all the projects from both countries or all projects from respective countries would be tested against each other there would be much smaller correlations. Those results are not presented in this study.

Further the standard deviation is calculated per project and per category of risk and category of cause of hazard. For standard deviation the following formula is used:

$$\sqrt{\frac{\sum (x - \bar{x})^2}{(n - 1)}} \quad \text{Equation 2}$$

The results of the operation are presented in Table 11, Table 12 and Table 13.

Risk Category	Standard Deviation
Working environment	2.9
Injury or impact to third person	5.1
Damage to property	6.3
Damage or other impact to third party property	9.4
Cost	33.3
Time/schedule	19.6
Trust/goodwill	3.9
Affects environment	8.7
Quality of product	5.5

**Table 11: Standard deviation for the risk distribution**

Cause of Hazard	Standard Deviation
Contract packaging, procurement and strategy	14.0
Regulatory requirements and permit issues	12.5
Caused by environmental issues in ground	6.2
Problems related to method	71.3
Geological or geotechnical conditions	49.9
Other ground conditions or other obstructions	14.7
ROW Legal, funding and insurance	13.1
Project reconfiguration or other scope change	30.7
Space issues or lack of available transport capacity	10.4
Material delivery issues time and capacity	3.6
Inexperience or lack of resources	4.0
Inadequate planning such as design, survey etc.	18.1
Weather	4.3
Communication problems	2.8
Cost fluctuation for materials, equipment and or labor	5.8
Neglect in safety preparedness and execution	3.2
Third party impacts with work	7.9

**Table 12: Standard deviation for cause of hazard distribution**

Project	Risk Distribution	Cause of Hazard
A	30.6	16.9
B	11.4	9.7
C	4.0	1.3
D	11.2	7.2
F	31.8	61.1
G	13.1	2.9
H	7.2	2.1
J	13.2	7.7
K	34.2	13.3
L	18.2	5.7

**Table 13: Standard deviation per project and respective category**

## 2.4.5. Conclusions

Regarding Risk categories:

- Due to a number of risks mostly from the Swedish projects; the number of used categories was expanded in the study by adding the category “Quality of product” from the categories as presented in the literature review, see shaded cells in bottom row in Table 14 for occurrence of that type of risk.
- One trend fairly easy to spot in this analysis is that in both countries cost and schedule are the main concerns.
- Damage to the environment is the 3rd most frequent risk in Sweden whilst in USA the 3rd category is damage to third party property, calculated as number of hits per category divided with total number of risks for all projects together per country, see Table 15.

Project Risk Category	A [%]	B [%]	C [%]	D [%]	F [%]	G [%]	H [%]	J [%]	K [%]	L [%]
Effect on the working environment	3	6	5	6	3	2	7	3	0	1
Injury or impact to third person	1	5	5	6	6	2	2	6	1	2
Damage to property	2	10	0	8	7	2	16	5	0	1
Damage or other impact to third party property	6	11	0	6	12	3	0	9	0	6
Cost	50	31	55	30	36	43	49	50	88	43
Time/schedule	16	23	27	15	26	29	26	15	4	40
Trust/goodwill	2	2	0	7	4	2	0	6	1	2
Damage to the environment	12	9	5	15	5	15	0	3	6	1
Quality of product	9	3	5	7	0	0	0	3	0	4

**Table 14: Percentage of allocation for specific risk category/type per project**

Risk Category \ Country	Sweden	USA
Effect on the working environment	4.6%	2.3%
Injury or impact to third person	3.8%	4.0%
Damage to property	5.6%	4.7%
Damage or other impact to third party property	7.1%	6.8%
Cost	39.5%	49.1%
Time/schedule	17.7%	23.6%
Trust/goodwill	3.1%	3.0%
Damage to the environment	12.1%	5.4%
Quality of product	6.5%	1.1%

**Table 15: Percentage of number of hits for respective category in proportion to total number of risks, when adding all projects' risks together per country**

Regarding causes/source of the hazards, for tables see Table 16 and Table 17:

- In both countries the main cause for a hazard to occur is related to the contractor having problems to carry out the work as well as un-favorable ground conditions.
- The Swedish projects raises more concern for contractual issues mostly due to the less common PPP solution chosen for one of the contracts and also due to interface issues a contractor envisaged.
- The reason one project from USA showed a high presence for project reconfiguration causing risks was largely explained by this assessment being done very early on in the project and the scope of the project was not completely finalized.

Identified Cause/Source \ Project	A [%]	B [%]	C [%]	D [%]	F [%]	G [%]	H [%]	J [%]	K [%]	L [%]
Contract packaging, procurement and strategy	3	16	13	6	5	7	6	0	1	4
Regulatory requirements and permit issues	4	6	0	4	5	9	3	0	3	13
Caused by environmental issues in ground	1	2	0	1	2	2	3	7	3	5
Contractor's problems to carry out works	44	30	25	28	27	16	12	27	4	19
Geological / geotechnical conditions	16	9	25	24	19	9	18	50	6	21
Other ground conditions or other obstructions	7	2	6	0	5	2	6	3	15	4
ROW Legal, funding and insurance	1	2	0	0	5	7	3	0	16	15
Project reconfiguration or other scope change	2	5	6	13	10	11	0	0	51	1
Space issues or lack of available transportation means	3	13	6	1	4	2	0	0	0	0
Material delivery issues time and capacity	4	0	0	1	1	0	0	0	0	2
Inexperience or lack of resources	2	2	6	0	1	0	0	2	0	5
Inadequate planning such as design, survey etc.	5	3	0	20	7	13	12	7	0	1
Weather	2	1	0	0	2	4	18	2	0	1
Communication problems	3	2	0	0	1	0	0	0	0	1
Cost fluctuation for materials, equipment and or labor	1	2	13	0	2	13	12	0	0	2
Neglect in safety preparedness and execution	1	2	0	3	1	0	0	0	0	5
Third party impacts with work	1	4	0	0	3	5	6	3	2	0

**Table 16: Percentage of project total for respective cause/source of the hazard occurring.**

Identified Sources	Sweden	USA
Contract packaging, procurement and strategy	8.5%	4.5%
Regulatory requirements and permit issues	4.6%	5.1%
Caused by environmental issues in ground	1.3%	2.8%
Contractor's problems to carry out works	35.1%	23.3%
Geological / geotechnical conditions	16.0%	19.1%
Other ground conditions or other obstructions	4.1%	5.9%
ROW Legal, funding and insurance	0.8%	6.2%
Project reconfiguration or other scope change	5.2%	12.5%
Space issues or lack of available transportation means	6.2%	2.6%
Material delivery issues time and capacity	2.1%	1.0%
Inexperience or lack of resources	1.5%	1.5%
Inadequate planning such as design, survey etc.	7.2%	6.2%
Weather	1.0%	2.0%
Communication problems	1.8%	0.7%
Cost fluctuation for materials, equipment and or labor	1.5%	2.6%
Neglect in safety preparedness and execution	1.5%	1.1%
Third party impacts with work	1.5%	2.9%

**Table 17: Percentage of number of hits for respective category of cause/source in proportion to total number of risks, when adding all projects per country.**

Other findings worth mentioning, hidden within the categorization of sources/causes above, are:

- Issues related to settlements and prevention of settlements is represented in each and every one of the risk registers studied, in some form. Normally several issues are brought forward on this subject in each register.
- In the registers from the US a large group of risk issues are related to stakeholders and third party. The assessors have brought up wide spectra of issues covering the subject of interface with authorities, building owners, nearby businesses and the public for the different projects. In the Swedish registers you do not see as much of this, even when looking at registers compiled by owners or owner's consultants.
- The fluctuation in economical cycles is taken in consideration. When the steel prices when up a lot during 2001-2007 this was mentioned in two different registers. Likewise in more current registers, the opportunity of low bids, cheaper workforce and cheaper rental is included today, 2008-2009, and the assessors believe that with right timing the project will be served advantageous due to this circumstance.

## 2.5. Risk Formula

### 2.5.1. Literature Review

After a qualitative risk assessment has been done the risk is calculated as the product of the probability of occurrence and the severity of impact.

**Risk (R)** is considered the product of **Likelihood/Probability of Occurrence (P)** and **Severity of the Impact (S)**, as noted below. Severity of impact was under paragraph 1.10 defined as L; magnitude of loss. After reviewing more literature Severity of impact; seem to be the generally adapted term in risk assessments in the construction business.

$$R = P \times S$$

Equation 3

R = Risk rating

P = Probability of occurrence

S = Severity of the impact

In the below section probability of occurrence and severity of impact is discussed further, Table 18 and Table 19 show samples of ranking of these two parameters.

### 2.5.2. Application in Sweden

In all of the projects studied, in Sweden as well as the US, the risk formula as stated above was customary. This was again expected as this is the prevailing formula used in the theoretical literature studied.

In the Swedish documents studied for projects A through E; **P** and **S** are represented by a discrete number respectively and the risk ranking was the product of these two numbers. Similarly to the Swedish projects all risk in the US risk registers which were not numerically analyzed; **S** and **P** are represented by discrete numbers, or a percentage in some cases. This approach of attributing discrete numbers to **P** and **S** was used for all hazards in the risk registers in all studied project documents, or where no register were provided; it was at least described in text in the document for the particular project.

### 2.5.3. Application in USA

For projects F, G, H, J, K and L where Monte Carlo simulations are included in the analysis of risk exposure; **S** is represented by a discrete value of cost or days. For those risks in the US risk assessments where a Monte Carlo simulation was run; **P** is represented by a formula corresponding to chosen distribution. Choice of distribution type varies. The authors normally reason in the text why a certain distribution is chosen. See Appendix C for various distributions used. Out of the US projects studied

the Project I risk related documentation represents **S** and **P** in the same way as the Swedish project documents, described here above.

## 2.5.4. Conclusions

- The same formula to determined risk was used for all projects as a starting point
- The Swedish projects did not use simulations to determine cost and schedule risk exposure but the US risk assessors did.

## 2.6. Ranking and Terminology Used for Likelihood and Severity

### 2.6.1. Literature Review

In order to quantify the importance of the risk the assessors need to rank the likelihood of occurrence and the severity of impact. This could be done in many different ways. Table 18 shows a way of ranking the severity of impact (Reinschmidt, 2005).

Impact	Severity of impact	Ranking
Hazardous without warning	May impact the viability of the entire project. Problem occurs without warning. Very high severity	10
Hazardous with warning	May impact the viability of the entire project. Problem occurs with warning. Very high severity	9
Very high	Major disruptions to the project. The project plan, scope, cost estimate and schedule may have to be scrapped and redone. Major impact on project schedule and cost; even termination	8
High	Moderate disruptions to the project. The cost estimate and schedule may have to be considerably revised Rework may have to be done out of sequence (ripple effect). Considerable impact on project cost and schedule. Possible termination	7
Moderate	Disruption to project operations. Rebaselining of the schedule and cost estimate. Rework may have to be done out of sequence (ripple effect). Moderate impact on project cost and schedule	6
Low	Moderate disruptions to project operations. Major increase in costm duration, or affect on quality of some step or activity, but minor impact on the project as a whole	5
Very low	Minor disruptions to operations. Work is acceptable but not according to specified quality, and works takes longer than is should. Considerable increase in cost and some increase in duration, or no increase in non critical activity duration	4
Minor	Work is acceptable but not according to specified quality. Operations are not smooth or optmal. Impact wil occur on following activities. Increase in cost or duration of activity, but project cost and schedule within contingency	3
Very minor	Slight disruption or departure from plan. Little impact on following activities. Cost and schedule increase but within contingency	2
None	No discernible effect	1

**Table 18: Sample set of categories for severity of impact**

The likelihood of occurrence also, depending of type of analysis, called probability of occurrence also needs a ranking in order to define the risk ranking. Table 19 shows an example of ranking for likelihoods of occurrence (Reinschmidt, 2005).

Likelihood of occurrence	Possible approximate occurrence rate	Ranking
Very high	> 1 in 2	10
	1 in 2	9
High	1 in 3	8
	1 in 10	7
Moderate	1 in 50	6
	1 in 100	5
	1 in 500	4
Low	1 in 1,000	3
Very Low	1 in 10,000	2
Remote	1 in 100,000 or less	1

**Table 19: Sample set of categories, occurrence rates and ranking for likelihood of occurrence.**

Generally in construction projects the severity of impact and the likelihood of occurrence both have 5 steps of ranking, or less. The level of detail depends on what phase the project is in and what is deemed suitable by the risk manager (O'Carroll, 2010).

### 2.6.2. Application in Sweden

In the Swedish documentation for Projects A to E; when directly translated, *likelihood of occurrence* is used, likelihood is the direct translation of *sannolikhet*. But in a case where a few of the Swedish project's risk related documents have been written in English *probability of occurrence* is used, see Project A.

The steps of ranking for likelihood of occurrence and severity of impact are generally 5 each in the Swedish project documentation studied, Table 20.

*Severity of impact* is the standard term used for the Swedish projects studied when ranking the impact of a certain hazard. The word *consequence* is also occasionally used in project A and C.

Project	Number of steps in ranking for likelihood of occurrence	Number of steps in ranking for severity of impact
A	5 / 9	5
B	5	5
C	n. a.	n. a.
D	5	5
E	5	5

**Table 20: Number of levels for categorizing likelihood of occurrence and severity of impact in the Swedish projects.**

The terminology used for the ranking two parameters varies, between Swedish projects, see Table 21. Even within assessments from one soul provider the terminology differs. This variation seems to be a possible source of confusion.

For example if we look at Project A and B and the 3<sup>rd</sup> level of severity of impact; Project A describes this level as “serious” whilst the same level is described as “limited” for Project B. These two would possibly then be ranked down to level 2 for Project A and thereby possibly be placed in a lower risk category than it would have been if it was evaluated in Project A.

Project	Terminology for likelihood /probability of occurrence ranks	Terminology for severity of impact ranks
A	<ol style="list-style-type: none"> <li>1. negligible/försumbar</li> <li>2. very seldom/väldigt sällan</li> <li>3. seldom/sällan</li> <li>4. happens occasionally/förekommer</li> <li>5. will happen/inträffar</li> </ol>	<ol style="list-style-type: none"> <li>1. insignificant/obetydlig</li> <li>2. considerable/betydlig</li> <li>3. serious/allvarlig</li> <li>4. very serious/mycket allvarlig</li> <li>5. catastrophe/katastrof</li> </ol>
B	n. a.	<ol style="list-style-type: none"> <li>1. insignificant/obetydlig</li> <li>2. small/liten</li> <li>3. limited/måttlig</li> <li>4. serious/allvarlig</li> <li>5. catastrophe/katastrof</li> </ol>
C	n. a.	n. a.
D	<ol style="list-style-type: none"> <li>1. improbable/osannolik</li> <li>2. rare/sällsynt</li> <li>3. possible/möjlig</li> <li>4. probable/trolig</li> <li>5. very probable/mycket trolig</li> </ol>	<ol style="list-style-type: none"> <li>1. insignificant/obetydlig</li> <li>2. small/liten</li> <li>3. limited/måttlig</li> <li>4. very serious/allvarlig</li> <li>5. catastrophe/katastrof</li> </ol>
E	<ol style="list-style-type: none"> <li>1. negligible</li> <li>2. very seldom</li> <li>3. seldom</li> <li>4. happens occasionally</li> <li>5. will happen</li> </ol>	<ol style="list-style-type: none"> <li>1. insignificant</li> <li>2. considerable</li> <li>3. serious</li> <li>4. very serious</li> <li>5. catastrophe</li> </ol>

**Table 21: Terminology usage for likelihood of occurrence and severity of impact in projects from Sweden.**

### 2.6.3. Application in USA

The term *probability of occurrence* is used in the United States in documentation from Projects F through to L. The steps of ranking for likelihood of occurrence and severity of impact are generally 3 each in the US project documentation studied, except for Project L where the documents described 5 levels for each the likelihood of occurrence and the severity of impact, see Table 22.

*Severity of impact* is the standard term used for the projects from USA, when ranking the impact of a certain hazard.

Project	Number of steps in ranking for likelihood of occurrence	Number of steps in ranking for severity of impact
E	5	5
F	3	3
G	3	3
H	3	3
I	3	3
J	n.a.	n.a.
K	3	3
L	5	5

**Table 22: Number of levels for categorizing likelihood of occurrence and severity of impact, US projects.**

The terminology used for ranking of the two parameters varies between the projects from USA too, see Table 23. Even within assessments from one source provider the terminology differs. It seems this variation could lead to some confusion.

Proj.	Terminology for likelihood /probability of occurrence ranks	Terminology for severity of impact ranks
F	1. low 2. medium 3. high	1. low 2. medium 3. high
G	4. low/unlikely 5. medium/likely to occur 6. high/definite or multiple occurrences	7. insignificant 8. significant 9. serious 10. very serious
H	11. low/improbable/unlikely to occur on the project 12. medium/probable/ judged likely to occur at least once on the project 13. high/definite/multiple occurrences likely	14. low/ insignificant/ no to little delays, additional cost, or serious injury 15. medium/ significant/ potential serious injury or fatality, delay in schedule, costs significant 16. high/ serious/ fatalities possible, delay up to months, project shutdown possible, costs substantial, litigation likely
I	17. low/improbable/unlikely to occur on the project 18. medium/probable/ judged likely to occur at least once on the project 19. high/definite/multiple occurrences likely	20. low/ insignificant/ no delays, additional cost, or serious injury 21. medium/ significant/ potential serious injury or fatality, delay in hours to days, costs significant 22. high/ serious/ fatalities possible, delay up to months, project shutdown possible, costs substantial, litigation likely
J	Unlimited scale; percentage applied for what was considered adequate	n. a. (Frequency of occurrence was stated and cost per occurrence.)
K	23. low/ improbable/ unlikely to occur on the project 24. medium/ possible to probable/ judged possible to probable to occur 25. high/ highly probable/ very likely or definitely will occur	26. low/ insignificant/ minimal additional cost, no delays or serious injury 27. medium/ significant/ costs significant, delay in days to weeks potential injuries resulting in lost work time 28. high/ serious/ costs substantial, delay up to months, project shutdown possible permanent disabilities or fatalities possible.
L	29. negligible 30. very seldom 31. seldom 32. happens occasionally 33. will happen (in another part of the risk documentation this project had 3 categories identical with Project I)	34. insignificant 35. considerable 36. serious 37. very serious 38. catastrophe (in another part of the risk documentation this project had 3 categories identical with Project I)

**Table 23: Terminology use for likelihood of occurrence and severity of impact in US projects.**

## **2.6.4. Conclusions**

- Slight difference in use of terminology is found within the Swedish project documentation for *probability of occurrence*.
- *Magnitude of loss* is not used at all in the studied projects, rather *severity of impact* across the projects, regardless of country.

The variation of ranking which occur in both the Swedish and US projects may lead to miss-categorization and in worst case that a risk that should be considered important can be given a lower importance. This type of concerns are brought forward in theoretical literature on the subject (Cox 2005) where the authors highlights that successive layers of qualitative coding can introduce loss of information and inconsistency in the interpretation of labels. As a practical necessity the hazards must be grouped into manageable categories. Defining such categories requires value choices and that can have important implications for the ranking that may be undesirable (Morgan 2000).

## 2.7. Risk Matrix

### 2.7.1. Literature Review

After determining the ranking for likelihood of occurrence and severity of impact the risk are related to a risk matrix, also called likelihood-impact matrix or probability-impact matrix. In this predetermined risk matrix there are ranges of risks that are considered unacceptable, acceptable or negligible respectively, or also sometimes classified as unacceptable, serious and acceptable, see example in Figure 3.

After likelihood of occurrence and severity of impact have been multiplied the resulting risk ranking is relate to the risk matrix so the risk analysts or risk assessors can see under what risk ranking the particular items falls. After the decision has been made on each specific risk about what rank they fall into the risks are then handled accordingly. One feature of the risk matrix is that it shows how a risk of high probability but low severity of impact is according to the risk-matrix be considered similarly important as a risk with low probability and high severity of impact.

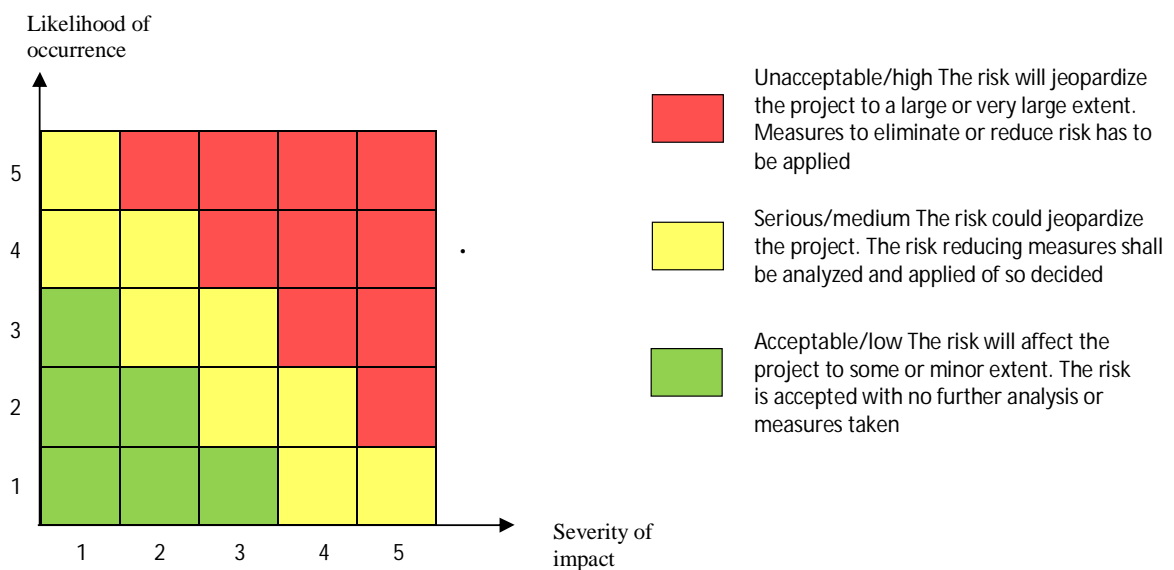


Figure 3: Typical risk-matrix

If the specific risk is determined unacceptable or high, as described in the above example, a more to dept discussion takes place determining mitigations for the risk to either, eliminate, reduce, transfer or control / plan for that occurrence. Here follows a brief description of what those different measures entail.

*Eliminate:* To change the planned production method or the change the project settings in a way to avoid the hazard completely. The importance of having a Plan B. or even Plan C if the risk cannot be sufficiently reduced or eliminated; is stressed in the literature (Reinschmidt 2006).

*Reduce:* To either reduce probability of occurrence or severity of impact so the specific issue falls in to the acceptable range or even into a lower grade of importance.

*Transfer:* To transfer the risk is to place the risk with another party, preferably the part that is best capable of handling the risk.

*Control / plan for:* Control the risk through survey and inspection programs.

### 2.7.2. Application in Sweden

In the project documents studied the risk ranking always follows the three levels, as represented above in Figure 3. As previously shown the likelihood of occurrence normally has 5 steps in the Swedish but the three groups of risks is a rule, see Table 24. Also if colors are used to represent the three levels of risk it is without exception coded with green for the low-risk items, yellow for the medium risks and red for the high risks.

Level of Risk Project	Acceptable / low	Serious / medium	Unacceptable / high
A	Low	Medium	High
B	Low	Medium	High
C	Low	Medium	High
D	Acceptable	Serious	Unacceptable
E	n. a.	n. a.	n. a.

**Table 24:** The terms that describe the 3 risk levels in the Swedish projects.

The mitigation measures in Sweden correspond to the ones described in the literature review here above.

### 2.7.3. Application in USA

The projects from USA, as for the Swedish projects, show risk matrixes with 3 groups of risks, see Table 25. Also if color coding is used it is the green, yellow and red which are used for low, medium and high risks respectively.

Level of Risk Project	Acceptable / low	Serious / medium	Unacceptable / high
F	1/ Low/ Tolerable	2/ Medium/ ALARP	3/ High/ Intolerable
G	Tolerable	ALARP	Intolerable
H	Tolerable	ALARP	Intolerable
I	Tolerable	ALARP	Intolerable
J	n. a.	n. a.	n. a.
K	Low	Medium	High
L	Tolerable	ALARP	Intolerable

**Table 25: The terms that describe the 3 risk levels in respective project from USA.**

The expression ALARP, as low as reasonably practical is used for the US projects in general. In the risk management plan of project F this level of risk is described as follows:

“This level of risk is undesirable. Efforts should be made to reduce the risk. Proceeding with the project knowing such risks exist can only be justified if risk reduction is impracticable or if the costs to mitigate are ‘grossly’ disproportionate to the improvement gained. Detailed assessment may be required to demonstrate that all potential risk reductions have been identified and properly considered where they are not justified.”

The limit between the ALARP level and the intolerable is that the intolerable level risks have to be reduced whilst the ALARP risk level can be tolerated without mitigation. The classification seems to be related to if the risk is worth reducing; what the benefit is to reduce the risk and how much it would cost to reduce the risk.

The mitigation measures in the projects from USA correspond to those stated in the literature review here above.

## **2.7.4. Conclusions**

- Levels of risk: When it comes to the risk matrix there is no difference, all projects utilizes 3 groups of risk, just as in the theoretical literature studied.
- Terminology varies between projects within country and between the two countries.
- The ALARP risks level corresponds to medium/serious/yellow risk level.
- Mitigation measures appear to be the same on all projects studied.

## **2.8. Numerical Methods versus Non-Numerical Method for Risk Analysis**

First of all the above heading was quite hard to formulate because of the confusion in terminology encountered when reading various articles on the risk subject. Under this heading and its sub sections I am not only relating projects studied to a generally accepted theoretical approach for risk assessments and risk analysis I am also bringing forward a finding about inconsistent use of terminology.

### **2.8.1. Literature Review**

#### **2.8.1.1. Qualitative Risk Analysis**

In chapter 1, the qualitative part of the risk assessment was defined as the identification of hazards. It would not include evaluating likelihood / probability of occurrence or severity of impact for the hazard. However I have found that there is another definition to the term qualitative risk analysis (Cox 2005). This alternative definition of qualitative risk analysis includes more activities. The quantification in terms of relating the severity of impact and likelihood of occurrence to a value is part of the qualitative analysis in this alternative manner of defining qualitative risk analysis. The analysis then also includes calculating the product of S and P and obtaining the ranking of the risk.

#### **2.8.1.2. Quantitative Risk Analysis**

In chapter 1 the quantitative part of the risk assessment would be evaluating the level of the likelihood/ probability of occurrence and severity of impact and also analyzing and determining the level of the resulting risk. However at least one other definition exists (Cox 2005). This alternative approach is to consider any analysis not based on a numerical model as qualitative and the quantitative part would be to run numerical simulations such as Monte Carlo to determine level of risk. This means migrating from giving S and P a simple value of say 1, 2 or 3 or ranges of percentage for example: 0-20%, 20-80% and 80-100% for the low, medium and high levels respectively, to S and P being represented by functions instead and simulations are made.

### **2.8.2. Application in Sweden**

The non-numerical method is used in the quantitative analysis of risk throughout the documentation from the projects in Sweden.

In the documentation for the Swedish projects studied, I found no reference to any numerical simulations. The broader assessments made for the Swedish project studied where other categories than cost and schedule are evaluated are possibly not possible to apply numerical simulations to.

### **2.8.3. Application in USA**

In the documentation studied it is clear that the US consultant uses the numerical methods often. For the projects studied in this thesis numerical analysis was carried out for all projects except for Project I.

The US consultant uses this tool to determine cost and schedule impacts to the project. The analysis is carried out on the highest ranked risks in terms of cost and schedule. This numerical analysis is carried out as the next step after the initial non-numerical method when the probability of occurrences and severity of impact ranking has determined the risk level for all hazards identified in the risk register. It is normally the red/unacceptable/high risks for cost and schedule which then becomes subject of the numerical analysis.

Also types of distribution varied between simulations made. PERT was used most commonly but also Normal distribution. In one case triangular and uniform distribution was combined with PERT, see Appendix C for descriptions of the distributions. It was not clear exactly how the PERT, uniform, triangular analysis was made but I assume a the distribution curve from the Monte Carlo simulation based on a PERT distribution was hyper posed with a triangular shape and a constant value and a weighted resulting curve was established.

The goal of these numerical simulations is to come up with a level of risk contingency in dollar for the cost risks and in number of days for the schedule risks, to apply to the engineers estimate and schedule for the project.

In one case, project G, the task was slightly different; the project already had a contingency level identified in the engineers estimate and the numerical simulation aimed to see how confident the client could be that the applied level of cost contingency was adequate.

### **2.8.4. Conclusions**

- The Swedish projects have not used numerical simulations for evaluating cost and schedule risk.
- The US project analysts have used numerical simulations when looking to determine cost and schedule contingencies for high level cost and schedule risks. These simulations are a second step of quantification of only the highest ranked risks for cost and schedule. All risks were in a previous step identified and quantified with the non-numerical method.
- Numerical simulations seem applicable only on cost and schedule risks.

## **2.9. Detectability and Toll Gates**

### **2.9.1. Literature Review**

In the list of definitions for expressions and terms commonly used in risk related documentation and work, see paragraph 1.10, I define expressions commonly used in risk related work based on theoretical literature read in preparation for this thesis.

Looking back on those definitions and descriptions there are two expressions that I do not see anywhere in any of the project specific documents studied. The missing terms are *detectability* and *toll gates*.

The detectability is referred to in theoretical literature as the third factor that should be considered, equally important to study as probability of occurrence and severity of impact (Reinschmidt, 2006). This third factor is described as how easy or difficult the hazard is to detect; detectability.

Toll gates, as described in chapter 1 are actions that have to be taken before entering into a new phase of a project to ensure measures/procedures are followed to avoid hazards.

### **2.9.2. Application in Sweden**

In all Swedish project specific documentation studied this third factor detectability, in addition to probability of occurrence and severity of impact; was not mentioned. However the subject is handled in the risk registers by suggesting monitoring programs, testing etc. during construction, which would increase the detectability.

The term toll gates, was mentioned once in Project A documentation. Even though the term is not widely used for the studied projects, going deeper into the risk registers and specifically looking at mitigation measures suggested here is where I see indications that toll gates, even if not explicitly mentioned more than once in the studied projects' risk documents, are indeed used.

In all risk registers studied from the Swedish projects, there is emphasis on mitigation measures for various risks which involve pro-active measures in place before executing work activities such as tunneling and other excavation. I consider these measures being toll gates. A very obvious example is the requirement to perform ground improvement works before starting the excavation as described in more than one place in the documents studied from the projects.

In addition; in all risk registers except for Project K, there are mitigations measures suggested which relate to method statements, work plans, work procedures and /or health and safety management plans, and also statements about having these types of documents ready in place before construction. In these kinds of plans and procedures you would normally see descriptions of how and in what chronological order work should be preformed.

Requirements for soil investigations prior to construction are also mentioned for more than one project, likewise pot-holing which is a shallow type of soil investigation. Monitoring of existing structures and surface is also highlighted for almost all projects studied. In one of the risk registers for Project A in particular a lot of emphasis is made on timely monitoring and also having the monitoring up and running before the tunneling underneath takes place. The above are only some examples to illustrate that toll gates are indeed an integral part of risk management in the studied projects even if the term is not clearly spelled out in the documents.

### ***2.9.3. Application in USA***

As in the Swedish project-specific documentation studied the expression detectability, is not mentioned in the US projects either. However, similarly to the Swedish project documentation; the subject is considered in the risk registers through suggestions for monitoring programs, testing etc. during construction, which would increase the detectability of a hazard.

The term toll gates, was not mentioned in the project documentation from US. But similarly to the Swedish risk registers, there are several examples of that toll gates are used throughout the risk management of the projects. Similar examples as described for the Swedish projects are present in the US risk registers.

### ***2.9.4. Conclusions***

- Detectability and toll gates are not mentioned in the project specific documents studied with one exception for tollgates being mentioned once in the documentation from Project A.
- The absence of mention of detectability of a hazard and mention toll gates does not mean that the intent is not present in the project documentation studied. The risk registers studied contain by suggesting monitoring programs, testing etc. during construction, which would increase the detectability. They also include descriptions on activities which have to happen before other activities. This indicates the use of toll gates.

### **3. DISCUSSIONS**

#### **3.1. Further Studies of Project Risk Documents**

In the above part, the analysis; I have tried to follow a structure where a general description of risk theory is presented in literature for the construction business not specific to any of the studied projects, followed by how the particular subject is handled within the studied projects' risk related documentation in sections for Sweden and USA respectively.

While that part of the analysis should be considered the main part of the thesis, there are also other aspects to the studied material which I though should be presented. Thus, here below, in chapter 3.1, follows a more ad-hoc approach to the studied subject where I have not consistently tried to include all projects studied but rather ideas and findings I found interesting.

##### ***3.1.1. Comparing US Documents Only***

As all studied material from the US is from one single source it could be interesting for me to see how this single source portrayed different projects. Are approaches different? And if yes; in what way are they different?

The common feature of all the studied US documentation of projects F-L, which was not consistently included in the Swedish documentation, was the introductory theories of risk analysis. Surely these descriptions varied slightly in content and length from document to document but in essence they described the same kind of theory.

In some of the documents studied from Projects F-L the author went deeper into explaining the Monte Carlo simulations and its benefits whilst for other projects the text only touched on the subject briefly or not at all. The content was generally similar but the amount of text varied. Some of the descriptions were of a summary level and some went more into detail and normally there were no opposing information included between them.

The second featured that distinguished the US project specific documentation from the Swedish was the inclusions of numerical simulations, as described in chapter 1. Executed to determine risk ranges for cost and schedule high ranking risk. However one US project, Project K, did not included one.

The studied US project documents i.e.: the products of the consultant; the reports, memoranda or other documentation, are of different level of detail and the intuitive reason for this is to me that different budgets were available for the risk management/assessment task of each of the projects. It has later been explained to me, by one of the authors, that it also depended on if the documents studied were provided to clients as introductory information or as part of an ongoing major effort for a client.

### **3.1.2. Comparing Two Underground Projects in Metropolitan Areas**

When reading through the memorandums prepared for a major extension of an underground system in western US, project F, and one for a railroad tunnel project in Sweden project A; both prepared by the owners' consultant, hired as risk experts in the initial design phase of the projects; there are a few items that can be pointed out as unique in one memo, not included in the other. There are also similarities, which indicate that the risk managers of the projects, in many ways, have similar priorities when it comes to what is important in a risk assessment of a large underground project.

#### **3.1.2.1. Mutually Important Concerns**

The memorandums studied describe the risks management as a process, where reoccurring risk workshops or brainstorming meetings are central.

What theses studied risk analysis memorandums both do not include is a list of which documentation shall be used as basis for the workshops/risk meetings. It is probably understood that all participants bring their expertise to the table during these meetings but a lot of important aspects could be overlooked. I am surprised that a predetermined risk register is not used to tick off generally important issues in similar projects. However this could very well have been done "off-line" in preparation to the workshops / meetings. From the US consultant this was also the case it turned out, after I followed up and got an explanation on the issue. From the Project F documents this seems not to be the case. However no follow up question was asked on the subject.

#### **3.1.2.2. Specific Features from Swedish Example, Project A**

The Swedish memo clearly stated that the consequences shall be judged from the perspectives of time, cost, person, infrastructure, environmental and confidence. Each of these perspectives is further described as follows:

**Time:** how large the delay will be to important milestones, partial completion dates and final completion date of the project if the hazard occurs.

**Cost:** What is the cost to the project if the hazard does occur? And how does this relate to the budget? The cost added to the project due to compensations to third party outside of the project shall also be considered.

**Person:** Damage to people working on the project or public.

**Infrastructure:** What will be the disruptions to important infrastructures? Subways, regional trains and roads, as well as electrical and telecommunication systems are mentioned to define the term infrastructure.

**Environment:** What is the damage on the surrounding environment?

**Trust:** How would the occurrence affect the way the public conceives the project? Also; whether the relations to media and working relations between people within the project will be affected are issues mentioned in the Swedish example.

This way of specifying in what perspectives each occurrence shall be evaluated is not the same as in the US west coast example. And not of the other US examples either. In the US documentation I did not see these preset categories of risk.

Another passage in the risk related documentation for Project A brought up a set of standard measures to reduce or mitigate the risks. This was not mentioned in the US example, Project F. Here follows a list that summarizes those measures:

- Measures to handle errors in the production, malpractice of the construction company
- Adequate information flow through the project
- Clear decision paths
- Comprehensible, well structured and simple method statements
- Surveys and inspections
- Preventive measures
- Action plans to be established for the most critical risks

Additionally to the mentioned specific features of the risk related documentation studied from project A; the focus of identifying new hazards throughout the project is highlighted. The documents also explained that to attain a good practice in this regard it is important to follow control plans and also, in addition, to use toll gates.

### **3.1.2.3. Specific Features from US Example, Project F**

Having read through a few risk assessment reports in preparation for this thesis the thing that struck most when reading the USA sample in the purpose of comparing only the two mentioned reports is how the US sample is very specific to the project it covers. Not only does the introduction and conclusion reveal this but also the general writing of the text seems custom made.

Another feature of the US example is that it includes evaluations that you would usually see in a constructability review. Also the sessions of the risk assessment workshop included a write-up of a quite long list of recommendations for the tunneling specific specifications to be written sometime further down the design phase of the project. It seems the consultant gives the client a bit more than a risk assessment and the lead risk manager of this consultant company does agree that this is normally his group's practice; it is practical and meaningful to combine a risk assessment session with for example a constructability review or present other insight to the client that the risk assessor think the client will benefit from.

In a way, the two above features, indicates that risk assessment has a much broader meaning than what was previously perceived as normal for a risk assessment, by the author of this thesis. The US consultant does agree that they prefer to combine risk assessments and other risk management tasks with constructability reviews. He also expands on this and states that the best is if the same core team of a limited number of consultants has the responsibility for risk management, constructability and for example scheduling and estimating as well. These stated disciplines are closely connected and if they are led by the same entity the structure and control is much better and the results as well.

Also the approach for Project F risk management is distinguished by inclusion of a Monte Carlo analysis run for the mayor risks affecting the schedule of the project.

### ***3.1.3. Good Ideas and Concepts***

#### **3.1.3.1. A Useful Tool: To Cover All Aspects in One Sheet**

In the risk analysis documents gathered for this thesis there are certain things that have stood out as being very useful. One example is a sheet created by the contractor where a large number of aspects of the project have been cleverly displayed as part of the risk register. This was not that evident in the rest of the material studied. This tool seems useful for several different phases of a project and could with advantage be used by all parties, with some modifications.

The format of this risk register includes columns and rows that enables the distinction between for example when in the project the hazard was identified, what is the probability of occurrence, what would be the severity of impact, when the measures to eliminate or reduce the risk should be implemented, what should be the contingency associated with the risk, what would the measure to eliminate the risk or reduce the risk be, who in the project organization is responsible to follow up the specific risk and what would the risk be after measures taken, see table for similar format.

The ability to see such a range of different information at once was striking in the mentioned sheet; see Figure 4 for a similar example.

It seems that this way to display such a number of aspects in one sheet is beneficial compared to having to know where in several different documents to get the same amount of information. All details cannot be shown with this format but having the cells in the sheet refer to the backup documentation is a way to have traceability to any other document needed.

Most likely these kinds of sheets exist for the other assessments studied in this thesis, but they were not provided with such detail. I see this sheet as a good example on how to have good control of what has been analyzed and how the project members/risk management group should all have current for a mutual approach to following risk program activities and decisions to be made.



### **3.1.3.2. Owners Standardized Risk Management Process in Sweden**

So far I have not discussed the owner generated risk assessment guidelines I have read for Projects A and D in detail. These guidelines are very specific and explained various parts of the risk management process. The guidelines, generated by the owner/client for Project A and D are very standardized and this specific public agency apparently seems to use the same or very similar process descriptions for their mayor projects.

I think it is excellent that an owner organization has this detailed requirements as reflected in the documents studied for the two projects. An owner with good knowledge in the subject is a client better prepared for a major underground construction project.

I have not seen this standardized process description for any of the US project samples studied in this thesis. I think the reason is simple. With risk of simplifying slightly; I would say that in Sweden large infrastructure projects including underground construction normally has one single owner who is also the funding party. The owner is either “Banverket” or “Vagverket”. Banverket” is Sweden’s rail authority and “Vagverket” is the Swedish road authority. Very seldom does either of the two agencies/authorities co-own projects, with each other or other parties.

Therefore, as I see it, a project for either of these two owners can follow the respective owner’s standard, in terms of risk management. The above is true as long as the projects are not BOT or privately funded in some other sense. These are types of projects which are increasing in number in Sweden but do not currently constitute a considerable part of the infrastructure projects built (Nilsson 2007).

In the US the situation is more complicated. A large infrastructure project normally has several owners and funders. A typical rail project, of substantial size, is owned by the cities it passes through, the state and also funded by the government and also sometimes additional parties. A large rail project could typically be co-funded by:

- MTA (municipal transit authorities of affected cities)
- DOT (the state department of transportation in which the project is being built)
- FTA (federal transit authority)
- Private funders

What happens is that most large public infrastructure projects are regularly promoted and partly funded by local agencies such as a city. Depending on size of project and extent the state could also have a similar role. However, the main part of the funding often comes from the federal government.

A city that wants to build an extension of a local transit line can for example apply for so called “New Starts” funding from federal funds. This is commonly done in the US (Altshuer 2003). Thus a project such as a local transit is therefore often co-funded by

the city, state and the federal government. For these projects the FTA normally requires a formal risk assessment structure as a condition for access to federal funds (Touran 2006), along with other managerial restrictions to the project. Now the city personnel who would normally manage the project have to perform risk management which does not come from within their own organization. These city and or state employees are most probably not knowledgeable enough about the FTA procedures and requirements for risk management.

Due to the above circumstance the projects of this type normally then hire a consultant with expertise about the FTA procedures to guide the project in the risk management process. Even if the same type of owner relations exist in Sweden a project does not seem to be scrutinized in the same way during the later planning phase before construction but once the money has been founded the decision is made. I understand this has to do with the planning process differences in the two countries. Whilst Swedish projects go through a very lengthy process with years of pre-studies to get the approval from several government agencies with a lot of public consensus requirements etc. (Andersson 2009); when the process is through the money is available. But in the US there is a shorter process but the 2<sup>nd</sup> part of this approval phase, follows a later stage of the pre-construction planning and design phase (Andersson 2009). Thus the definite funding agreement occurs later in the project's timeline, often as late as when the design is ready and close to when contracts are being advertised for contractors.

Also for other large underground/tunneling projects in the US the owner structure is often a mix of agencies and or private companies. It seems like the "standard" applied in the Projects F through L follows the consultant's experience and not the regional/city-owners'. The consultant knowledge bridges the gap between various funders it seems.

It appears that the Swedish more strictly one-owner set-up for public projects indicates less complicated owner and funding related settings in Sweden than in the US and provides for the possibility of an owner following its own standards in terms of how risk shall be managed. In the US where a public project has normally the state, the city and federal government, and possibly additional parties as funders this is less likely to follow one standard for a large infrastructure underground project.

Without having done much research for American equivalents to the owner generated procedures as the two mentioned studied documents for Swedish Projects A and D and based on the above few lines of reasoning; the funders/owners in Sweden may be better prepared to take on large underground projects. Probably this is not a feature or a simple procedure that can be established in the US but it seems to be more of the cultural/ political settings in the two countries that formulate the conditions for the difference.

### **3.1.3.3. Risk Matrix for Each Risk Area**

Reading through the Project handbook of one recently completed major infrastructure project in Sweden, Project A, the concept of having several risk matrixes was introduced to me. In that project defined matrixes existed for the following areas:

- Working environment –work injury on person working on the project
- Third party –injury on person that is not engaged within the project
- Project property –damage to project property or property of participating parties in the project for example to permanent or temporary structures or equipment etc.
- Third party property –damage to property belonging to third party not engaged in the project
- Environment – damage to natural resources (ecosystems)
- Time – delay of activity activities that delays the project in relation to existing schedule
- Cost – ”damage” that pass on the necessity to use reserves and thereby a budget overrun
- Trust – occurrences that reduces the interested parties and/or stakeholders trust in the project organization, the contractor or the project

The usefulness if this division into several specific separate categories is that it really provides a tool to cover all aspects of the particular issue. In the proposal from one of the contractors for a contract within the project mentioned above, to display all these aspects, tables were used for each risk; with all the different areas of concern in one table for each risk see Figure 5 . That seems to be a systematic method to help the process of going into all aspects of a risk related issue. At the same time each table display the results of the effort; the different rankings for the specific risk regarding each different aspect separately.

		Rank	Risk
Working environment	Consequence		
	Likelihood		
Injury to third party person	Consequence		
	Likelihood		
Property damage	Consequence		
	Likelihood		
damage to third part property	Consequence		
	Likelihood		
Cost	Consequence		
	Likelihood		
Time/schedule	Consequence		
	Likelihood		
Trust/goodwill	Consequence		
	Likelihood		
Environment	Consequence		
	Likelihood		

**Figure 5: Table used in a Swedish assessment covering 8 different aspects of risk.**

### 3.2. Need for Continuity

As previously shown between the literature review, application in Sweden and applications in USA the projects studied seem to follow similar procedures, theories and generally accepted standard practices for risk management.

The frequency of different kinds of hazards in the risk registers and sources of hazards between the countries was apparent. Legal and insurance issues as well as damages to third-party property were more frequent in the USA project documentation than the Swedish. I do believe that this has to do with the differences in legal and litigation climate in the two countries. But on the other hand I think it is worth considering that these differences could also be due to the project specific settings and not necessarily have to be a result of the country specific settings.

One of the largest risks when it comes to risk management as I see it is if the continuity of the risk program of a project is broken. It seems hazardous to not ensure the continuity of the risk management work within a project. The benefits of early stages of risk assessments may not be harvested if the follow through is not properly handled. The anticipated risk exposure in an early stage of a project may totally change unless the mitigation actions follow the recommendations in the mitigation measures. Continuity in the risk management process is especially strongly highlighted in the US project documentation but also the Swedish documentation brings up the importance of constant follow up and feedback in the risk management cycle. In the Swedish documentation it is also often mentioned the importance of good and open communication between all parties.

If and when continuity and communication would be lacking, this is when I think the problems can grow significantly in a project. One example would be when risk registers are inherited between an old and new team of consultants, contractors or just a new person taking over after somebody who retires or for any other reason leaves the project.

When this happens the individuals responsible who are now new individuals probably do not have exactly the same perspective as their predecessors which may lead to correct or incorrect re-categorization of one or several risks. Also the new responsible party may have different views on mitigation measures which may also be correct or incorrect. Mitigation measures which are imperative for one individual may not have the same significance to another person.

Also when continuity is broken in terms of exchange of personnel on a project differences in what terminology the new and previous person involved are used to and can relate to may also cause confusion not beneficial for the risk management work of a project.

The variation of ranking which occurs in both the Swedish and US projects may lead to mis-categorization and in worst case a risk that should be considered very important can be given a lower importance and not be sufficiently mitigated or monitored. This type of concerns are brought forward in theoretical literature on the subject (Cox Jr. 2005) where the authors highlight that successive layers of qualitative coding can introduce loss of information and inconsistency in the

interpretation of labels. Further; as the hazards must be grouped into manageable categories. Defining such categories requires value choices and that can have important implications for the ranking that may be undesirable (Morgan 2000). A statement which seems also to be important as subjective evaluation and categorization must be accurate or the risk may end up not handled correctly.

The one really big difference in the risk assessments between Sweden and USA was the numerical analysis carried out for most of the US projects but absent for all of the Swedish projects. I see the simulations carried out for the US projects as useful tools to come up with realistic ranges for contingencies in terms of cost and schedule. Again if there is not a complete understanding within the project for this fairly sophisticated analysis method the benefits may be lost. The ingoing parameters, the type of distribution chosen for the analysis and also the results of the numerical analysis must be fully understood by all parties involved or the consequences can be severe.

What did not shine though much in the studied projects, both from Sweden and the US was if the quality of the risk registers established were adequate neither if the follow through during the life length of the project was well executed. It seems the most important tool must be the actual knowledge of the risk manager or person assigned with conducting/facilitating a risk assessment or a risk workshop as well as the knowledge and experiences of the participants. The quality of the assessment is very dependent on the knowledge brought to the table at the time of the workshops. Similarly the quality and benefits of the continuing risk related work throughout a project depends on the knowledge on how risk work should be conducted and at the same time the technical expertise regarding underground construction.

Going into this study of written documents I thought that the way risk assessments and the overall risk program in underground projects would differ more than it is now obvious to me. It is reassuring that the differences are not too large. The fact that the approaches are similar in dealing with risk in underground projects, regardless if you are in America or in the north part of Europe; Sweden, indicates that the approach is well founded.

### **3.3. Who Should Be Responsible for the Risk?**

The studies of risk documentation of different caliber, created by different parties: owners, owner's consultants and contractors revealed different approaches to ownership of risks. What party should be made accountable for the specific risks identified?

When studying the project risk related documents the short term, easy way out, solution: "transfer risk to other party" is mentioned surprisingly often, without further to me satisfactory explanation or reasoning. This way of action when applied by the owner of a project or its consultants, which is where I find this type of reasoning both in Swedish and US documentation. Forcing these types of possibly immature transfers by including conditions in the specifications, drawings and contracts vis-à-vis other parties, normally lead to higher cost proposals. The less adept the part with whom the

risk resides is the more expensive (globally) the project is going to be. If the transfer of risk is not done for the right reasons it could lead to delays, bankruptcy of the new owner of the risk, danger to personnel or third party, environmental problems, safety issues and/or higher project cost etc.

The more correct way to formulate the issue of transferring risk is to: “Transfer the risk to the party most suitable to manage it”. This has been the philosophy in some of the technical memorandums and other documentation studied within this thesis, but not in all.

Maybe the difference in phrasing on this is not that imperative but to follow the latter example would surely lead to a more successful management of the risk. The latter also indicates that a transfer would not be necessary if the party in question consider itself the most suitable and adept to take on the risk in question. The intention to “Transfer the risk to the party most suitable to manage it” rather than just “transfer risk to other party” indicates that the judgment is better grounded.

### **3.4. Insurance**

Insurers in the construction business seem to be quite involved in the risk program of the projects. In a large infrastructure project, including different types of underground construction the owner of the project had an extensive insurance taken to cover their own organization but also each contractor and subcontractor.

The insurance company with which the insurance had been signed required constant updating on risk issues and their status. Changes were vital to report by the project. The insurance company also conducted regular risk inspections. The inspection mainly targeted completed works and / or technically challenging solutions to problems identified as significant in the risk assessment process.

In case of injury or damages in one contract or elsewhere in the supplier chain, where a contractor or supplier was the responsible party; the owner were required, by the insurance company, to actively help reducing the adverse effects of the incident.

### **3.5. Right-of-Way**

Looking at the risk registers for variously projects, Project A though K; right-of-way concerns are more common in the US than in Sweden. The laws of right-a-way also seem clearer cut in Sweden. I will not develop this idea further as it is merely a timid statement that I yet have not a well informed opinion on. But business and private persons affected by a project in the US seems to have more rights in terms of compensations for easements etc. On the other hand they also seem to have more obligations to perform adjustments on their properties if required by a publicly owned project in USA.

A property owner in Sweden do not own the ground beneath the property to an unlimited depth and the term “right-of-way” still applies in its original meaning; a

transportation project that benefits the public has the right to take over land which is needed to build the project (Andersson 2009).

### 3.6. Risk Assessment Standard

Under this section of the thesis the intention is to suggest what could be more standardized and used in both Sweden and the US. However I find that the theories of the assessments studied are already very standard for the two regions combined. Whilst for applications on different projects, and in the two different regions, the variation noted seems to serve the purpose of making the best possible risk management program rather than trying to streamline further. “Best possible” would also, I think, depend on how much budget the project has available for risk management.

As stated in the thesis the risk assessment/workshop documentation from the US consultant did without exception include a few paragraphs up front about risk theory and its usefulness. It seemed to serve as a sort of introduction to risk theory with the perspective of the consultant. The fact that this was recurrent in each of the US examples may be due to that assessing risk in a structured way for underground projects in the US is less standardized than in Sweden. Possibly the practice is more mature in Sweden.

The US tunneling and geotechnical consultant from which all US documentation is sourced, is developing and maintaining a risk database including a risk register with hazards from previously studied projects. I think a risk database is where there should be room for standardization.

Or maybe standardization is not the right term but creating a global all inclusive risk register and in a database-style setting then applying the right actions to it will be useful for starting up the risk assessment process in any new underground construction project.

A gather an important feature for a risk database is the ability to sort / filter easily depending on type of structure, setting and method of excavation. In that way the database would be easier to manage than if this functionality was not there. For each new project, depending on method etc. in that way it would not be hard to pull out an initial risk register suitable for the method, structure and settings.

I think it is very important to choose the right tools for this. There is a range of database software on the market and they are all more or less flexible and sophisticated. Building a database based risk register library with the wrong software can lead to below required functionality and not all advantages initially sought for. Then having to go through the effort of changing software would be a huge time-consuming effort in most cases. The tool/software chosen initially shall have the appropriate features to get the most out of the relational triggers and other constraints.

## **4. GENERAL CONCLUSIONS**

### **4.1. Literature Review**

Generally it seems like the theoretical approach in the literature review is followed in the two countries. The risk management in the projects studied involves the same or similar methods and tools to manage, to assess and to analyze hazards as in the theoretical literature.

The two large differences where both countries' approaches differ a lot from the presented literature review are:

- There are 10 categorization steps in the literature review for severity of impact. For both countries the number of levels are much less
- The two terms detectability and toll gates are frequently mentioned in theoretical literature but not mentioned in the project specific documentation from Sweden and USA. The exception was 1 occurrence of the term toll gates in the Swedish project specific documentation

### **4.2. Application in Sweden**

Here follows features from the Swedish documentation which was not included in the project documents from projects in USA:

- Repeatedly the Swedish project specific documentation mentions the importance of good communication and transparency.
- Documentation from project D mention fault-tree-analysis as a means of evaluating probability of occurrence
- The 5 most frequent risk categories in descending order for the Swedish projects are:
  1. Cost
  2. Schedule
  3. Damage to the environment
  4. Quality of product
  5. Damage to third party property

- The 5 most frequent causes/sources for hazards occurring in the studied projects from Sweden are:
  1. Contractor's problems to carry out works
  2. Geological / geotechnical conditions
  3. Contract packaging, procurement and strategy
  4. Inadequate planning such as design, survey etc
  5. Space issues or lack of available transportation means
- Generally 5 step ranking is used for severity of impact and probability of occurrence
- Terminology of the level/ranking of probability of occurrence vary
- The Swedish project uses 3 levels of risk, generally the terminology is: low, medium and high

### 4.3. Application in USA

Here follows features from the Swedish documentation which was not included in the project documents from projects in USA:

- For all but one project studied from US the consultant made a Monte Carlo simulation to determine cost and schedule ranges for contingency levels related to a limited number of high ranking risks. In all but two cases the US consultant also did a similar simulation for schedule risk.
- Project H uses fault-tree analysis when determining probability of occurrence for tunnel collapse
- The 5 most frequent risk categories in descending order from USA are:
  1. Cost
  2. Schedule
  3. Damage to third party property
  4. Damage to the environment
  5. Damage to property
- The 5 most frequent causes/sources for hazards occurring in the studied projects from USA are:
  1. Contractor's problems to carry out work
  2. Geological / geotechnical conditions
  3. Project reconfiguration or other scope change
  4. Inadequate planning such as design, survey etc
  5. ROW, legal, funding and insurance

- Generally the project documentation describes 3 or 5 steps for both severity of impact and probability of occurrence
- Terminology of the level/ranking of probability of occurrence vary
- The US project uses 3 levels of risk, generally the terminology is: tolerable / low, ALARP / medium and intolerable / high



## 5. PROPOSAL FOR FUTURE STUDIES

Based on the conclusions of this thesis and the general knowledge acquired during this study the following are suggestions for further studies that would be beneficial to carry out:

- Development of a standards risk registers for different kinds of standard underground projects. For example grouped related to excavation and support methods and what type of settings the construction takes place, such as:
  - EPB machine tunnels
  - Slurry machine tunnels
  - Drill and blast tunnels
  - Tunnels by new Austrian tunneling method / sequential excavation method
  - Top - down constructed underground structures in urban areas
  - Conventional cut and cover structures
  - Slurry wall supported shafts
- Another topic would be to develop a good risk database with the right software where the right features such as relational triggers and constraints, key-word usage, tables and indexes should be chosen and carefully incorporated during the process(s) of encoding is performed. So that a large risk register could be managed and so that new risk registers for coming projects can be developed in the most efficient way.
- When an initial study has been done like this thesis, mostly analyzing documents from design phase or early production; a study of the same projects after construction would be of value to learn for example if the risks anticipated occurred or not and what impacts they had.



## 6. REFERENCES

### Thesis

Altshuer, A & Luberoff, D (2003) *Mega Projects: The Changing Politics of Urban Public Investment*, Washington D.C. Brookings Institution Press, Mass; Lincoln Institute of Land Policy

Andersson, B et al. (2009) *Rapport: Effektivisering i fysisk planering*. WSP for Regionplanerings- and Trafikontoret i Stockholm

Bajaj, D et al. (1997). *An Analysis of Contractor's Approaches to Risk Identification in New South Wales, Australia*

Choi, H H et al. (2004) *Risk Assessment Methodology for Underground Construction Projects* Journal of Construction engineering and Management, Vol 130, No 2, March/April

Cox, L A Jr. et al. (2005) *Some Limitations of Qualitative Risk Rating Systems*, *Risk Analysis*, Vol. 25, No. 3, DOI: 10.1111

Ericson, C et al. (1999) *Fault tree Analysis – A history* Proceedings of the 17th International systems Safety conference

Eskesen, S D et al. (2004) *Guidelines for tunnelling risk management*, ITA Working Group 2, Research, ITA-AITES, c/o EPFL, Bat GC, CH 1015 Lausanne, Switzerland

Hintze, S; (2011) personal communication

Moergeli, A et al. (2004) *Risk Management in Tunneling – Occupational Safety & health Plans for Drill & Blast and tunnel boring machines*

Morgan, M G & Henrion, M (1990) *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis*, Cambridge University Press, Cambridge UK

Morgan, M G et al. (2000) *Categorizing Risk for Risk Ranking*, *Risk Analysis* No 20, Vol 1, 2000

Nilsson, J E & Pyddoke, R (2007) *Public Private Partnership in transportation Infrastructure: State-of the art /Offentlig privat samverkan kring infrastruktur* VTI Rapport 601

O'Carroll, J; (2011) personal communication

Raschperger, R (2011) *Risk Analysis Presentation* University of Linköping / Ericsson AB

Reinschmidt, K F (2006) *Introduction to Project Risk Management, Course Notes*, University of Dallas, USA

## References

---

Touran, A (2006) *Owner's Risk reduction techniques Using a CM* department of Civil & environmental Engineering Northeastern University, published by Construction Management Association of America

RAMP 199 (2005) second edition

Wikipedia(2009) *the Free Online Encyclopedia*

## Appendix A

Bernstein, P L (1996) *Against the Gods: The Remarkable Story of Risk*, Wiley, New York

Cooke, R M. (2009) *A Brief History of Quantitative Risk Assessment*

## APPENDIX A

### Developments of risk analysis

#### Very early:

The very first known serious attempt to develop statistical principles of probability was made by Girolamo Cartano, 1500-1571, also called The Renaissance Gambler, when he wrote the book *Liber de Ludo Aleae (Book on Games and Chance)* (Bernstein PL, 1996). Thus; the first use of probabilistic theories were most urgently needed among gamblers in southern Europe.

In 1654 Blaise Pascal and Pierre de Fermat solved the Paccioli's puzzle and created the theory of probabilistic (Bernstein PL 1996).

#### In the industrialized USA:

##### Aerospace

A systematic apprehension with a new form of quantitative risk assessment called probabilistic risk assessment (PRA), derived from Europe, started in the aerospace sector following the fire of the 1967 Apollo flight test in which three astronauts were killed. Before the Apollo accident, NASA relied on its contractors to apply good engineering practices to provide quality assurance and quality control. NASA's Office of Manned Space Flight subsequently commenced the development of quantitative safety goals in 1969, but they were not adopted. The reason given at the time was that managers would not value the uncertainty in risk calculations. Following the inquiry into the Challenger accident of January 1986, we learned that distrust of reassuring risk numbers was not the one and only reason that PRA was abandoned. Rather, initial estimates of catastrophic failure probabilities were so high that their publication would have jeopardized the political viability of the entire space program. Since the shuttle accident, NASA has instituted quantitative risk analysis programs to sustain safety during the design and operations phases of manned space travel (Roger M. Cooke (Summer 2009).

##### Nuclear Power

Throughout the 1950s, following President Eisenhower's "Atoms for Peace" program, the American Atomic Energy Commission followed a philosophy of risk management based on the concept of a "maximum credible accident." Because credible accidents were covered by plant design, residual risk was estimated by studying the hypothetical consequences of "incredible accidents." An early study released in 1957 focused on three scenarios of radioactive releases from a 200-megawatt nuclear power plant operating 30 miles from a large population region. Regarding the probability of such releases, the study concluded that no one knows how or when we will ever know the exact magnitude of this low probability. Succeeding design improvements were intended to reduce the probability of a catastrophic release of the reactor core inventory. Such improvements could not have any visible impact on the risk as studied with the above methods, "credible and incredible accidents. On the other hand, plans were being developed for reactors in the 1,000-megawatt range located close to population centers; these were developments that would certainly have had an unfavorable impact on the consequences of an incredible accident. The desire to

quantify and assess the effects of these improvements led to the introduction of PRA. While the earlier studies had dealt with uncertainty by making conservative assumptions, the goal now was to offer a realistic assessment of risk, which necessarily involved an assessment of the uncertainty in the risk calculation. Basic PRA methods that were developed in the aerospace program in the 1960s found their first full-scale application, including accident consequence analysis and uncertainty analysis, in the 1975 Reactor Safety Study, published by the Nuclear Regulatory Commission (NRC). The study caused substantial commotion in the scientific community, so much so that the American congress created an independent panel of experts to review its accomplishments and limitations. The panel concluded that the uncertainties had been “greatly understated,” which led to the study’s withdrawal.

Shortly after the Three Mile Island accident, a new generation of PRAs appeared in which some of the methodological flaws of the Reactor Safety Study were avoided. The NRC released the *Fault Tree Handbook* in 1981 and the *PRA Procedures Guide* in 1983, which shored up and standardized much of the risk assessment methodology. An authoritative review of PRAs conducted after Three Mile Island noted the need to model uncertainties properly in order to use PRAs as a management tool. A 1991 set of NRC studies known as *NUREG 1150* used structured expert judgment to quantify uncertainty and set new standards for uncertainty analysis, in particular with regard to expert elicitation. Next came an U.S.–European program for quantifying uncertainty in accident consequences models. Expert judgment methods, as well as screening and sensitivity analysis, were further detailed. European studies building off this work apply uncertainty analysis to European consequence models and provide extensive guidance on identifying important variables; selecting, interviewing, and combining experts; propagating uncertainty; inferring distributions on model parameters; and communicating results (Roger M. Cooke, Summer 2009).

#### **National Research Council, USA:**

The National Research Council has been a constant voice in advising the American government to enhance its risk assessment methodology. A 1989 report entitled *Improving Risk Communication* inveighed minimizing the existence of uncertainty and noted the importance of considering the distribution of exposure and sensitivities in a population. The issue of uncertainty was an apparent concern in the *National Research Council reports on human exposure assessment for airborne pollutants and ecological risk assessment*. The 1994 landmark study *Science and Judgment* gathered many of these themes in a request for quantitative uncertainty analysis as “the only way to combat the ‘false sense of certainty,’ which is caused by a refusal to acknowledge and attempt to quantify the uncertainty in risk predictions.”

The 2003 *National Academy of Sciences report Estimating the Public Health Benefits of Proposed Air Pollution Regulations* identified three barriers to the recognition of recent EPA health benefit analyses. These are: large amounts of uncertainty inherent in such analyses, EPA’s manner of dealing with them, and the fact that “projected health benefits are often reported as absolute numbers of avoided death or adverse health outcomes.”

The Office of Management and Budget released a draft bulletin proposing technical guidance for risk assessments produced by the federal government. A National Research Council review found many shortfalls in this proposal and recommends that it be withdrawn. A revision is presently in preparation. The latest National Research Council publication tries to move forward risk assessment at EPA by harmonizing a diversity of approaches and method (Roger M. Cooke, Summer 2009).

## APPENDIX B

Project references:

Project, as referred to in this thesis	Project Description	Location [Country]	Size [order of magnitude, million \$]	Documents Studied
A	Regional train bored tunnels with underground mined and cut and cover stations in urban environment.	Sweden	2000	1. Project Handbook: Risk Management; The Risk Management Process (owner) 2. Bid document: Risk Management for Tunnels and Cavern Contract (contractor) 3. Various action plans with risk and opportunity analysis for a number of disciplines like tunnel excavation, structural, design etc. (contractor)
B	Cut and cover station for regional train, and very dense city area.	Sweden	100	1. Tabular risk register with analysis for various areas of the station or neighboring area (contractor) 2. Short project description in terms of risks identified and short description of project (contractor)
C	Drill and blast and NATM/SEM roadway tunnels, cut and cover and at grade roadway in urban environment.	Sweden	100	Risk analysis during bid period (contractor)
D	Regional train tunnels and partly at grade, drill and blast, with underground minded stations and cut and covers, mostly in urban environment.	Sweden	2000	1. Technical risk analysis for existing structures when building the station (consultant for owner) 2. Technical Risk Analysis-for one tunnel contract within project (consultant for owner) 3. Project Handbook: Risk management process (consultant for owner) 4. Technical risk analysis-risk register for surroundings and existing structures (consultant for owner) 5. Technical risk analysis, ventilation (consultant for owner)
E	Drill and blast roadway tunnels and cut and cover ramps in urban environment.	Sweden	1000	1. Risk management handbook (contractor)
F	Subway extension including bored tunnels, top down cut and cover and SEM stations in metropolitan area.	USA	2000	1. Working paper: Risks and Insurance Analyses Station Risk/Opportunity Assessment 2. Working paper: Risks and Insurance Analysis Tunnel Risk and Opportunity Assessment
G	Regional light rail train way partly at grade, with retaining walls and as cut and covers respectively, mostly in urban environment.	USA	2000	Risk assessment methodology and results (consultant for owner)
H	Construction works in maritime environment impacting an underlying older large diameter sewer tunnel.	USA	50	Risk assessment (consultant for owner)
I	Outfall sewer tunnel in partly urban environment.	USA	50	Risk management plan (consultant for owner)
J	Twin bored large diameter tunnels and cut and covers.	USA	2000	Geotechnical risk workshop memorandum (consultant and owner)
K	Light rail transit project partly in urban environment.	USA	1000	Risk assessment: methodology and results (consultant for owner)
L	Main water distribution tunnel	USA	150	1. Technical memorandum: Risk Management (consultant for owner) 2. Tunnel risk assessment register (consultant for owner)



## APPENDIX C

Brief description of simulations used for the US projects F, G, H, I, J and L:

**Monte Carlo Simulation** is a technique where single value estimates (of duration, resource, and cost) are replaced by a distribution to reflect the perceived uncertainty in those estimates. A random number is generated and a corresponding value sampled from the distribution. Once samples have been taken from all variables in the model, a single value is calculated for each target (e.g., a milestone or out-turn cost). The process is repeated a large number of times (iterations) to give a distribution of possible outcomes (a simulation) using Latin Hypercube sampling.

**Latin Hypercube** is a stratified sampling technique used in Monte Carlo simulations modeling. As opposed to pure Monte Carlo sampling, which is perfectly random, Latin Hypercube tends to force convergence of a sampled distribution in fewer samples than purely random sampling. This sampling also is able to collect values from the extremities of the range....

Formulas for various distributions used or mentioned in the US documents for projects F, G, H, I, J and L follows, as well as a description of the distribution and reasoning for using it:

### UNIFORM

Uniform distribution is where all possible outcomes have the same probability to happen. This type of distribution was assigned where the evaluators were unable to determine a more precise most likely value within the current range. The uniform distribution ranged from an optimistic value (the least possible impact should the event occur) to a pessimistic value (the greatest). Within this range any value was equally likely to be selected at any particular iteration.

### TRIANGULAR

Density function:

$$f = kx + m$$

Distribution function:

$$F = \frac{kx^2}{2} + mx + c$$

**Triangular distribution:** This distribution is where the mean value is the top of a triangular shape distribution. Similarly to uniform distribution there is no need for simulation. Determining confidence intervals is merely a simple trigonometric math exercise. No reason wfor when to use it was given in the projects studied.

**NORMAL (standard)**

Density function:

- 
- 
- $$f(x) = \frac{1}{\sqrt{2\pi}} e^{-1/2 x^2}$$
- 
- 
-

Distribution function:

$$\Phi = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^x e^{-t^2/2} dt$$

**Normal Distributions:** Unlike PERT distribution there is no most-likely value present to take advantage. But the mean value is simply the x-axis values for the top on the y-axis. This distribution places progressively more emphasis on values around (near) the mean value, in favor of values around the edges.

## PERT

Density function:

$$f(x) = \left\{ \begin{array}{ll} \frac{x^{v-1} (1-x)^{w-1}}{B(v, w)} & 0 \leq x \leq 1 \\ 0 & otherwise \end{array} \right\}$$

Where  $B(v, w)$  is the beta function  $B(v, w) = \int_0^1 t^{v-1} (1-t)^{w-1} dt$

Distribution function:

$$F(x) = \left\{ \begin{array}{ll} \frac{B_x(v, w)}{B(v, w)} & 0 \leq x \leq 1 \\ 0 & otherwise \end{array} \right\}$$

Where  $B_x(v, w)$  is the incomplete beta function  $B_x(v, w) = \int_0^x t^{v-1} (1-t)^{w-1} dt$

**PERT Distributions:** Is an alternative distribution to the Triangular and normal distributions, it also requires three parameters, in our terminology pessimistic, most likely and optimistic estimates. The PERT distribution emphasizes the "most likely" value over the minimum and maximum estimates. However, unlike the triangular distribution the PERT distribution constructs a smooth curve (similar to the normal distribution) which places progressively more emphasis on values around (near) the most likely value, in favor of values around the edges. In practice, this means that we "trust" the estimate for the most likely value, and we believe that even if it is not exactly accurate, (as estimates seldom are), we have an expectation that the resulting value will be close to that estimate.