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RISK MANAGEMENT
IN CANADIAN TUNNELLING PROJECTS

By

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Abstract

Unforeseen ground conditions are the main cause of delay and cost overruns around the world in tunnelling construction. Underground uncertainty demands extensive efforts for risk reduction and management. The insurance sector has reacted drastically to the tunnelling industry after experiencing losses for up to 500% against premiums earned in 2001. Consequently, insuring tunnelling projects has become a challenging process around the world where auditable Risk Management practices are becoming mandatory. This trend is having a global impact that has reached Canadian projects. This thesis analyses the impact of "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" in the international insurance market and its influence in Canada, as well as the state of practice of Risk Management in the Canadian tunnelling industry. The start-up guideline for the practice of "Systematic Risk Management in Tunnelling Projects" consolidates these findings.

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Chapter 1 Introduction

1.1 Problem Statement

Insuring tunnelling projects has become a challenging process around the world as the performance of the construction industry in general has shown a high rate of projects exceeding planned budgets and schedules; this is particularly true in the tunnelling industry where the insurance sector has reacted drastically after experiencing losses of up to 500% against premiums earned in 2001 (Woods, 2002). After the suspension of insurance cover for tunnelling in the UK and some insurers leaving the market entirely, the insurance sector is sending a clear message to the tunnelling industry: an auditable Risk Management System might not change premium price, but might be the only option if insurance cover is to be obtained, while the insurance industry is limiting coverage extensively. The global loss/premium ratio of the tunnelling industry urges the sector to reconsider their practice of Risk Management (RM) regardless of insurance requirements.

1.2 Objectives

This thesis is aimed to:

- analyse the impact of "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" (BTS and ABI, 2003) in the international insurance market and its influence in Canada in tunnelling construction
- analyse the state of practice of Risk Management in the Canadian Tunnelling Industry
- provide a set of start-up guidelines for the systematic practice of Risk Management in Tunnelling Projects

1.3 Research Methodology and Thesis Organization

The thesis is organized in a paper format, where each paper stands alone (Chapters 3, 4 and 5). They are preceded by Chapter 1, Introduction and Chapter 2, Background and Literature Review. Finally, Chapter 6 contains the conclusions derived from the research.

Chapter 2 contains literature review concerned with the management of uncertainty in underground construction. The estimation of uncertainty and risk is described through the role of Probability; this is subsequently presented by the Frequentist and Degree of Belief views of probability together with some numerical approaches to uncertainty estimation from Geostatistics and Historical analysis. The Observational Method is introduced as the RM methodology traditionally used in geotechnical engineering. A description of the role of Model Uncertainty is presented as well as an introduction to RM.

Chapter 3 addresses the impact of the "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" in the international insurance market and its influence in Canada, the criteria followed by reinsurance and insurance companies towards Canadian tunnelling projects (including the impact of RM practices to premium costs and contract preferences), as well as the current state of the global and local insurance markets towards tunnelling projects. The information presented in Chapter 3, was gathered from insurance and reinsurance underwriters as well as brokers from world leading firms about their corporate practices. Finally, findings are presented on the benefits of adopting systematic RM practices based on the performance of the tunnelling industry.

Chapter 4 describes the state of practice of Risk Management of the Canadian Tunnelling Industry based on practitioner's opinion in a case study approach through a questionnaire. This chapter identifies: the most common Risk Analysis tools and techniques in the identification and probability estimation of risks, the RM practices more frequently used in the monitoring and control of risks, as well as the identification of practitioners' perception of the advantages and difficulties in adopting systematic RM procedures. This chapter also presents the most valuable Project Management practices in tunnelling according to Practitioner's opinion together with the identification of human errors that most frequently affect tunnelling projects, in the geotechnical, design and construction phases. Finally factors gathered from Practitioner's recent tunnelling projects provide the most frequent ground conditions that affect the completion of tunnelling projects within schedule and budget, and the most common risk reduction measures used to minimize the impact of difficult or unforeseen ground conditions. The findings of this chapter are intended to serve the Canadian Tunnelling Industry as a measure of where it stands today, and provide areas for improvement of current RM practices and Insurance Industry requirements.

Chapter 5 presents the Systematic Risk Management for Tunnelling Projects (SRMTP) Start up Guideline. The guideline consolidates RM practices among different industries towards its use in tunnelling at an introductory level. The majority of RM elements are taken from guidelines focused on projects and construction. Emphasis is given to the underground nature of tunnelling works in its different stages; it includes input from best practices of Risk management in Canadian Tunnelling works elicited in Chapters 3 and 4. This guideline intends to be a first step to the adoption of Systematic Risk Management in Tunnelling Projects (SRMTP). Owners, consultants and contractors starting in the practice of SRMTP would find it useful as the content is intended for projects that do not have enough data and the evaluation is based on practitioner opinion as the main source of information. Bureaucratic procedures are particularly avoided.

Chapter 6 contains a summary of conclusions developed from this research. Recommendations for future research are presented based on the findings made in this thesis.

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Chapter 2 Literature Review

2.1 Introduction

Civil Engineering projects range from repetitive to unique; retail stores, housing developments, office buildings, etc, are almost identical from project to project. Underground projects like tunnels, chambers, deep open cut foundations, are always unique. Consider a twin tunnel with an parallel alignment 3 meters apart from each other, one might have an alignment under a car park building' footing that its twin does not, this single condition impose different levels of risk (Martin, 2003). Risk in underground construction can lead to catastrophic failures as a collapse in an urban area can dramatically affect buildings at the surface. Undetected methane gas can cause an explosion endangering the crew. A Tunnel Boring Machine (TBM) in squeezing ground might get stuck if logistics delay lining support to be in place immediately. A minuscule unsupervised drainage trench in a Sequential Excavation Method (SEM) tunnel can change the flow of water around the invert of the tunnel inducing collapse. The main bearing of a TBM can break in the middle of the alignment or unexpected water reservoir flood the tunnelling front endangering crew and losing the TBM. The tunnelling industry is faced with challenges that are not only the rare occurrence of collapses but the overwhelmingly common number of projects going over budget and over schedule (Lane, 2003; Klien, 2004; Wassmer et al, 2001; Woods, 2002). Tunnelling construction demands high levels of skill in an uncertain environment where Risks Management is not an option but a need. Understanding uncertainty helps us understand risk, understanding risk help us differentiate what we can and cannot do about it, and live with the decision.

2.2 Uncertainty and Risk

Uncertainty denotes lack of knowledge to estimate an outcome liable to variation, an outcome that cannot be precisely determined.

Risk is the product of the likelihood of an event times its possible consequence.

Most of the time in the evaluation of risks, both, likelihood and consequence are uncertain.

Uncertainty is time dependent. An uncertain situation today will be known with absolute certainty afterwards. The outcome of throwing a dice is uncertain, some seconds later the result is a fact. Prior to the construction of a tunnel for example, there are many uncertain factors related to the ground conditions along the alignment, once the tunnel is complete the conditions are known and are no longer uncertain.

2.3 The Nature of Uncertainty

Uncertainty is a concept that deserves some thought, let's consider the circumstance of a random event, like throwing a dice (Christian, 2004). If we throw it an infinite number of times and record the frequency at what each number appears, we will find out that the probability of any of the numbers (1 to 6) to appear is 1/6. Knowing this for a fact, the next time we roll the dice we are uncertain of which of the six numbers will appear but this time we have a measure of the uncertainty. This type of uncertainty is due to the random nature of the event, also known as *Aleatory Uncertainty*. On the other hand after a complete set of domino pieces is shuffled over a table and each of the four players take its pieces, the arrangement of the pieces is fixed but its values are unknown. We can find the exact pieces each player has by examining them but this is exactly what the game is all about. The key to win the game consist in finding the values of the pieces through observation and induction based on the information provided during the game. In this scenario the uncertainty is due to lack of knowledge. The more pieces with its respective values we are allowed to see, the less the uncertainty in guessing on the value of the remaining pieces. The former is known as *Epistemic Uncertainty*. Once these differences are understood it can be seen that, when more information becomes available, epistemic uncertainty tends to reduce, while aleatory uncertainty will not. It can be inferred that geotechnical engineering practice relates more to epistemic than to aleatory uncertainty. When analysing geotechnical uncertainty for underground construction this difference is relevant.

2.3.1 Probability as a measure of uncertainty

Uncertainty can be quantified with the use of probability but its mathematical interpretation is not always straightforward (Whitman, 1996). There are two schools in the interpretation of probability: Frequentist and degree-of-beliefers (Vick, 2002).

The *Frequentist* point of view assumes that the probability at which an event happens is the result of an intrinsic frequency underlying the system being observed. Repetitive trails or experiments would describe this "state of nature". The *Degree of belief* school of probability estimates uncertainty in circumstances where not enough evidence is available and its estimation needs to be elicited from people's minds. Judgement plays a paramount role in this evaluation, as many things that appear evident for a practitioner might be difficult to evaluate for another. Geotechnical Engineering practitioners are prone to make permanent use of judgement as limited knowledge of geotechnical properties are almost always present in projects, for example, Due to the nature of underground construction, the professionals involved in these projects should be exposed to probability and its applications in RM practices. It has been suggested by Whitman (1996), Morgenstern (1995), Faber and Stewart (2003), among others, the need for the early teaching of Risk Analysis in the Engineering curricula.

2.3.2 Experiment and calibration

As probability estimation through degrees of belief is highly dependent on the mind of the elicited practitioner or practitioners, a brief observation on personality theory might help understand some of the sources for the difference in criteria from a person to another and the difficulty in providing an objective assessment. Murray (1943) defined a list of 27 psychogenic needs. To illustrate its relevance in the evaluation of probability, let's review two in particular: infavoidance (to avoid failure, shame, or to conceal a weakness) and achievement (to overcome obstacles and succeed). Both needs can coexist in one person's personality, if both are strong, the individual struggles to take a decision, or to evaluate a risk. On the other hand two individuals with the same evidence and knowledge but one with infavoidance needs and the other with achieving needs would give a different assessment of the likelihood and probability of a risk. An infavoidance personality would seek for acceptance in a group and this can modify its particular judgement. An achiever would tend to dominate or impose opinion. As uncertainty is a main element in RM, the process should consider these elements and its impact while modeling a problem.

To show the influence of the personality needs in a group in the elicitation of an uncertain situation, an exercise was performed with a group of twenty-one graduate students and two professors in a classroom. The objective was to analyze:

- the different approaches and the extent of detail that each individual used to represent a model to calculate a finite number of particles in a glass and
- to challenge each individual's model in light of additional subjective information generated by the group

A transparent glass was filled with particles of the same size and shape and with different colors that allowed distinguishing between particles. The audience was asked to provide an estimate of the number of particles in the glass, providing three numbers: their best guess, lower and upper values of the range they considered the actual number of particles was. The group was not calibrated in order to challenge each individual's model as mention in the second objective. Calibration in an exercise like this would be to provide the audience with a container different in size but with the number of particles known.

The results of the first assessment are shown in Figure 2-1.

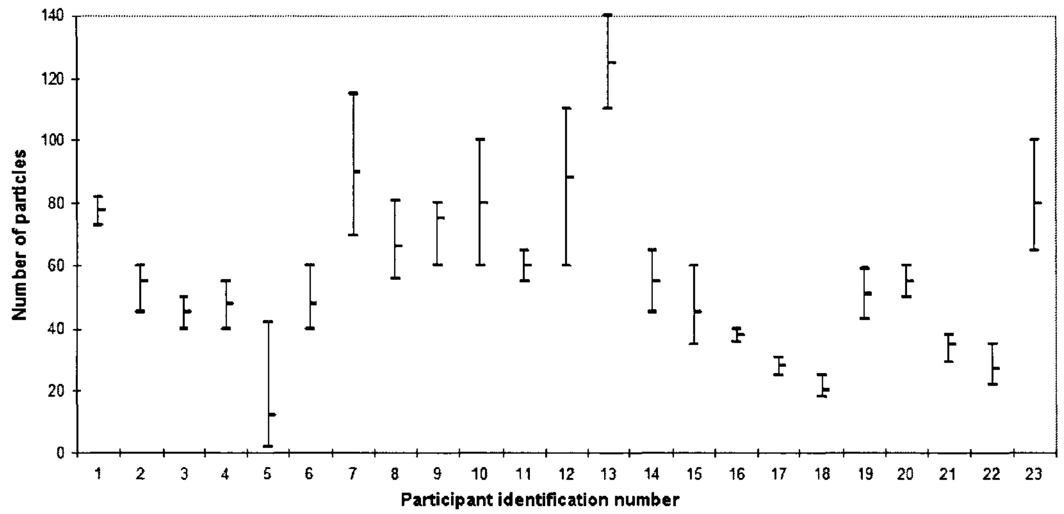

Figure 2-1 Particle size estimation, first assessment

After a first estimation, the group was provided with the means of the lowest, highest and most likely values elicited. With this information a second estimation was done. The results appear in Figure 2-2.

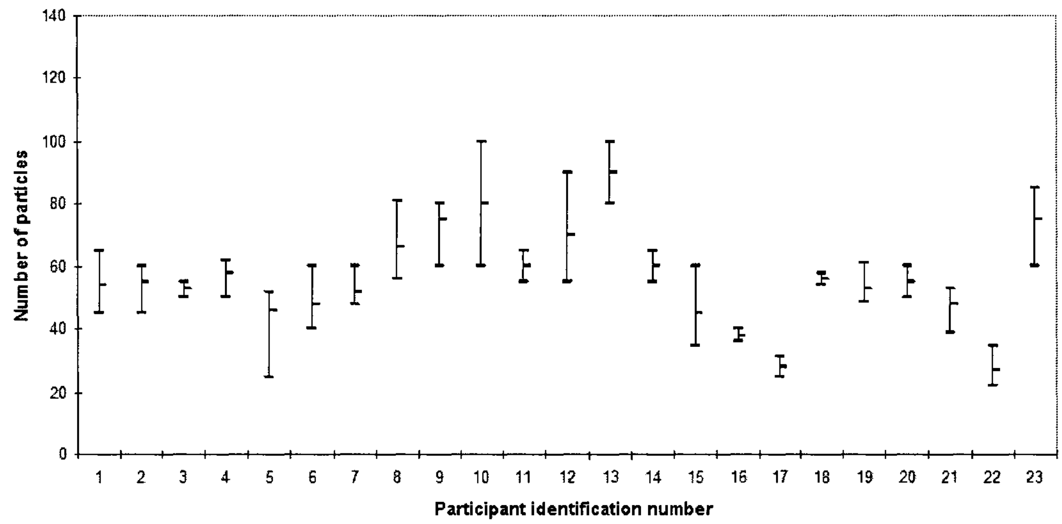

Figure 2-2 Particle size estimation, second assessment

Figure 2-3 presents the histograms and data statistics of the two assessments. The results are very useful for illustrative purpose on the difficulty in estimating uncertainty.

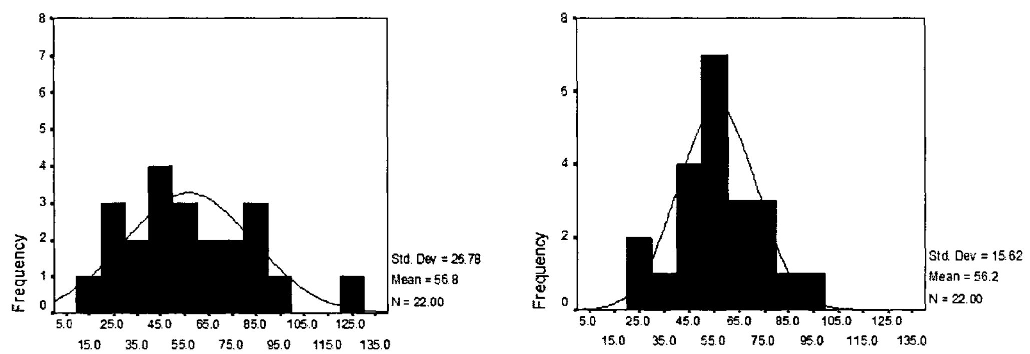

Figure 2-3 Assessments histograms (X-axis: "best guess" class interval)

The coefficient of variation (mean/std deviation) of the first assessment was 47%, whilst for the second it was 28%. This implies the group had increased agreement in their judgement in the second assessment based on the data provided by the group. The reduction of the range of variation in the assessment would provide more confidence to a decision maker. This could resemble a real case where practitioners are elicited on the number of boulders to be encounter in a specific tunnel alignment for example.

Practitioners are elicited on values before the fact and with limited information. In this case the number of particles was disclosed afterwards to the group to their surprise. While in both assessments the mean was almost the same, 57 and 56 respectively, and the standard deviation dropped from 26.8 to 15.62, the total value of the particles was 82. It is, we have reasonable agreed elicited practitioner opinion with a misleading result. This should not indicate that Practitioner elicitation is wrong, but the contrary. This example just points out how difficult an assessment can be and how misleading the result if the group is not previously calibrated, trained or knowledgeable of the issue to be evaluated.

Four of the six people that remain in the range of the correct answer were interviewed about how they calculated the number of particles. The four referred to the same "model": counted the number of particles in the face of the glass they could see and multiplied by four, new information did not modified in great extent their assessment. Four people that made changes in their assessment estimated the volume by looking at the top of the glass, counting the particles and estimated "X" times that number. The second assessment was following the group's averages. The experiment presented the influence of the model generated in each people's minds to generate an answer with limited information and the influence of other people's opinion in their own.

2.4 Uncertainty in Underground Construction

Underground construction represents a major source of uncertainty within Civil Engineering. Unforeseen ground conditions are the main cause of delay and cost overruns around the world in tunnelling construction (Woods, 2002). The gap between the data available through Geotechnical Reports and the actual ground conditions to be encountered on site, demands extensive efforts for risk reduction and management. In geotechnical construction works, it is common to find sources of uncertainty related to (Auvinet, 2002):

- Spatial variation and scale effect (heterogeneity of the soil mass)
- Limited soil investigation (incompletely known parameters)
- Lack of agreement of field and laboratory tests

- Measurement errors (lack of precision of instruments)
- Subjective estimations
- Random nature of static and dynamic loadings
- Environmental conditions (water pressure, erosion, water table fluctuations, etc.)
- Validity and accuracy of geomechanical models
- Use of empirical correlations
- Human error

It is frequent to observe notorious discrepancies between theoretical predictions and the actual behaviour of subsoil due to many different variables involved in the analysis. Figure 2-4 and Figure 2-5, derived from the studies of Wheeler (1999) and Clayton et al. (1988) are illustrative examples. In both figures the variation results from the different approaches and assumptions to solve the problem. In these cases the results are compared with the actual result measured in-situ.

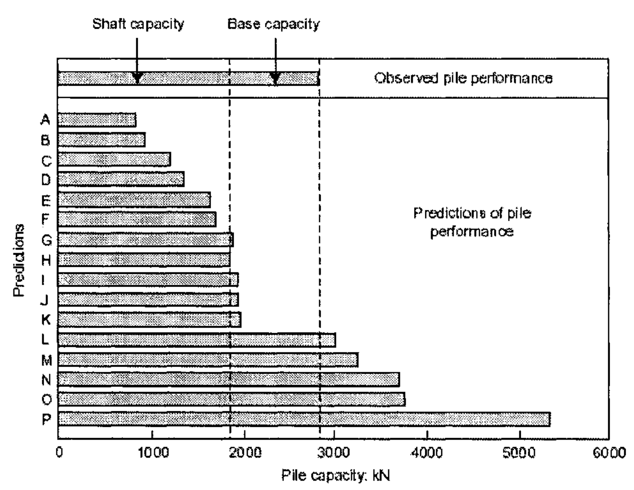

Figure 2-4 Comparison of predicted and observed pile capacities (Wheeler, 1999)

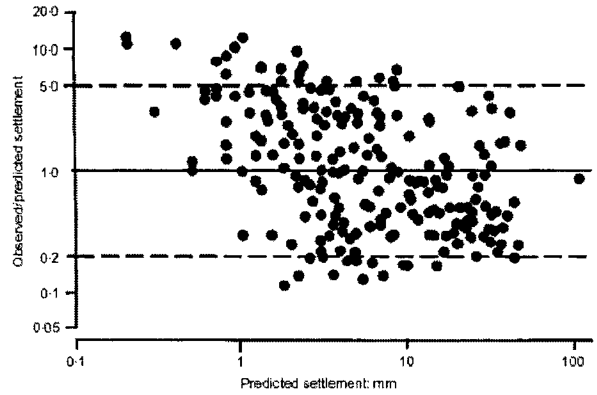

Figure 2-5 Predicted and observed settlements on sand (Clayton et al., 1988)

Figure 2-6 shows eight different empiric correlations for the same purpose, the calculation of bearing capacity, a fundamental value in geotechnical engineering. It can be observed from the dispersion of the curves that there is no clear correlation among the two variables but the one found by each author in light of their particular data set. This is a clear example of how variable the interpretation of soil properties can be. Underground construction is highly susceptible to the different interpretation of the parameters of the ground. The adequate interpretation of the variation of soil and rock properties through the alignment of a tunnel represents a difficult challenge as full knowledge of the profile is almost never available and assumptions are subject to the information at hand with the limitations presented above.

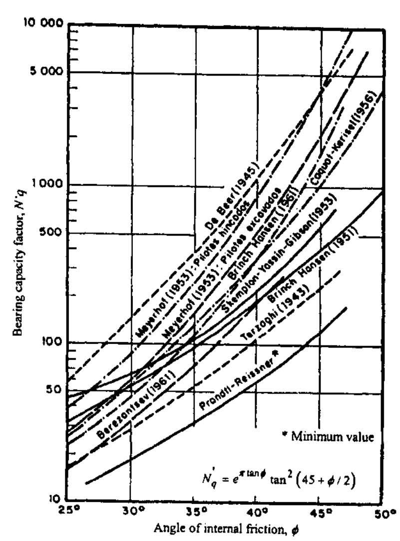

Figure 2-6 Bearing capacity factors for circular deep foundations (Vesic, 1967)

2.5 Numerical Approach to Uncertainty

Dealing with underground media represents an enormous challenge and efforts to overcome its empiricism in estimating geotechnical uncertainty have been successful with the use of historical analysis, statistics and probability.

2.5.1 Geostatistics

The spatial variation of soil properties is one of the main sources of uncertainty (Vanmarcke, 1977). Geostatistics encompasses a methodology that has the ability to describe more realistically the spatial variations of the soil media than a linear profiling of the subsurface, so common in geotechnical practice. Geostatistics relies in sufficient field data to provide a degree of certainty (Deutsch, 2004). The level of certainty depends on the data available. Its benefits have been realized and developed in the mining and petroleum industries where factors of scale and the cost/benefit ratio of exploration are substantially higher than most civil engineering works. Geostatistics has been used extensively in offshore projects to represent the property's variation of marine soils in La Sonda de Campeche in the Gulf of Mexico and the North Sea among many others (Lacasse and Nadim, 1996). It has been used in urban areas in the characterization and simulation of Mexico City Valley subsoil (Auvinet and Juarez, 2002). Geostatistics was used in the characterization of subsoil for the foundation of the 90 m precast footings of the Rion-Antrion Bridge across the Gulf of Corinth in Greece (Auvinet and Medina, 1998) among others. The Channel Tunnel still is today the most soil investigated tunnel in history. Additional to previous studies, including a large diameter horizontal borehole made in 1973, 100 boreholes, worth half a million pounds each, were done (Harris et al. 1996). The adequate identification through Geostatistics of the Chalk Marl layer provided a suitable ground for the overall tunnelling operations and was probably the major RM tool used. Some cities in Canada have a network of soil borings made by the Canadian Research Council that allows Geostatistics to model the underground spatial variations and estimate probabilities of encountering even detailed elements based in different parameters like the sequence and topology of layers, the distance between soil borings, elevations, ground water table, mechanical properties of soil, etc. The accuracy of such models is highly dependent on the input detail and the modelling process. There are some geostatistical softwares for the development of such studies being the most popular GSLIB (Deutsch and Journel, 1998).

2.5.2 Historical analysis

When data is available, a historical analysis can provide information to estimate probabilities and consequences of risk factors. This analysis can provide the reasons why conditions differed and in which extent, the impacts caused and how things could have been deferent if possible to minimize the hazards. The analysis of these case histories can help identify patterns of hazards and their likelihood in specific cases. This approach relies in data collected in "Risk Registers" (see 4.5.2). The probabilities that can be obtained should be looked with caution and within the context of the projects. A relevant frequency in one area might likely be meaningless in another, on the other hand the calculation of small probabilities is almost impossible to elicit from practitioners without probability trees for example (Fischoff et al, 1977).

2.6 Observational Method

The understanding of geotechnical uncertainty by Karl Terzaghi is presented in his own words (1948):

> *"In the engineering for such works as large foundations, tunnels, cuts, or earth dams, a vast amount of effort and labour goes into securing only roughly approximate values for the physical constants that appear in the equations. Many variables, such as the degree of continuity of important strata or the pressure conditions in the water contained in the soils, remain unknown. Therefore, the results of computations are not more than working hypotheses, subject to confirmation or modification during construction. In the past, only two methods have been used for coping with the inevitable uncertainties: either to adopt an excessive factor of safety, or else to make assumptions in accordance with general, average experience . . . . The first method is wasteful; the second is dangerous. Soil mechanics, as we understand it today, provides a third method which could be called the experimental method (renamed later by Peck as Observational Method). The procedure is as follows: Base the design on whatever information can be secured . . . . On the basis of the results of . . measurements, gradually close the gaps in knowledge and, if necessary, modify the design during construction. Soil mechanics provides us with the knowledge required for practical application of this 'learn-as-you-go' method"*

Terzaghi's understanding of geotechnical risk was further developed by Casagrande's concept of "Calculated Risk" (1964) and Peck's "Observational Method" (1968). The Observational method was conceived intrinsic to the practice of soil mechanics. It is indeed the foundation in which RM for underground construction should be based on. An important characteristic is that each observation should be measured in order to provide improvement (Powderham, 1998).

2.7 Model Uncertainty

When several people are assigned the solution of a problem it is likely that each would see different approaches. The more complex the problem the more paths that can lead to a possible solution. Let us consider the model adapted from Moore and Weatherford (2001) in Figure 2-7:

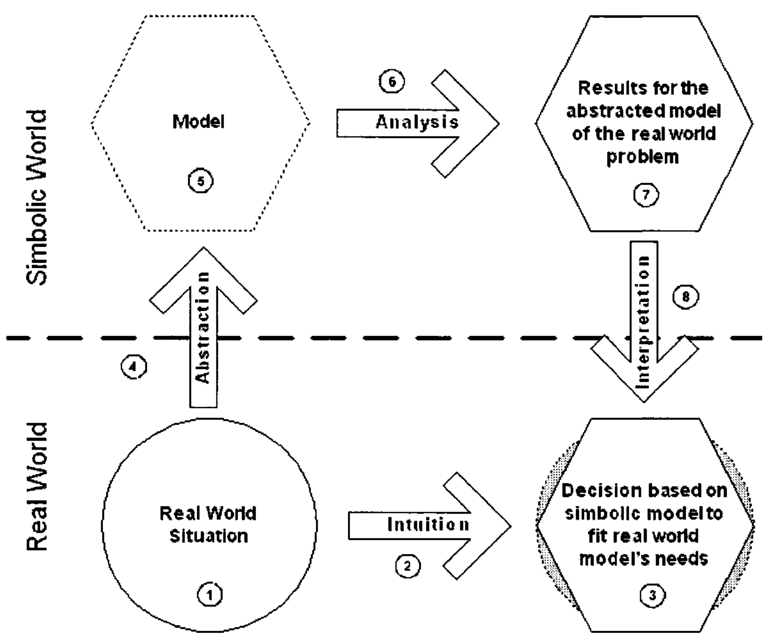

Figure 2-7 Problem modelling (adapted from Moore and Weatherford, 2001)

In Figure 2-7 a situation in the real world is represented with the circle (1). After this starting point, two paths can follow: Path A, 1→2→3 and Path B, 1→4→5→6→7→8→3. Path A will suit the majority of everyday decisions where a solution is straightforward or is not worth further analysis; this would be entirely based on intuition. For more complex scenarios Path B would be desirable. Through abstraction (4) the brain generates a representation of the real situation, a model (5). After an analysis of the model (6), results that reflect a solution of the abstracted model are obtained (7). After the interpretation of the results, from the abstracted model to the real world situation, a decision is taken and applied to the real world situation as a solution or decision (3). The model depicted with the hexagon represents the inaccurate representation of the real world situation. In most cases, the model can only be an approximation due to a series of factors like: lack of information, misinterpretation of the situation, contradictory or unclear information, lack of system perception of the overall situation, etc. The level of accuracy of the model, to the real world situation, is represented in the figure with the difference in shapes. When taking a decision based on the results of a model it is necessary to bare in mind the gaps between the results of the model and how close these results are from the real world solution needed including the relevance of model error (Morgenstern, 1995). When possible the model should be compared with expected and actual results and to be modified as information becomes available. In the model of the figure this would be equivalent to the hexagon to increase in sides and get closer to the circle's shape, resembling Terzaghi's Observational Method described before (Therzaghi and Peck, 1948). Models that have human interaction and limited information are complex to represent. The overall process of design and construction of underground projects offers a particular challenge as some relevant variables of the ground are partially known throughout the project. In these circumstances judgement becomes the driving force in an uncertain environment. Figure 2-7 can represent the modelling abstraction process for decision making that resembles the RM process among other reasoning situations.

A relevant point embedded throughout this research is in the extent at which RM is performed in all levels within the Tunnelling Industry including: owners, consultants and contractors as well as the outside influence of the insurance industry. A main element in RM is Risk Identification, based on Figure 2-7, Risk Identification would be equivalent to generating the model. It can be perceived that regardless of the detail of the analysis, the result will only be as good as the model.

2.8 Risk Management

Risk Management is a dynamic process that transcends the specific project and offers the opportunity to build valuable knowledge to better confront future projects. It enriches engineering judgment to better assess the coming risks in a team building effort. RM forces the project team to think about all possible hazards, even those not directly related with technical issues, as they all are contributors to cost and schedule overruns of projects like the Channel Tunnel or Boston's' Big-Dig (Reilly and Brown, 2004). Following are some of the benefits on the practice of RM (Simon et al. 1997):

- Enables more realistic plans, schedules and budgets
- Increases chances of a project adhering to its plans
- Improved team spirit
- Helps in the selection of better contract strategy and procurement
- Helps distinguish good luck/good management vs. bad luck/bad management
- Helps staff to develop skill to assess risks
- Discourages unsound financial projects
- Focuses project management attention to the most important issues
- Building of knowledge for better management of future projects
- Enables greater risk taking as well as more opportunities derived by them
- Allows the more objective selection of alternatives
- Offers a convincing marketing tool through a responsible approach to customers
- Helps in the allocation of risk to the best party to handle it
- Gathers stakeholders opinion in a framework where everybody can express its views on issues over the project

It can be observed that the many benefits of adopting Systematic Risk Management share credit with other project management practices like Value Engineering, Partnering, Quality Management Systems etc., which makes difficult to measure the sole contribution of RM. Through the global and local perspectives of the performance of the tunnelling industry though insurance claims, it is possible to assess the contribution of RM practices. RM in the context presented can be measured in terms of loss prevention and related positive and negative outcomes. The use of a structured and auditable RM system is beneficial to owners, designers and contractors in gaining more control over their projects, retaining and controlling more risks, and getting insurance only for those risk that have minimal predictability and which can have catastrophic consequences, but most importantly, to maintain business operation.

Risk Management does not guarantee that a project will be completed at a certain time and budget as uncertainty is inherent to underground construction. The reduction of this uncertainty represents tradeoffs among better knowledge of the underground through geotechnical investigation and its costs. A study made by the National Research Council in the US of 89 underground projects showed that 85% of the time the level of site investigation was insufficient to allow an adequate characterization of site conditions leading to delays and cost overruns (NRC, 1984). Risk Management as many other management tools, has been developing largely from common sense, this situation together with the different attitudes towards risk among individuals makes the measurement of RM practices difficult. For an individual the practice of RM can represent to go over a checklist, while for other the use of sophisticated probabilistic models fulfills its concept of RM. Different individuals would ascertain they do practice Risk Management but it is the context and common sense what defines, if a checklist is addressing the relevant risks for a particular project, or if further studies should be undertaken to arrive to a satisfactory outcome. Risk Management is performed at different levels of detail in the Tunnelling Industry the present thesis provides insight to the gap between the current practice and the new challenges the Tunnelling industry is facing to get insurance and remain in business.

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Chapter 3 Insurance in Canadian Tunnelling Projects: Current Practice

3.1 Introduction

Tunnels are complex infrastructure works due to their size, duration, and high specialization in comparison to other civil engineering structures. Tunnels are capital intensive endeavours built underground. These two factors make Risk Management (RM) a natural companion during their planning, design, procurement, and construction stages. Tunnelling projects have continuously experienced tender that greatly exceed the engineering estimates. This is primarily due to the risk involved in underground works leading to changes during construction, cost overruns, and delay in start up. In particular this is true with large construction contracts and financial expenditures associated with reduced competition (Romero et al. 2002). In the UK, the performance of the construction industry in general shows that 52% of construction projects were over budget, 58% were over schedule and 42% had defects which significantly affected clients' business (Lane, 2003). As discussed in this chapter, the performance of the tunnelling industry has been unsatisfactory. Tunnels are unique but even tenders for the same tunnel can have different approaches to evaluate the costs. This was the case in the tenders for the Capilano-Seymour Tunnel in Vancouver as prices ranged from CAN$99.6M to CAN$237.5 showing an immense variation in project costs (GVRD 2004). Tunnelling demands the highly skilled interdisciplinary work of practitioners and contractors. Thus the complexity of the project is increased by the human interaction. These characteristics make RM an inherent part of the tunnelling practice. This chapter looks into the role of insurance and other risk financing options. It also examines its relevance in the context of a systematic use of RM Practices for tunnelling projects as a result of the new trends of the insurance industry towards tunnelling projects, as outlined in this chapter.

There are different elements that compose the practice of RM and each has different levels of detail. Figure 1 shows the areas of RM from a financing standpoint and the role of Insurance as an integral part of any major infrastructure project. Once risks have been identified and assessed, methods to be used for their control are selected. Reduction and elimination of risks are loss prevention measures. The remaining risks, identified or not are managed financially. The awareness and adequate balance of the use of risk financing is paramount in the planning stage. The goal is to retain the risks that the organization is able to manage and transfer only those ones that are out of its expertise. This is the point where insurance comes in to play in tunnelling projects, as part of an integral RM system. As explained in this chapter, commercial insurance should be seen as a last resource in Risk Management.

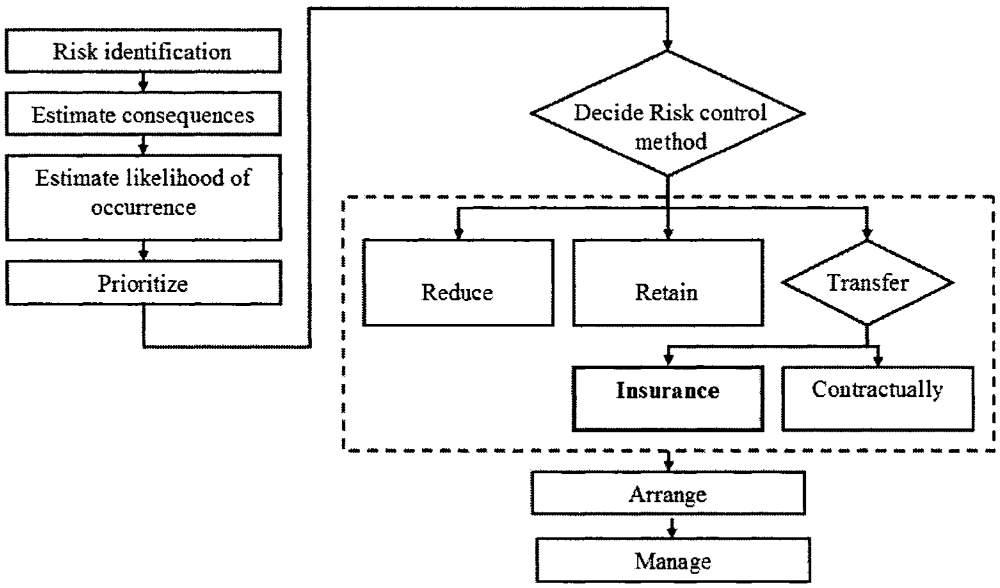

Figure 3-1 Overview of Risk Management practices from a financial standpoint

In the construction industry insurance offers contractors the possibility to offset different risks as summarized by Edwards (1995):

- Client cancels
- Client fails to pay
- Force majeure incident
- Suppliers start delay
- Transport start delay
- Contractors start delay
- External Start delay
- Client duration extension
- Suppliers duration extension
- Transport duration extension
- Contractor duration extension
- External duration extension
- Escalation estimation error
- Supplier performance failure
- Contractor performance failure

Most risk factors can be handled through RM either in their probability or impact components or both. This allows the optimum use of insurance but requires maturity of the organization participating in a project. The maturity on the practice of RM of a tunnelling project depends on the awareness of stakeholders of the risks involved and the capacity to handle them.

In recent years, the frequency and size of tunnelling claims around the world raised concerns of the insurance industry that tunnels have become an unprofitable segment. The worst year in the insurance industry in the past decade was 2001, this lead to a major re-evaluation of profitable and non-profitable segments. The underwriters' target for global insurance loss ratio (losses/premiums) in the construction has been 60% in order to cover overheads and profits with the remaining 40%. In 2001 this ratio reached up to 110% but in tunnelling was 500% (Woods, 2002). Although these numbers are for international projects insured in the UK, this negative claims record is not limited to the UK. These conditions have increased the pressure on the tunnelling sector worldwide. In some cases, major reinsurance companies have left the tunnelling market out of their portfolios while others have switched to limit their exposure and increased the cost of insurance to levels never seen before. Additional, underwriters tend to limit coverage extensively when new technology is involved. This environment has put the practice of structured and auditable RM in the first place where owners and contractors can gain more control over their projects, retain and control more risks, and acquire insurance only for those risks that have minimal predictability and can have catastrophic consequences. Meanwhile the loss/premium ratio of the tunnelling industry urges the sector to reconsider their practice of RM.

This chapter addresses the current state of the insurance market towards tunnelling projects, the impact of the "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" (BTS and ABI, 2003) in the international insurance market and its influence in Canada. Additionally it presents the RM procedures from reinsurance and insurance companies towards Canadian tunnelling projects. The information presented herein was gathered from insurance and reinsurance underwriters as well as brokers from world leading firms in integrated RM. The interviewees were asked from their corporate point of view to comment on the different issues regarding their corporate experience with Canadian tunnelling projects. The data was gathered by personal and phone interviews as well as email in a case study approach. The information obtained was complemented with official reports of regulated insurance bodies in Canada and overseas, reports from consulting firms over the market, official policies of reinsurance companies as well as tunnelling-insurance related literature.

3.2 Background on Insurance in Tunnelling Projects

3.2.1 Economic size and frequency of losses in soft ground tunnelling

The majority of tunnels are embedded in other complex infrastructure projects like dams, water distribution systems, underpasses, etc. where claims are within the context of the overall project. Underwriters at Swiss Re filtered and obtained reliable figures related to claims in soft ground tunnelling projects (Wassmer et al, 2001). They documented 300 different cases that occurred between 1986 and 2001. They found that losses exceeded net premiums by a ratio of 160%. They analyze the fact that until 1992 the loss ratio was 81%. These findings indicate a sudden increase in the last nine years. They estimate that this sudden increase was due to two main reasons:

- the decrease in premium rates, and
- the increased accepted risk exposure of projects by underwriters

Figure 3-2 shows the losses as a percentage of the total loss amount in soft ground tunnelling projects from 1982 to 2001. The amounts are in millions of Euros.

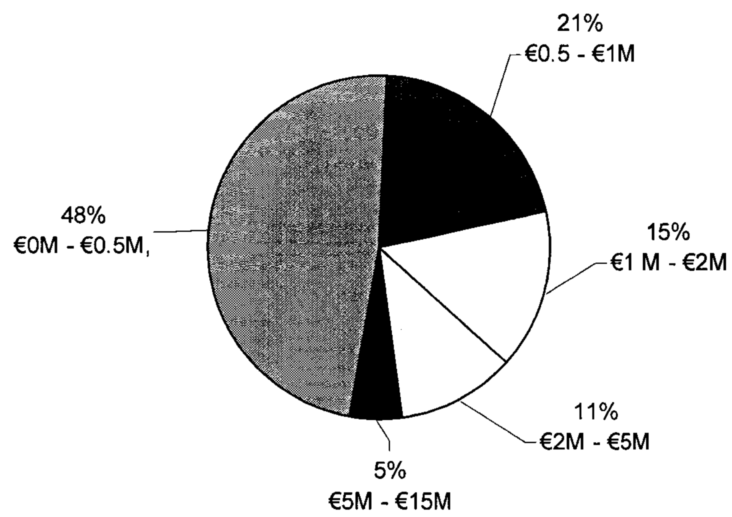

Figure 3-2 Total loss amount in soft ground tunnelling projects from 1982 to 2001 (Source data: Wassmer et al, 2001)

Low frequency but high consequential events in tunnelling normally represent considerable sums of money as they can trigger the collapse of a building over the alignment of the tunnel. A loss of that magnitude can cost many times the value of the tunnel itself. Considering this, it can be seen from Figure 3-2 that the vast majority of losses that characterize soft ground tunnelling are related to events of monetary consequences lower than €2 million. This group represents 84% of total losses. It is important to note that the loss ratio of 160% described in the Wassmer et al. (2001) study does not reflect the impact of catastrophic events but a high number of low consequence events. The monetary value of these numbers provides light into the opportunities on the implementation of systematic RM practices, where the majority of consequences are represented by a diversity of risk factors that should be identified, analyzed, and managed. Moreover, research into tunnelling disasters has revealed that they are not "single cause events" but arise from mismanagement and incompetence (Anderson 2002).

3.2.2 The Joint Code of Practice for Risk Management of Tunnelling Works in the UK

One of the findings in the interviews conducted in this research was the limited knowledge of the Code of Practice in the Canadian Insurance and Tunnelling industries; therefore the Code is briefly described here.

From an insurance perspective, tunnels are highly exposed structures in terms of risks not only during construction but also in its operation life. In this second stage, and depending on different conditions, risks are relative to: water inflows, earthquakes, collapse and above all fire. The former condition generated the "Code of practice for fire prevention in tunnels in the UK". The Association of British Insurers (ABI) and the British Tunnelling Society (BTS) jointly made this work. This document is where "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" (referred here as the Code of Practice) is based on. The challenge of this new code was more complex as the hazards related to fire are easier to contain. Tunnelling operations have a lot more complexity and are prone to a long list of different hazards in each project due to the natural uncertainty of the underground.

The Code of Practice was a European initiative from the insurance sector. The previous work with the "Fire Code" among the ABI and the BTS made the UK the starting point for an international endeavour focused on an auditable process of RM in tunnelling for insurance purposes. The Code of Practice should be perceived as an opportunity for the tunnelling and insurance sectors to avoid a situation in which tunnelling works become uninsurable. The impact of the Code of Practice has been expressed by the International Tunnelling Association (ITA) as:

> *"The entrance of the reinsurers into project Risk Management by requiring certain procedures and practices to be followed as a condition for the provision of construction insurance will be the focus of detailed urgent consideration (ITA 2004)"*

The purpose of the Code of Practice is *"to promote and secure best practice for the minimisation and management of risks" (BTS and ABI 2003).* This document gives the right to insurers to audit and, in the event of non-compliance, suspend insurance cover. The Code relies on the following fundamental principles (Mellors and Southcott 2004): operation in parallel with existing Standards, statutory and legislative duties, identification of hazards and associated risks during planning, design, procurement and construction on a project-specific basis and the management of the risks to ensure their reduction to a level ''as low as reasonably practicable''. Recording and summarising of risk assessments in risk registers must include the identification of the party responsible for the control and management of each identified risk at each stage of a project.

> *"Cascading" of risk assessments/registers throughout a project to ensure that parties, at any time during a project, are made familiar with previously identified hazards and assessed associated risks; risk registers should be 'live' documents which are continuously reviewed and revised as appropriate and available for scrutiny at any time; and insurance should not be considered as a contingency or mitigation measure in risk assessments."*

One opinion of a tunnelling practitioner interviewed in another part of this research (see Chapter 4) wrote that their perception of the Code of Practice was:

> *"The Code of Practice is moved by the client looking for low premiums. Is self imposed on one hand and it is for the insurance an excuse to not pay".*

Whether this statement is the common practice or not is unknown. However, such a perception towards RM procedures can have organizational obstacles if there is unclear communication of the legitimate benefits to the parties involved.

The high claims/premiums rate in the tunnelling industry depicts an inconsistent approach to RM that the Code of Practice is intended to improve. The consequences of the current inconsistency to the management of risks has constrained the extent of insurance coverage or even stopped from being offered. Other consequences are an increase in the underwriters' requirements and the potential to become price prohibitive.

This is an opportunity for the tunnelling industry to improve, from other successful tunnelling players, where RM practices are well established.

3.2.3 Insurance for tunnelling projects

In order to present the areas where systematic RM can help in the improvement of tunnelling projects, some insurance products and sources pertinent to tunnelling works are explained. Stakeholders' (owner, consultants, contractors, general public, etc.) interests are affected by the positive and negative aspects of infrastructure projects development, thereby generating a wide gamut of potential consequences that have to be managed. When dealing with tunnelling, particular attention needs to be devoted to effective RM practices towards loss prevention, insurance costs, and benefits. There are many different sources of risk that can be identified assessed, reduced and controlled, for some of the recognized risk, insurance is the best available option. For a client, insurance is a financial way of distributing the cost of its losses in a period of time providing financial stability, plus a fee paid to the insurance company for the service. From an insurance company perspective, it is a way to obtain capital to be invested in order to obtain gains to offset losses of what has been insured, plus a profit.

Although insurance offers benefits in the management of projects there are motivations to rely on it only when there is no other available option, these motivations include (Edwards, 1995):

- Some risk can only be partially insured
- Premiums are based on the record of a pool of similar clients where there is no distinction between good and bad RM
- The mark up that covers overheads and profits in insurance is high
- Cover availability and premium costs are variable
- Claims, disputes and delay of payments from the insurer can happen

From this perspective, insurance should be considered as an option once all efforts have been made in lieu of the reduction of potential losses in order to minimize its costs. Ostrowski (2002) presents a broad view of these issues for blasting complaints in urban areas and its prevention.

Generally tunnelling projects are capital intensive endeavours, and it is for this reason insurance companies frequently require the support of reinsurance; the former shares the risk exposure and profit/loss with insurance companies. Insurance companies evaluate the risks to be underwritten, sometimes with support of reinsurance companies. In most cases, if not all, insurance policies are covered in part by the insurance company and the rest through reinsurance capacity (see Figure 3-3). This practice allows insurance companies financial diversification of risks, not only sharing different risks for different projects spreading them among other insurance companies, but in different industries providing lower insurance costs. The costs of insurance increases as commissions for brokers, insurers and reinsurers have to be covered. This is another motivation in the implementation of systematic RM practices.

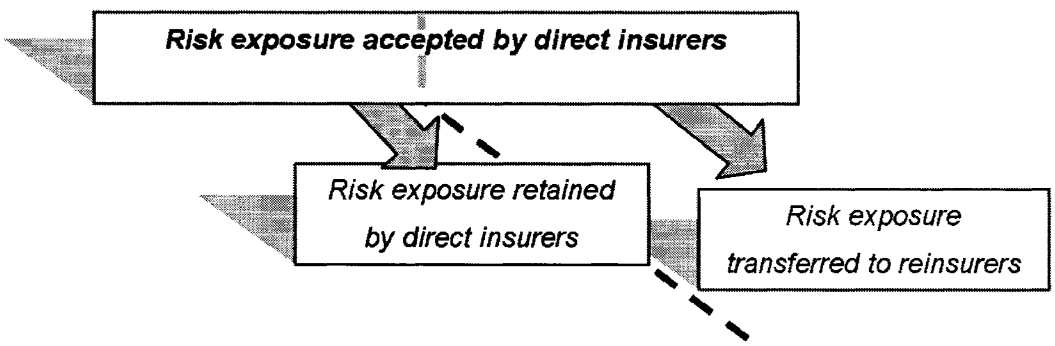

Figure 3-3 Risk exposure distribution among insurers and reinsurers

Canadian insurance has two main reinsurance sources, the European and the North American markets. Where European insurance companies are domiciled in Canada, negotiations are within the country. A particular case worth mention is London, which operates in two separate markets for North American business. One is The Lloyd's of London Insurance Market (Lloyd's) and the other is generally classified as the "London market". The latter operates as independent insurance companies; while Lloyd's operates with a pool of underwriters that are not licensed in Canada and an intermediary is required. This practice is called “fronting”. The majority of commercial insurance is written through brokers, direct contact with insurance companies is not common. All major international insurance brokers are represented in Canada, with Aon Reed Stenhouse Inc. and Marsh Canada Limited being the largest. Normally, brokers are compensated via commissions, with the average rate being 15% (Keller and Amodeo, 2001). The brokers’ job is to represent the risks to the underwriter fairly and accurately in order to allow him/her to make a decision on a specific project, and ultimately to obtain the best possible insurance package that fits the clients needs at a reasonable price.

For clarification purposes we explain the difference between Surety and Insurance. Surety is used to guarantee that a company will complete a work that it has contracted to do. In a tunnelling project a contractor may purchase a surety bond to guarantee to the owner that it will complete the tunnelling works as stated in the contract. If the contractor then fails to complete the work, the surety company will find the means to finish the work or indemnify the client. In this case it is worthy to note that with insurance the risk is transferred to the insurance company contrary to surety bonding where the risk remains with the contractor or principal. The guarantee provided by the bond is not for the contractor, but for the owner or obligee to which a bond is given. Insurance companies make their business calculating that a certain percentage of the policy’s premium will pay to offset losses. In the case of surety, the premium paid is for "service fees" charged for the use of the surety company’s financial backing and guarantee. In rough terms, the point of view of a surety is equivalent to providing credit to the contractor and the fee would be the interest.

3.2.4 Insurance cover for underground projects in Canada

There are plenty of insurance companies (IBC, 2005) in Canada, however, there only exist a limited number of underwriters for tunnelling. The main products offered from tunnelling projects are:

Property and casualty (P&C) are also known as Contractors All Risks in Europe ("CAR"). Property insurance, also known in Canada as “Course of Construction” (COC), provides the financial means to replace it in the event of loss if anything happens to the property, such as the loss of the TBM due to fire or natural disaster. It covers among other things: materials, buildings, structures, works, and other property pertaining to the construction. The policy can be extended to include the contractor's plant and equipment on site. Casualty or "Third Party" liability insurance covers the legal responsibility of damaging someone's person or property. In the case of cracking of neighbouring structures in a tunnelling excavation due to settlements, casualty insurance will cover the cost of repairing the damaged property (or in the case of injury, the cost of rehabilitation and medical costs). In order to provide full coverage against possible damages and losses it is convenient to obtain both P&C, even though this arrangement can be obtained with a different insurance company depending on factors as availability or specialty of a certain firm over another. As a result Property can by insured with one company and Casualty with another. The property and casualty (P&C) insurance industry in Canada provides coverage for all risks other than life.

Professional liability insurance protects from claims, damages and allegations as a result of the professional practice and it is embraced by The Association of Consulting Engineers of Canada and the Canadian Council of Professional Engineers. The following areas of the engineering profession are classified for professional liability purposes as having "significant exposures" by the insurance sector:

- Geotechnical engineers
- Structural engineers
- Tunnels and bridges
- Rehab work, in particular with old buildings in larger older cities
- Power plant projects, especially nuclear

It is worthy to note that most tunnelling projects are related with these areas, therefore classifying tunnelling as a "significant exposure" activity. Due to the interdisciplinary nature of tunnelling works, Professional Liability insurance has a high demand for "design and build" contracts, a common practice in tunnelling around the world. Flanagan (2002) reported that design risks accounted by insurance companies indicated that 40% of latent defects in buildings are design-related and 40% are workmanship-related, while the remainder is accounted for component failures. 80% of maintenance costs are built in during the first 20% of the design process. These numbers explain why professional indemnity insurance premiums have risen over the past ten years. The reasons are the increase in claims for negligence and higher construction projects' complexity.

Wrap up insurance is the general liability policy that insures everyone involved in the project. It would insure the owner, the general contractor and all the subcontractors. It is project specific, where a liability limit amount is purchased, and any third party damage that the project can cause is covered by the policy, up to the insured amount. The Wrap up insurance can either be bought by the owner or the contractor; it works as a centralized insurance loss control program. This insurance offers large projects a potential for savings in premium costs over individual contractor insurance. The insurance coverages that can be included in a Wrap up program and benefits are (Gilmartin, 1998):

Coverages:

- Professional liability (depending on the market used)
- Commercial general liability (included completed operations)
- Employers' liability
- Workers' compensation
- Pollution liability
- Excess liability

In Canada Course of Construction it is not included in the Wrap Up. This is a different practice than in the UK where Builders' risk insurance is included. In Canada, some companies are not specialized in Professional liability and might not include it in a Wrap Up program.

Benefits of Wrap up:

- Centralized insurance administration
- Cash flow advantages resulting from reduced premium payments
- Extended protection for claims occurring after completion of construction

- Broad insurance protection with uniform limits and coverages for all parties insured
- Reduced substitution of one creditor for another (subrogation) and cross liability actions
- One team safety program towards improvement to minimize accidents, improve safety records and consequently premium savings

Best practices in order to obtain the full benefits from an insurance program involve the insurance of the project under one program normally arranged by the owner. On these arrangements it is common that the insurance of contractor's equipment is not included as this is not of interest to the owner.

Contractors seeking insurance for their machinery are required to provide elements that allow the appraisal of equipment as: type, year of manufacture, etc., in order to set the insured amount. It is important to understand that this type of insurance is only for external causes of loss. Normally what is offered from insurers is up to the reimbursement of the value as new of the insured equipment (as this can be calculated with certain accuracy). When partial loss occurs, the repair costs are reimbursed with no deduction of the substitution of new for old. When total loss occurs the current value is reimbursed. The way this insurance works is very similar to automobile insurance where deductibles are applied in order to compensate a large number of individual losses. Loss prevention plays a major role in order to reduce costs to the contractor and insurer. During the selection of a TBM for a particular project, provisions should be established in order to retain the risks of mechanical and electrical breakdown as these are normally excluded in the cover as the premiums are excessively high. Assessment of the probability of TBM failure is difficult, but possible, an example of low frequency with high consequences event happened in British Columbia at Roger's Pass tunnels where the main bearing of the TBM broke down consequently affecting the project (Martin 2004).

3.2.5 Global Reinsurance in Canadian tunnelling projects

According to Keller and Amodeo (2001), major international reinsurance companies dominate the market for tunnelling and other high risk construction projects in Canada. They emphasize that the policy wordings follow the European coverage models. Figure 3-4 presents the ten largest world reinsurers companies ranked by gross premiums (data source A. M. Best Company, 2005):

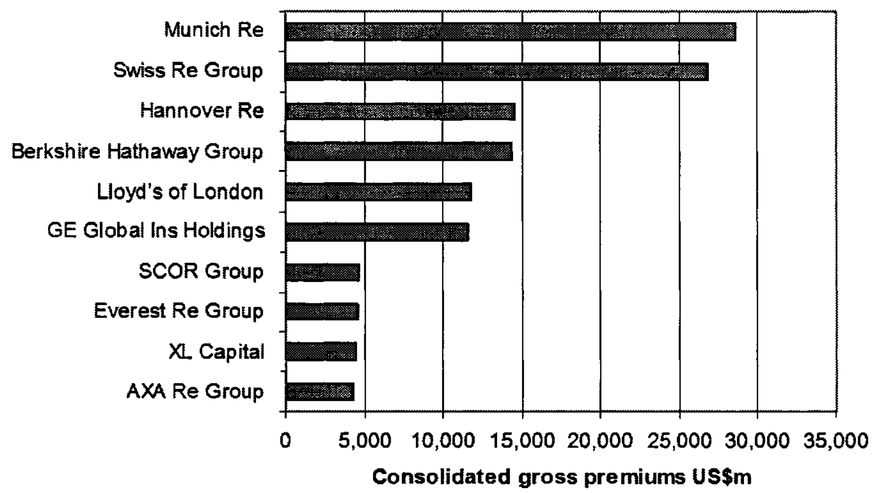

Figure 3-4 Ten largest world reinsures ranked by gross premiums in 2004

There are 28 active reinsurance companies in Canada (Keller et al. 2001), the top five that account for 48% of the total net written premium are:

- Munich Reinsurance Group (Germany)
- Swiss Reinsurance Group (Switzerland)
- Partner Re (USA) (SAFR France, Winterthur Re, UK)
- SCOR Reinsurance Company (France)
- Employers Reinsurance Corp. (part of General Electric Insurance) (USA)

The former reinsurance companies are all members of the Association of British Insurers (ABI) and require in the UK the mandatory Code of Practice for Risk Management of Tunnelling Works to grant insurance. Figure 3-5 a) and b) present the geographical origin of companies that sponsored the Code of Practice and their participation in the Canadian market.

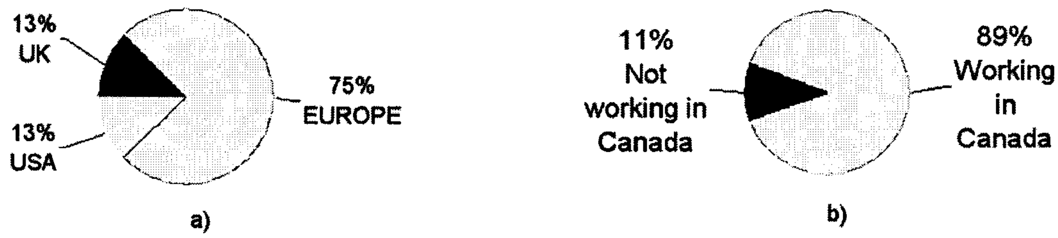

Figure 3-5 Geographic influence of the Code of Practice in Canada

The majority of participants that sponsor the Code of Practice are from Europe. It can be shown that the European version of the code is likely to follow the majority of guidelines established for the UK. The vast majority of companies that sponsor the Code of Practice in the UK have operations in Canada.

3.3 Questionnaire's Findings

3.3.1 Performance measures that brokers and underwriters look for in tunnelling projects:

According to brokers interviewed, they generally aim at two main areas: technical characteristics of the project and people involved. Within the technical characteristics every tunnel has different parameters to account for. These include: geology, geotechnical characteristics, location, tunnelling profiles, construction method (TBM, SEM etc.), lining support, depth, geometrical characteristics, intended use, cost, duration of the overall project and natural hazards among others. The aforementioned provides a general idea of the complexity of the project. However, the main source of confidence for the broker is regarding the people involved. It is the most important factor in which they support their confidence based on what the engineers in the project state. With this data they pass this information to underwriters. One of the interviewed underwriters that manages different insurance companies' accounts mentioned:

"Tunnelling is such a specialized and hazardous operation that all insurance companies require for project evaluation, full underwriting information for their specific approval of terms before they offer coverage for such projects".

Insurance practices suggest the following criteria when assessing risk (Münchener 2000):

- Qualifications and experience of the client or policyholder
- Urban or rural area
- Contract price
- Planning period
- Construction methods applied
- Use of new technology
- Particular geological conditions, groundwater conditions and natural hazards to be taken into account in the planning (floods, gas, fire, wedge collapse, etc.)
- Effect of settlements, vibrations or noise of construction work on the existing structures and people
- Use of explosives
- Particular circumstances augmenting the risk (e.g. collision with existing utilities, alignment under building's foundations, etc.)
- Responsibilities and liabilities accepted
- Number of stakeholders (partners and engineers) involved in the project
- Total fees
- Comparability to previous projects already completed in terms of technology, methods and geotechnical conditions

3.3.2 Do insurance companies have technical practitioners to help in the evaluation of tunnelling projects?

This expertise can be found at reinsurance headquarters for some projects, but it is not the common practice. One of the interviewed underwriters stated that:

> *"The standard practice by underwriters is more qualitative than quantitative due to the lack of statistical data. There are few people in the area with different approaches".*

Similar statements were obtained from the people interviewed noting a common practice as mentioned in the previous quote.

3.3.3 Would you consider the cost of insurance premiums would decrease with the practice of an auditable Risk Management system in tunnelling projects?

The cost of insurance depends on the overall behaviour of the tunnelling industry among other variables. An improvement in the loss/premium ratio is likely to reflect in the cost of insurance in the long run. On the other hand the projects the brokers have seen already had safety and risk mitigation plans. It is perceived by the interviewed brokers that the Canadian practice has been better in this regard compared to the UK as the North American market has not stopped tunnelling insurance in Canada. The panel of brokers consider that it is possible that Canada does not have the same environment that was present when the insurance sector in the UK and Europe and moved forward under the initiative of the Code of Practice in terms of tunnel losses. The perception of the brokers was that:

> *"It is possible that European underwriters have a lack of understanding of the environment in Canada and this has made the insurance of tunnels difficult when European Reinsurers are involved"*

The understanding of this geographical environment offers a good opportunity to the reinsurance groups on the fact that some companies that underwrote tunnelling in Canada have recently stopped, this is probably due to the new trends in Europe, while others are still in the market. This scenario takes place were insurance companies in Canada receive support from global reinsurances' capacity. More important than the effect on premium price is the availability of insurance. In infrastructure engineering the record of losses and RM among contractors is not uniform; underwriters tend to prefer to deal with those contractors with whom they have better records.

3.3.4 Is there any available record for tunnelling incidents, collapses or accidents in Canada (statistical data)?

As far as the people interviewed were concerned none reported to know of any Canadian tunnelling catalogue derived from insured projects or any other kind. This suggests that the statistical data for analysis of Canadian tunnelling experience should be formed. It is relevant to include among other parameters any incidents that impacted the projects' performance during construction. This catalogue would support the analysis of the cost of insurance premiums that today are compared with international data that does not necessarily reflect the same practice in Canada.

3.3.5 How are the premiums of Canadian tunnelling projects calculated?

The premiums for Canadian tunnelling projects are calculated based on a fraction of the total cost of the construction works. This approach offers a repetitive methodology that follows the same criteria from project to project in a simplified manner. The project itself (drawings, design, geotechnical reports, etc.) and the people involved (and their experience) represent to the underwriters the elements to determine whether to grant cover to a specific project or not.

One of the principal firms in Canada providing underwriting services for the insurance industry indicated that:

> *"The practice is to charge an overall average rate for the entire project, taking into account the various types of work involved, including the cost of tunnelling.*

This follows an assessment of the exposures and liabilities of the specific class of work. Exposures in the case of tunnelling are evaluated from different factors, the most important being: geotechnical conditions, the method in which the tunnelling works will be done (TBM/drill & blast/SEM, etc.), the experience of the general and major subcontractors and for liability the exposures for damage to property and injury to others. We have access to the rating formats of several international reinsurers... other major factors in determining premium are (for liability - the limit of insurance) deductibles and how these are to be applied, e.g. liability deductibles may or may not apply to claim investigation and defence costs, or may be applied on a 'per claimant' rather than 'per occurrence' basis. Other major factors include the quality of loss prevention that will go into the planning and execution of the work, including pre-construction survey, seismic monitoring, etc."

The insurance premium paradox

If an owner invests upfront in a well developed and structured RM program, Value Engineering, Partnering practices and a Quality Management System, the final result of the overall project will be improved as has been reported not only in the construction but in many other industries. The implementation of these practices during construction adds costs to the original budget towards a controlled project with increased certainty to perform as planned. As is the current practice, the underwriter would charge a premium of a fraction of the total cost of the project. In a project that has already reduced its risk, the cost of insurance should reduce too. The tunnelling industry has an excellent opportunity to improve in the reduction of uncertainty, loss prevention and risk retention regardless of how insurance account for these practices. On the other hand brokers should show insurers when a contractor has good RM procedures, providing better terms to negotiate premiums according to the contractor's RM maturity. One of the tunnelling practitioners interviewed in another part of this research stated:

"What irritates me is that Risk Management is seen on the downside but not on the upside (the benefits), the questions are focused on what can go wrong. It would be good to analyze what went wrong and what went good. We had an experience in Hong Kong where we use horizontal directional drilling (HDD) for probing before works started for a tunnel 1 km long, after 750 m of excellent ground conditions; we hit a reservoir of water".

The reward of this risk reduction practice was evident but this is not always the case. This makes the benefits of RM difficult to evaluate as its contributions are difficult to isolate from other practices. The interviewed added that the traditional 2% of project cost calculated for site investigation should be re-evaluated in terms of uncertainty reduction. Moreover, 85% of underground projects analyzed by the US National Research Council (1984) had claims due to the insufficient site investigation to allow adequate characterization of site conditions, ranging the cost of claims from 12% to 50% of original construction costs. These numbers are from 1984 where the most critical over budget projects where not as critical as in today's scenario.

3.3.6 Do underwriters have a preference to see a particular type of contract among Owner and Contractor in tunnelling projects or are they indifferent?

Underwriters in general prefer to see among Owner and Contractor in tunnelling projects:

> *"at least industry-standard contracts from the Canadian Construction Documents Committee (CCDC-2) as a basis for the contract. We do not like to see fixed-price contracts for projects of this nature, where many variables may enter into the picture and present unforeseen expenses for contractors, who may then be tempted to cut corners on loss prevention".*

Other underwriters mentioned that the conditions of the contract should state that the ground risks should be retained by the Owner. The former point can be very well managed through the use of Geotechnical Baseline Reports.

It is advantageous to clearly define the ownership of risks as early in the project as possible and make bidders aware of them. The early and clear definition of risks between the owner and the bidders is of great importance, not only for determination of the premium, but also for subsequent loss events (Münchener 2000). The owner is the driving force in the preparation of documentation that will provide benefits in the management of risk during the project. One of these benefits can be realized when underwriters see a reasonable negotiation of terms, risks, and responsibilities on each party. A project that shows from different perspectives good practices for RM and loss prevention makes it attractive to the eye of an underwriter, making its decision to support the project easier. This attitude benefits all parties: the owner has a tunnelling project that qualifies for insurance even in hard times and elements to avoid conflict; the contractor has clear lines of work and responsibilities and control over the managements of its risks in order to avoid conflict due to situations arising for example, from unforeseen ground conditions; and the underwriter supports a project that presents its risks reduced as low as reasonably practicable (ALRP). If the unexpected happens no one is to blame.

3.3.7 Is there any promotion or encouragement for the use of Dispute Review Boards and/or Geotechnical Baseline Reports?

At the time the interviewed underwriters indicate that there is no corporate preference to see contracts where a Dispute Review Board (DRB) is appointed by owner and contractor or with the existence of a Geotechnical Baseline Report (GBR). The reason is that generally, underwriters do not have much of a say in what type of contracts will be used. They are usually presented with these after most of the terms have been negotiated. Underwriters always have the discretion to decline insurance to any project or refuse to offer coverage stipulated in the contract. This situation is likely to change as the GBR and DRB are required by the Code of Practice for insurance coverage.

3.3.8 Is your organization requiring compliance with "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" for present or future projects in Canada? Is it doing it now in other countries?

Both questions were affirmative by the spokesperson-underwriter representing the major reinsurance company in the world. This is the corporate position in this respect and the literature available for their underwriters clearly states the Code of Practice as a requirement (Munich Re, 2004).

3.4 Insurance Environment for Tunnelling Projects

The construction industry is a sector highly influenced by economic trends, when economy is good, construction is at the top of industries; when the economy is not doing well construction shrinks promptly. This behaviour is a consequence of the capital intensive needs of construction and the inherent risk of the industry. In terms of insurance, when the market is weak, underground construction clients are the last priority for insurance in the construction sector. In order to explain the global environment that affects the availability of tunnelling insurance in Canada at a local level, the following section presents the environment behind these new trends.

3.4.1 Insurance Capacity

During 2002 the capacity of European reinsurance for tunnelling projects shrank, some reinsurers left the market entirely. The cyclic behaviour of insurance capacity in the construction industry is represented in Figure 3-6. The upper curve represents the fluctuation of insurance capacity for the construction industry in general and the lower for the tunnelling industry. The scenario depicted was found in Europe and the most stringent measures in the UK. As can be observed, the behaviours are parallel, having tunnelling higher constraints. The availability of capacity is reflected by a softening in underwriters' requirements and affordable premium price, whereas in hard times the opposite is experienced. As tunnelling construction normally is capital intensive and the possible maximum loss can be many times the cost of the actual construction, the capacity required for tunnelling makes it difficult to get insurance during hard times or even in some cases, capacity is not available (as in 2002). When capacity is scarce, the insurance market tends to move to less risky sectors, in the figure the construction industry curve would be preferred in hard times, but in reality even construction has difficulties as the insurance market move to safer accounts.

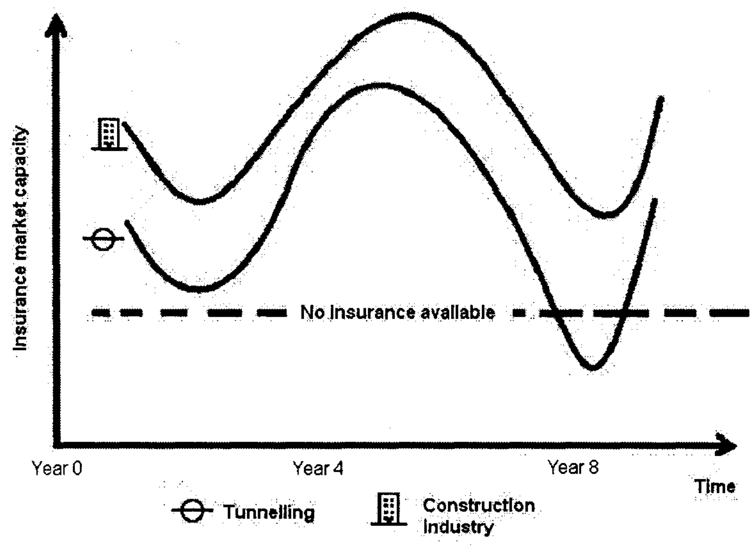

Figure 3-6 Cyclic behaviour of insurance capacity in the construction and tunnelling industries

The capacity of the Canadian market is improving with Lloyd's through Canadian brokers. Other companies are expanding into Canada offering mainly financial services (JLT 2005). The world insurance environment of the construction industry after September 2001 through September 2002, presented the following factors summarized by Jardine Lloyd Thompson Group plc. (JLT 2002):

Coverage restrictions; Coverage on all of the construction classes of business (i.e. Construction All Risks, Erection All Risks, Third Party Liability and Professional Indemnity) were significantly reduced over the course of 2001. Many of the coverage extensions, such as 'Increased Cost of Working' and 'Guarantee Maintenance', that were readily available were completely withdrawn.

Pricing and increase of rates; Continual rate increase of hundreds of percentages were recorded in the market. This trend is expected to continue. Particular types of exposure experienced a heavy increase in rates. The trend was driven mainly by the lack of available capacity, resulting from underwriters either withdrawing from the area or only being prepared to write excess of a high deductible. These characteristics are still present in the tunnelling industry.

Capacity availability; The lack of available capacity proved to be a significant factor in the construction market. A number of the most important carriers within the market, both in Lloyd's and in the London company market were experiencing severe restrictions in their ability to accept construction risks. This situation is improving as more capacity is gained. Some carriers underestimated the magnitude of the increase of rates, resulting in them exceeding their premium income limits. Other carriers decided to withdraw from construction as a class of business and instead allocating their capital to the underwriting of more profitable accounts.

Capacity for high risk exposures; The market's appetite for long-term projects involving material damage and/or professional indemnity, delay in start up and certain other hazardous activities like tunnelling, shrank. The availability of these specialized products at that time was denied. The overall situation and the insurance influence lead to a reduction of the insurance market, tunnelling construction particularly being affected. This was the environment that boosted the influence of reinsurers to a point that after putting a stop to insuring tunnelling projects in 2003 left the field to them to dictate the conditions on insurance terms.

Another study on the insurance conditions in the UK (Mbouga, 2002) indicated that contractors were facing not only an increase in the direct cost of insurance premiums but an increase in indirect costs due to the need of loss prevention and resulting increase in contingency levels. Another important consequence is the increasing restrictive conditions on insurance coverage. This is more stringent in the case of tunnelling, rail, and mining works. Roofers and scaffolders experienced similar conditions. The position of the insurance industry since has recommended actions to the construction industry in terms of loss prevention and contingencies. These measures provide means to reduce insurance exposure to small claims that can be numerous and to lower the overall figure of premium rates.

The experience in the UK shows that the construction industry was faced with a substantial increase in insurance premiums with very short notice (Mbugua, 2002). Insurers did not make a noticeable consideration between "good" and "bad" contractors in terms of their experience with past claims, RM practices, etc. The insurance sector considered that brokers have the opportunity to make these factors work in terms of insurance costs. This is an opportunity found in Canada where specialized tunnelling brokers can find a niche of work at the national level.

Comparing the Canadian and UK tunnelling markets based on the number of consultants and contractors, the UK has a ratio of seven consultants to one Canadian while contractors have a 4 to 1 ratio (T&TI, 2005). These ratios may be related to the fact that many cities in Canada still have the option of going above ground for transportation. Options such as the Light Rail Transit (LRT) system in Edmonton exist where the vast majority of the network is planned above ground unlike European cities where sometimes underground space is the only available option.

Hong Kong has experienced capacity restrictions from the reinsurance industry and the increasing difficulty to get insurance to provide cover for heavy civil engineering projects. This scenario is replicated in Canada and elsewhere. The reaction in Hong Kong has been the specialization of tunnelling insurance brokers to get the coverage needed for the industry at a reasonable price (Chung D; 2004). This practice would greatly improve the tunnelling and insurance industries in Canada.

A recent document from Munich Re (2004), one of the major reinsurance companies in the world operating in Canada recommends these specific actions to be followed by their underwriters:

- Apply the Tunnelling Code of Practice developed for the UK to international risks; the insured agrees to work closely with the insurers
- Decline extensions of cover such as "additional cost of working" or "un built portion" or offer these on a strictly limited basis
- Treat design covers with caution
- Grant "design and delay in start-up" (DSU) cover extremely restrictively or only after a detailed risk analysis
- Carry out detailed preservation of evidence measures on surrounding structures before construction begins (e.g. check whether buildings nearby already have cracks)
- Monitor construction work

3.4.2 World insurance environment

The world insurance environment is directly influenced by world natural disasters. Table 3-1 presents the top most costly insurance losses from 1970 to 2004 (JTL, 2005). As of today the only man made disaster in 2001 accounts for the biggest loss in the insurance market, more than US$42 billion. Figure 3-7 presents this data compared with the Non-Marine P&C price index data from 1987 to 2004 (CBSL 2004). The effect of the insurance loss can be seen in particular in the price index, as a result of the 1994 and 2001 events and the consequent index peaks. A cyclical behaviour can be observed from the two series of data, although price index depends on other factors such as global markets for example.

3.4.3 Canadian insurance market

The cyclic behaviour of P&C insurance in Canada is composed of three to four years of weak market followed for a similar length of time of improvement. The period composed from 1998 to 2002 (Figure 3-8) was a long cycle where the Return on Equity was below the industry's average (by 10%).

Table 3-1 Top 10 most costly insurance losses from 1970 to 2004 indexed from 2002 to 2004 using IMF world average core inflation rates

Insurance losses US$bn indexed to 2004	Date	Event	Location
42	11 Sep 01	Terrorist attack	US
21.4	23 Aug 92	Hurricane Andrew	US, Bahamas
17.8	17 Jan 94	Northridge earthquake	US
11	16 Sep 04	Hurricane Ivan	US
7.8	27 Sep 91	Typhoon Mireille	Japan
7	13 Aug 04	Hurricane Charley	US
6.6	25 Jan 90	Winterstorm Daria France,	UK
6.6	25 Dec 99	Winterstorm Lothar France,	Switzerland
6.4	15 Sep 89	Hurricane Hugo Puerto Rico,	US
4.9	15 Oct 87	Storm and floods France,	UK

Source: Swiss Re; Insurance Information Institute updated by JLT. (JTL 2005)

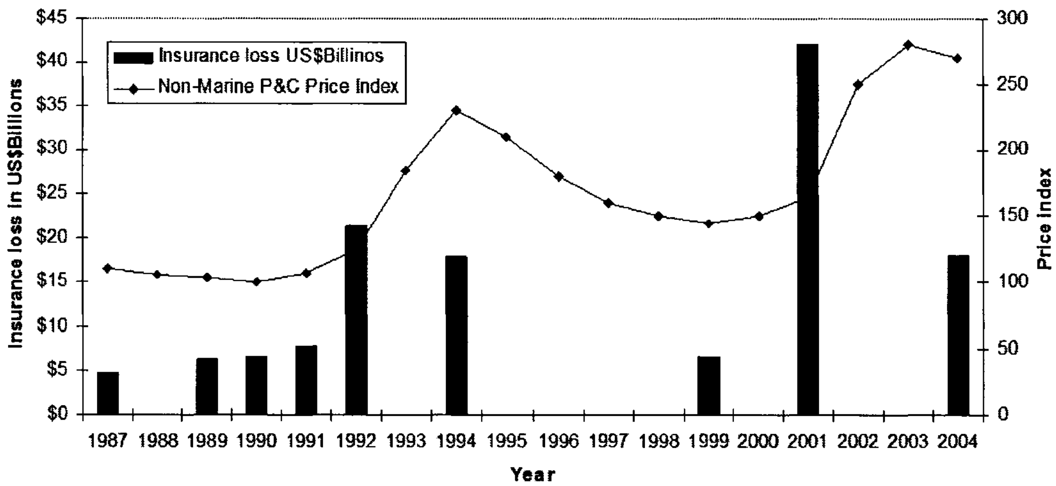

Figure 3-7 Cyclic behaviour of P&C price index vs world insurance losses

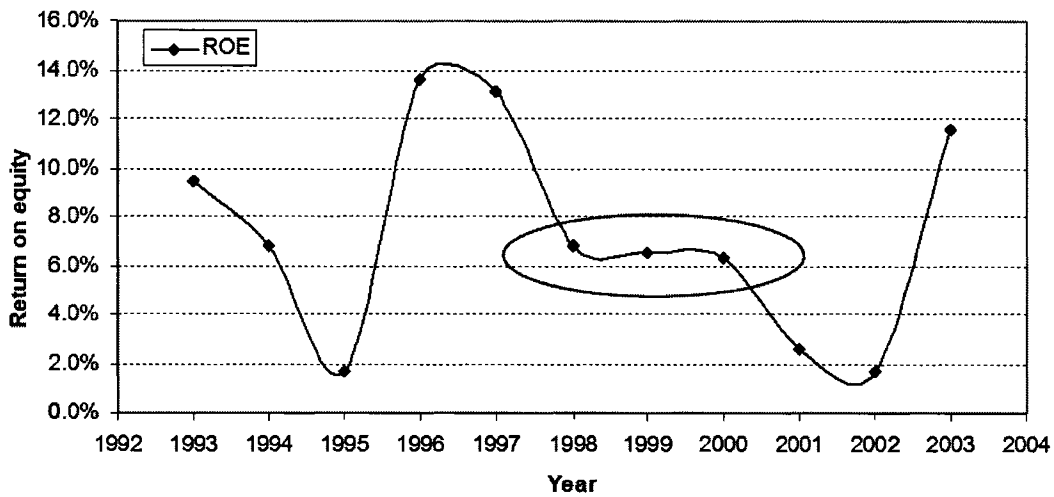

Figure 3-8 Return on equity from insurance (Source: IBC 2004)

The deficit generated in earnings is reflected in the price of insurance, where the industry is looking for returns above average to compensate the numbers generated from 1998 to 2002. The market became weaker after September of 2001. The price of insurance raised in a proportion that allowed the Canadian market to reach in 2003 (Figure 3-9) a positive balance of claims vs net premiums for the first time in the last ten years (IBC 2004).

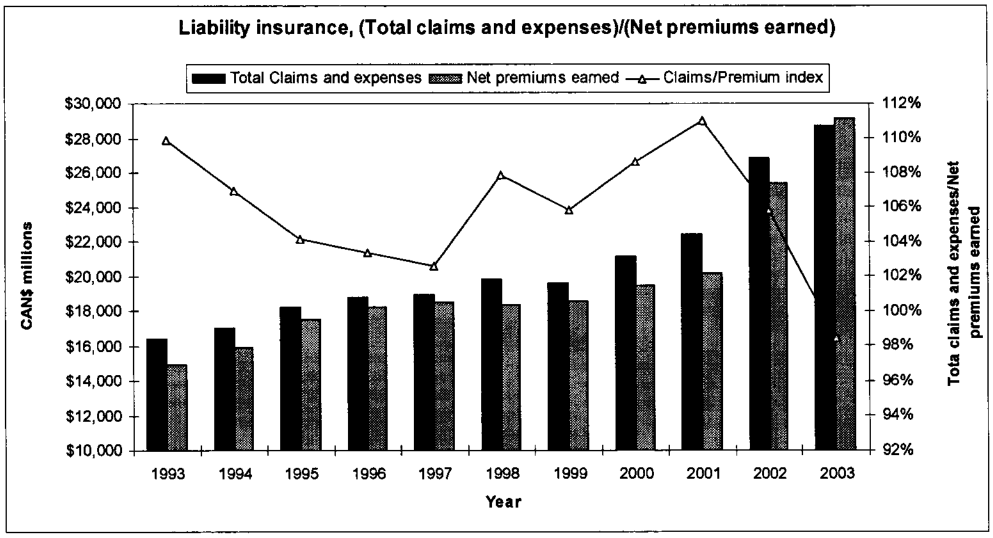

Figure 3-9 Liability insurance, total claims and expenses/ net premiums earned (Source: IBC 2004)

Although these numbers reflect an improvement in the financial standing of the insurance industry, firms must retain sufficient equity to cover, by a certain percentage, their premium income in the event of a company going bankrupt. Equity is to protect the clients for return premiums (Peters, 2005). These regulations are policed by The Superintendent of Financial Institutions in Ottawa. In the case that a company does not have sufficient resources, it has to reduce its market value and would be unable to write new accounts therefore its equity has to grow from net profits. Looking over the industry the positive numbers from 2003 are barely 1.6% (100%-98.4%). The environment in the industry is still tough as these are very fragile numbers where low scale events could create some undesirable consequences in the market as has happened before (see Figure 3-10).

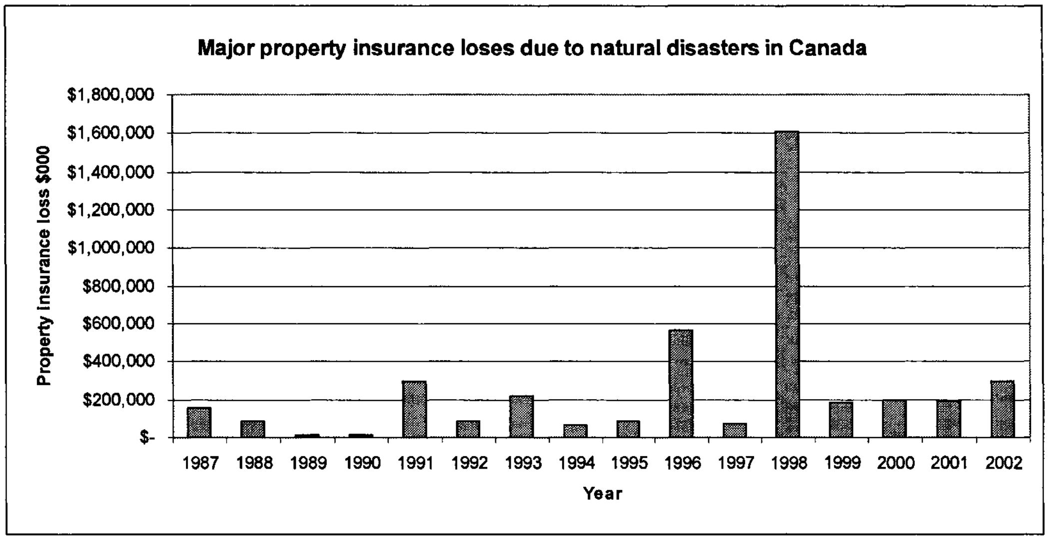

Figure 3-10 Major property insurance losses due to natural disasters in Canada (Source Data IBC, 2004)

The consequences of the international and domestic markets described above affect the Canadian tunnelling industry not only in the cost of insurance but also in its availability as the insurance sector moves to less risky accounts. The Canadian Tunnelling industry is likely to re-evaluate its risk exposures and alternatives to transfer risk as it has happened in Europe and in the UK. An example of this situation is the SLRT extension in Edmonton that was denied insurance cover by a major European reinsurer because tunnelling was no longer in its portfolio. Eventually this project received coverage with another insurance company.

Increase in premium rates have been experienced in the Canadian market since 1999. The natural trend for the tunnelling industry would be to increase the retention of risk and measures for its reduction and management in order to lower the cost of premiums. An example of this practice is being done by the City of Edmonton (Tan, 2005) in providing adequate insurance for a tunnelling project outside the City. The high premium cost of separate insurance for the TBM lead to further re-evaluation of the insurance strategy in order to obtain a balance between risk exposure and premium costs. Another example of "owner-controlled insurance program" as insurance reduction strategy was used at the Central Artery/Tunnel Project in Boston, USA where insurance cost reduction accounted for US$500 million of savings. This approach avoided the need for commercial insurance for the contractor or consultant. A successful safety record provided the elimination of overlapping coverage facilitating economies of scale to the owner (Bechtel et al. 2003).

Another motivation for the use of systematic RM is the implementation of higher deductibles and exclusions of coverage from insurers in order to reduce the cost of premiums.

3.5 Discussion and Findings

Insuring tunnelling projects has become a challenging process as the performance of the construction industry in general has shown a high rate of projects exceeding planned budgets (52%) and schedules (58%). In particular this is true in the tunnelling industry where the insurance sector has reacted drastically after experiencing losses for up to 500% against premiums earned in 2001. After the suspension of insurance coverage for tunnelling in the UK, the world tunnelling industry has experienced a clear instruction from the insurance sector: an auditable RM System might not change premium price but may be the only option if insurance coverage is to be obtained. Moreover, the insurance industry is limiting coverage extensively. Looking into the global and local scenario outlined in this chapter it can be seen that the present environment urges the practice of structured and auditable RM. The benefits for owners and contractors are to gain more control over their projects, retain and control more risks, get insurance only for those risk that have minimal predictability and can have catastrophic consequences, but most importantly, to maintain business operation.

The vast majority (84%) of losses in soft ground tunnelling are related to events of monetary consequences lower than €2 million. When catastrophic consequences happen most of the time they are not "single cause events" but arise from human error in the from of mismanagement or incompetence. Moreover, compared with general construction where 40% of latent defects in buildings are design-related and 40% are workmanship-related as well as 80% of maintenance costs are built in during the first

20% of the design process, it is evident that there is plenty of room for improvement through the implementation of systematic RM practices.

The released "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" is to be implemented not only in Europe but internationally (Thomas, 2003). Some Canadian projects have been experiencing unsuccessful insurance coverage when European insurers are involved. In fact some European insurers are already requiring compliance with the code for international tunnelling projects (Munich Re, 2004). It was found in the interviews conducted in this research that there is limited knowledge of the Code of Practice in the Canadian insurance and Tunnelling industries. It was confirmed directly at European headquarters of a major reinsurance company that compliance with the Code of Practice is being required in Canada as a policy more than as a directive. It is perceived that its full compliance in Canada is a matter of time. The Code of Practice makes allusion to many different Project Management practices recommendations and documentation that the Canadian tunnelling industry does not consistently conduct, leaving a gap to be addressed in the immediate future. Some people in the tunnelling industry perceive the Code of Practice as an excuse for Insurers to not pay. Whether this statement is generalized or not this perception towards RM procedures can have organizational obstacles if there is unclear communication of the legitimate benefits to the parties involved.

The data presented here reflects an inconsistent approach to RM of the tunnelling industry. The need for systematic RM practices is evident as Insurance costs and requirements raise or in some cases coverage is conditioned on compliance. The implementation of best practices of systematic RM is the highly recommended. Tunnelling construction has a long tradition of dealing with uncertainty as RM is inherent to the practice. The high cost and requirements of insurance represents an incentive to improve the focus of RM and direct resources not to high premium costs but better planning, exploration, design, and construction practices and perceive insurance as a last resource. Construction program is an important source of risk when schedules are not construction driven, forcing contractors to rush generating avoidable risks. Owners should be aware of the high potential savings of investing up front in systematic RM practices.

In Canada major international reinsurance companies dominate the market for tunnelling and other high risk construction projects and policy wordings follow the European coverage models. The top five reinsurance companies in Canada account for 48% of the total net written premium (DOFC, 1999); all of them are members of the Association of British Insurers (ABI). 75% of the members of the ABI that sponsor the Code of Practice are not UK based but European and 85% have operations in Canada (BTS and ABI, 2003). These numbers explain why Canadian projects have already been affected by European insurance trends.

Regarding the corporate practice of brokers and underwriters in providing insurance for tunnelling projects it was found that the approach is more qualitative than quantitative mainly due to the lack of statistical data as there is no Canadian catalogue of losses available. On the other hand insurance companies apply different criteria towards the evaluation of premium costs where the final number is set as a proportion of total projects' cost with not much consideration of loss prevention measures. There are different underwriting criteria within the country as insurance companies may decline insurance in one office but may provide insurance in their principal office. The former could be due to different levels of authority within an insurance company that brokers should recognize in order to provide optimum service.

According to the interviewees, tunnelling projects are likely to find a limited number of underwriters where inflexibility dictated from global headquarters can be a serious obstacle. The trend in business is that insurance products are shifting to more profitable non construction related products where reinsurance companies are primarily looking for means to find the best income from investments. The re-evaluation of risk appetite is shifting the scope of coverage in civil works where there are limits now that were not set in the past. This situation is affecting tunnelling works with the Code of Practice in the UK and in Canada, where some reinsurance does not have tunnelling in their portfolio anymore.

Insurance capacity behaves in cycles where availability for tunnelling projects can reach hard times reflected in coverage restrictions, pricing, increase of rates and capacity unavailability for high risk exposures. Since 1999 the global insurance market was experiencing capacity reduction that was acute after the 9/11 events in 2001. Coverage on all of the construction classes of business were significantly reduced. This situation remains today where higher deductibles apply. The effect in Canada was the increase of insurance prices that allowed a positive balance in 2003 for the first time in the past 10 years. The overall situation and the insurance influence lead to a reduction of the insurance market, where tunnelling construction was particularly affected. This was the environment that boosted the influence of reinsurers to a point that, after putting a stop in insuring tunnelling projects in 2001 (Anderson, 2002), is allowing them too, to dictate the conditions on insurance terms.

3.6 Conclusions

The appraisal of tunnelling projects to determine insurance premium costs is based on qualitative evaluations where two main variables dominate: the technical characteristics of the projects and most importantly the people involved. The premiums are calculated as a fraction of the total cost of the project where the criteria differ among insurance companies, in some cases, within the same company.

From the products offered by Insurance, Wrap-up represents the recommended centralized insurance loss control program that offers in most cases the best economic advantages. Some companies are not specialized in all areas and some coverage need to be found elsewhere, like professional liability insurance. Wrap up insurance represents a potential savings option when brokers are able to represent accurately the risks involved in the project when loss prevention is handled by RM procedures. It is relevant to note that it was found that there is limited knowledge of the Code of Practice in the Canadian insurance industry as well as in the Tunnelling industry.

Risk Management maturity in tunnelling projects depends on the awareness of stakeholders of the risks involved and the capacity to handle them. Risk financing options should be optimized as RM maturity of the organization is gained. Contractors should inform brokers when positive standing is present in terms of their experience with past claims, RM practices, etc. Brokers have the opportunity to make these factors worth in terms of insurance costs. There is an opportunity in Canada where specialized tunnelling brokers can find a niche of work at a national level.

The compliance to auditable RM practices in Canada for insurance purposes will occur in a matter of time. Increase in premium rates have been experienced in the Canadian market since 1999. The natural trend for the tunnelling industry is to increase retention of risk and measures for its reduction and management in order to lower the cost of premiums. The practice of systematic RM is highly recommended.

Owners should be aware that soil investigation is one of the main variables that influence the bottom line of underground construction. Owners are the driving force in establishing contract terms, the inclusion of Geotechnical Baseline Report and appointment of Dispute Review Boards are recommended. Although currently is not an insurance requirement, underwriters tend to favour projects with GBR and DRB.

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Chapter 4 Risk Management in Tunnelling Projects: State of Practice

4.1 Introduction

Geotechnical Engineering relies heavily in observation and interpretation of phenomena from an empiricist perspective due to the complexity of the underground in comparison with other well-known materials. The heterogeneity of the underground media makes it difficult to predict leaving plenty of room for uncertainty. There would not be a need to deal with this situation if the development of cities did not heavily rely in the need of tunnels for: water supplies, sanitary swage, transportation and other utilities. Figure 4-1 makes evident the need for tunnels and its use in Canada's infrastructure.

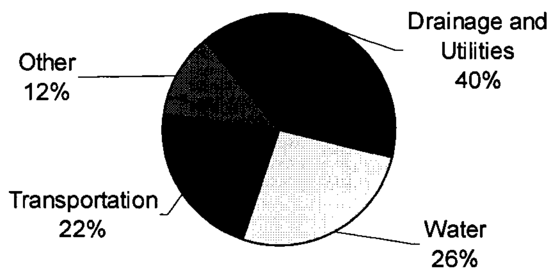

Figure 4-1 Use of tunnels in municipal infrastructures in Canada (Source: Lukajic, 2003)

An example of the important role of tunnels in municipal infrastructure is the network of the City of Edmonton, in Alberta, with over 100 km of tunnels for storm, combined and sanitary trunks constructed since 1913, tunnels of different diameters, construction methods and lining systems (Tzang, 2004; Bobey et al. 2004). The City's drainage infrastructure alone represents 45% of the total replacement value of the City's infrastructure, according to its Office of Infrastructure (2002) (Figure 4-2).

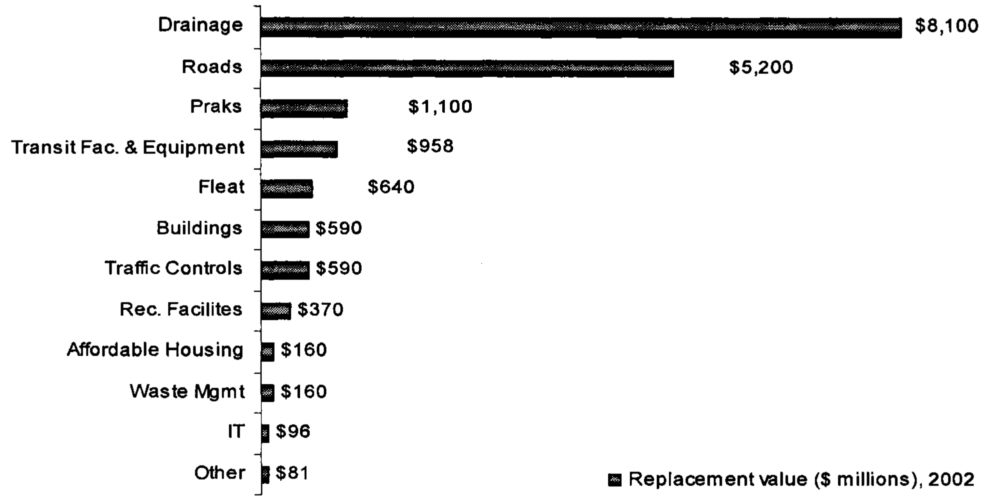

Figure 4-2 City of Edmonton, Infrastructure replacement value (Data: City of Edmonton, 2002)

Tunnel construction, most of the time under dense populated areas, involves high levels of risk, particularly to third parties, where the impact towards surface properties and the environment can transform a successful project in to a long list of failures. Although many tunnelling failures are related to unforeseen ground conditions, it is the mismanagement of risk that affect projects going overrun and over schedule. These factors have become characteristic in tunnelling projects around the world. Flyvbjerg et, al. (2002) found that from a study of 33 tunnels and bridges, the actual cost of projects were in average 34% higher than estimated. As the tunnelling industry deals with high levels of uncertainty, owners require contractors to have insurance to cover the unexpected. The world tunnelling industry has experienced in the last years a series of unfortunate events that have raised the issue from insurance companies and underwriters about the state of practice of Risk Management (RM) in tunnelling projects. Since 1999 reinsurance companies in the UK faced losses that by 2001 escalated to a loss ratio of 500% in tunnelling projects around the world (Woods, 2002). Important financial groups like Royal Sun Alliance and AXA, left the tunnelling market as a consequence of this trend in the industry. In 2001 the reinsurance sector in the UK took the stand to stop insuring tunnelling projects (Anderson, 2002). Recent years have seen increasing popularity of compliance with RM guidelines, this is the case of all Trans-European transport network tunnels, and The European Parliament (2004) is requiring the submission of a common and well-defined risk analysis methodology among participating counties. Since 2003, The Association of British Insurers (ABI) have required the implementation of auditable RM practices for tunnelling projects jointly with the British Tunnelling Society through "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" (BTS and ABI, 2003), for which an international version is being written. The objective of the insurers is the extension of RM to their clients. The Code intends to provide a common language between owners and underwriters abut the risk involved in each project. The result should reduce the probability of an underwriter to pay for the unforeseen. The Code of Practice is now mandatory in the UK for insurance purposes.

4.1.1 Industry's definition of Risk Management

Dealing with underground construction requires accepting that uncertainty will exist even in the most controlled of the circumstances (Muir Wood, 1990). Traditionally, Risk Management in tunnelling construction has followed Terzaghi's school, *the Observational Method (OM)* (Peck, 1969). The method considers a design for the most likely scenario that can accommodate changes if necessary if unfavourable conditions arise in order to provide the most cost effective solution. The OM's success is dependent on the iterative nature of the process (see Figure 4-3).

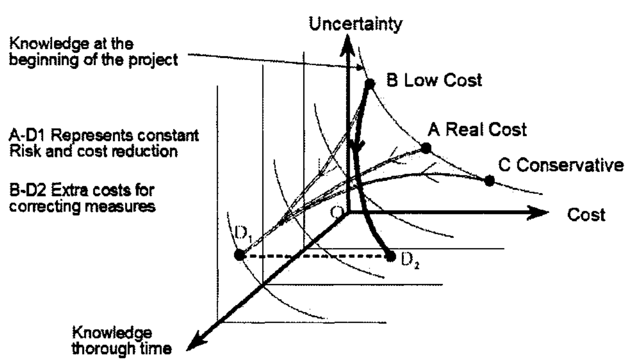

Figure 4-3 Observational Method in its uncertainty, cost and time dimensions (adapted from Powderham, 1998)

The essence of the observational method relies in permanent monitoring and adapting the design thorough construction in order to provide the most cost effective solution. From Figure 4- 3, option C would start in a conservative position that can be modified through construction providing savings without compromising the construction. For a project starting in B, the observational Method helps realize when a design needs to be modified in order to correct undesirable results. This practice is particularly suited for the Sequential Excavation Method (SEM-NATM). When a deterministic design is applied, tolerances and adaptability is constrained which reduces Observational Method's applicability. In the case of TBM driven tunnels, where the excavation method is not suitable for modification, the OM focuses on instrumentation to identify trigger levels for risk response. For any tunnelling method, underground design not only requires a factor of safety, but to understand the degree of variation in the calculations based on the uncertainty of the data. This is the mind set needed in tunnelling and promoted by Terzaghi's OM approach. There are many other sources of risk in tunnelling projects, not related to the Observational Method, this is where the use of systematic RM practices helps achieve more realistic budgets and schedules.

Risk Management is not a new discipline and it is practiced in Canada in tunnelling projects but in light of international trend of auditable RM practices there are questions not yet answered: at what extent? How big is the gap between the RM practices among the tunnelling community and these emerging international codes? This chapter discusses the current practice of RM in Tunnelling projects within Canada. The findings presented herein are intended to serve the Canadian Tunnelling Industry as a measure of where it stands today and provide opportunities for improvement.

4.2 Objectives

Analyze the state of practice of Risk Management of the Canadian Tunnelling Industry through the:

- identification of the most common risk analysis tools and techniques in the identification and probability estimation of risks
- identification of risk management practices more frequently used in the monitoring and control of risks
- identification practitioners' perception of the advantages and difficulties in adopting systematic risk management procedures
- identification of the most valuable project management practices in tunnelling
- identification of human errors that most frequently affect tunnelling projects, in the geotechnical, design and construction phases
- gathering and analysis of recent tunnelling projects to identify the most frequent ground conditions that affect the completion of tunnelling projects within

schedule and budget and the most common risk reduction measures used to minimize the impact of difficult or unforeseen ground conditions

The findings would serve the Canadian Tunnelling Industry as a measure of where it stands today, provide areas for improvement of current Tunnelling and Insurance industry guidelines.

4.3 Methodology

The research gathered practitioner opinion in a case study approach (Bonano and Apostolakis, 1991; Chhibber et al 1992; Hora, S. C. and R. L. Iman. 1989; Keeney and von Winterfeldt, 1991) through a questionnaire on the current practice of RM in tunnelling projects within Canada. It was distributed to executives, directors and members of the Tunnelling Association of Canada (TAC) and some international practitioners in the following groups: owners, project managers, geotechnical consultants, designers and contractors. Due to privacy issues, it was not possible to get access to TAC's members list. The questionnaire was distributed via email thanks to TAC's secretary. The number of questionnaires sent is unknown. Twenty three responses were received. Extensive literature review and input from practitioners in tunnelling design, construction and RM, with over 20 years of experience, gave base to the questions. The questionnaire (see Appendix A) gathered information in the following categories:

- Practitioner's experience
- Risk Management practices
- Human error (in geotechnical, design and construction phases)
- Most recent tunnelling projects' information
- Practitioner's comments

The practitioner's experience section provided information in their profiles. The Risk Management practices section gathered information on tools, techniques and control practices as well as benefits and obstacles for its practice. As the issue of human error frequently triggers adverse outcomes when dealing with difficult ground conditions, either known or unforeseen, one section of the questionnaire is devoted to this topic. Information on the most recent tunnels where practitioners have participated provides information on the management of difficult and unforeseen ground conditions as well as providing update to the Canadian tunnelling catalogue developed by Lukajic (2004). Finally, some practitioners' comments are included. The scope of the work is limited to the practice of RM for Projects and in particular, to technical risks dealing with difficult ground conditions. The results presented reflect the practitioners' experience elicited on the specific issues.

4.4 Risk Management in Tunnelling Projects Practitioner's Opinion Results

4.4.1 Practitioners' profile and aggregation of opinion

The criteria for practitioners' selection considered demonstrated hands-on experience in consulting or managing of tunnelling projects. Practitioners' were versatile enough to address issues related to different elements of a project and represented a wide variety of experiences regarding tunnelling phases, methods and uses. The contact of practitioners was possible through the Tunnelling Association of Canada (TAC), 23 responded, two questionnaires were discarded, one had an electronic error and the second was not used, as the experience was not representative. The number of practitioners responding to the questionnaire represents a growing participation according to previous questionnaires sponsored by the International Tunnelling Association and the Canadian Tunnelling Association (Parker, 2004) and (Lukijak, 2004). Based on the years of experience of practitioners, the sample was symmetric without the lowest and highest values, with a mean and mode in 20 years (Figure 4-4), the results were evaluated in three groups: 1) all practitioners, 2) practitioners with up to 20 years and 3) practitioners with 20 years or more.

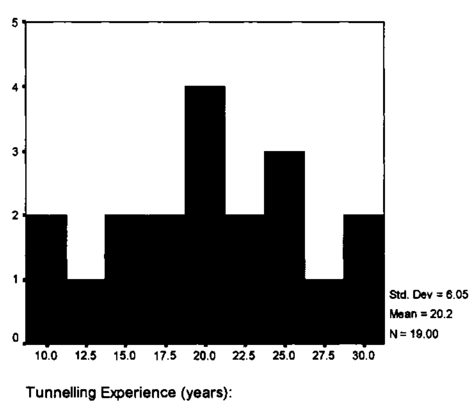

Figure 4-4 Histogram of practitioners' years of experience

The results in general are from the group of all respondents, when results from the younger and senior groups differed, a comparison is commented.

4.4.2 General respondent's information

Figure 4-5 shows the distribution of years of experience of the group where 1/3 has over 25 years of experience in tunnelling projects. Only one of the participants had less than ten years of experience in tunnelling but has practiced RM in the construction industry for the past 10 years.

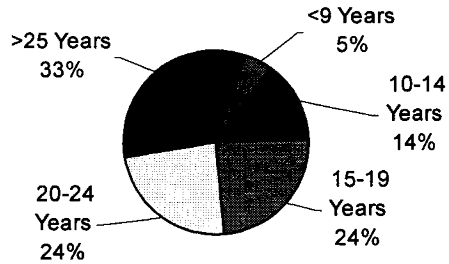

Figure 4-5 Practitioners years of experience

The Officers and Directors of the Tunnelling Association of Canada participated with 89% of them responding to the questionnaire. From all the group of practitioner the majority were from the Ontario region (43%) and 14% have based operations outside Canada. The complete distribution appears in Figure 4-6.

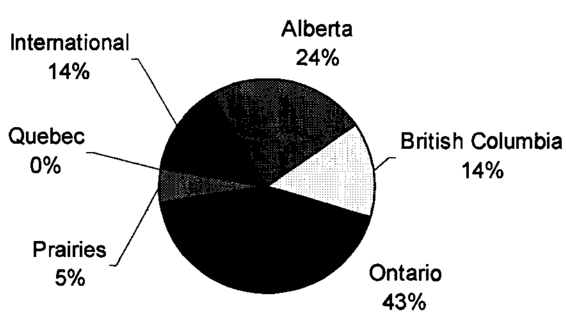

Figure 4-6 Practitioners according to TAC's region

From the tunnelling projects where experts have worked in the past five years, 42% were outside Canada indicating a strong international activity among practitioners (Figure 4-7).

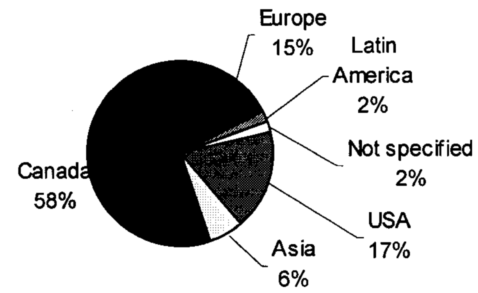

Figure 4-7 World regions where practitioners have worked in the last five years

Practitioners' working practice concentrates in three cities: Toronto, Edmonton and Vancouver Figure 4-8. Toronto and Edmonton share the same geological formation finding similar stratification despite the geographical distance among them. Both cities are below the Canadian Shield in the hydrocarbons region. Their common ground conditions and problems include: wet flowing sand within till and pre-glacial deposits, hard cemented sandstone stringers, cobbles and boulders in till deposits and contaminated soils, additional to Edmonton are risks related to abandoned coalmines and tunnel cover issues associated with river crossings (Bobey et al, 2004). Vancouver underground, in the coastal mountains of the cordilleran region is composed of sedimentary rock and in general, the Rocky Mountains and the British Columbia plateau are rock. These factors are reflected in the different tunnelling methods and lengths of tunnels indicated by the practitioners. The method more used is the TBM open face, suitable for Edmonton and Toronto's ground conditions.

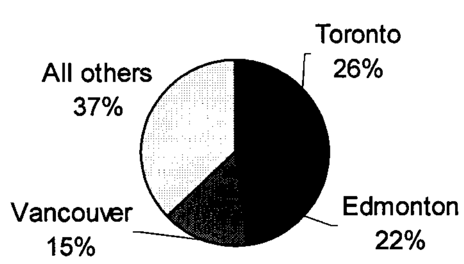

Figure 4-8 Canadian cities where practitioners have worked in the last five years

The number of tunnels in which practitioners had participated sum to 310 (Figure 4-9). Other tunnelling projects include: 17 Micro-tunnelling and Pipe Jacking, 21 km, 11 inspection and maintenance, 18 km. Additional were 3 projects, 5 km long that were not specified regarding construction method. The number of tunnels (310) should be read with caution; it represents the cumulative individual experience of practitioners. If two practitioners participated in the same tunnel, this tunnel is counted twice. This information is resented to support the practitioners' experience and knowledge in the Canadian tunnelling practice.

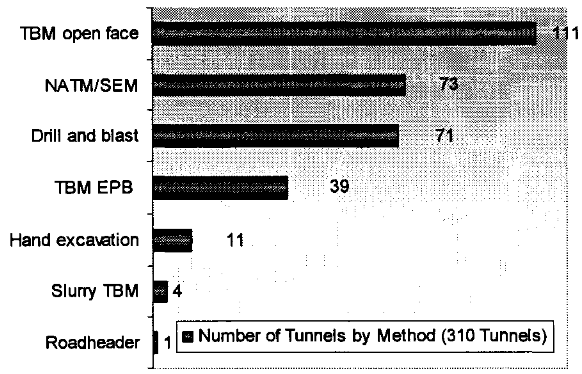

Figure 4-9 Total number of tunnels where practitioners worked by tunnelling method (310 tunnels)

Figure 4-10 presents the total length of tunnels by method where practitioners have participated accounting for 934 km. From the length of tunnels perspective, 43% of practitioner's experience is in TBM open face tunnels followed by TBM EPB.

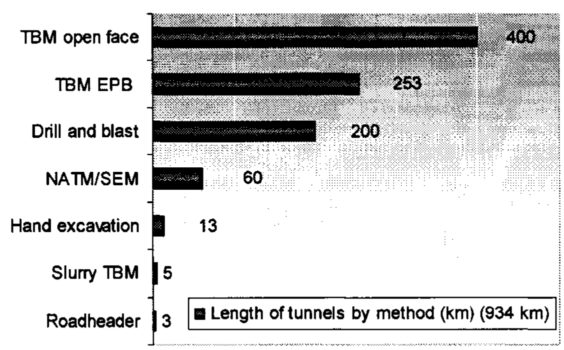

Figure 4-10 Cumulative length of tunnels in km where practitioners had worked by tunnelling method (934 km)

Figure 4-11 presents the ratio of length of tunnels in km and the number of tunnels where practitioners' have participated. TBM EPB has the highest ratio among tunnelling methods, this is likely to be due to the density of Canadian cities in transported soils (glacial till), as well as the safety and mechanized construction advantages of the method.

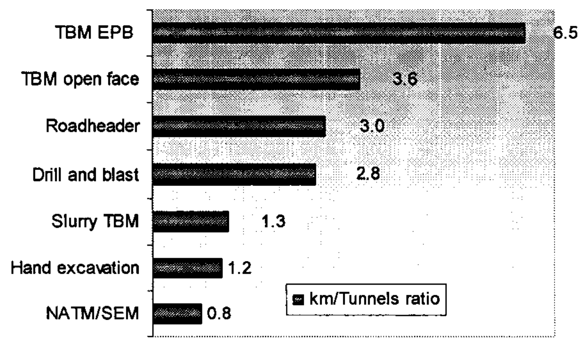

Figure 4-11 km/Tunnels ratio by construction method

The role of practitioners in their most recent projects involved: Contractors, Owners, Geotechnical Engineers, Design Consultants and Project Managers. When practitioners indicated two roles in Figure 4-12, they appear in the group they primarily belong (Owner, Geotechnical, Designer consultants or contractors). The percentage of Project Managers (24%) is composed for those identified with that position only. When pertinent, these different groups were analyzed separately as in the case of rank tables, when differences were found for a Designer that considered one item as the least important, while for the Project Manager the same item was the most important, both opinions related to the same project. When differences of opinion occurred from the role perspectives, these are commented.

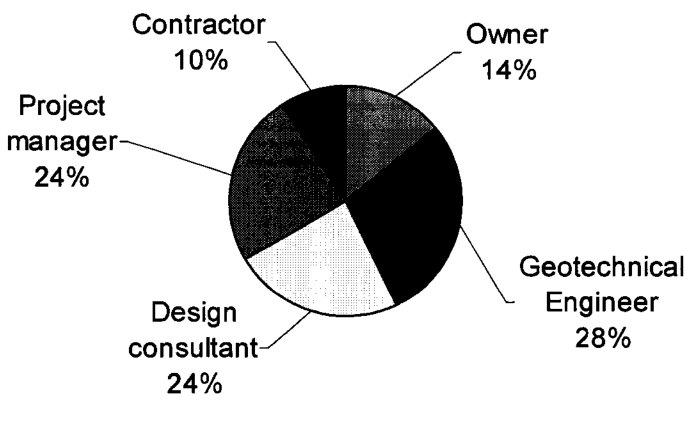

Figure 4-12 Role in most recent project

The majority of tunnels where practitioners participated in the last five years are for transportation purposes (38%), followed by water (33%). Figure 4-13 presents the distribution of the use of recent practitioners' projects.

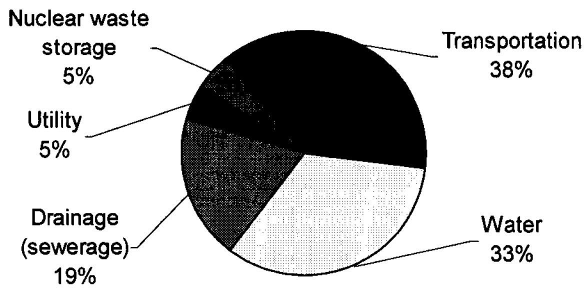

Figure 4-13 Use of most recent tunnel

4.5 Risk Management practices

The practitioners were asked about their practice on the different elements of RM to evaluate the depth at which this practice is performed, and obtain a snapshot of the Canadian Tunnelling Industry that could be compared in the future once RM procedures becomes a requirement as explained before. Risk Management practices were compared and measured versus other Project Management practices to evaluate its relative importance on positive outcomes in tunnelling projects. Following are the questions submitted to practitioners and its outputs.

4.5.1 Does your company conduct formal Risk Management for tunnelling projects?

Practitioners were given a generic definition of Risk Management: "identification and treatment of risks", nothing else was specified as this question was aimed to provide grounds on how practitioners consider their own practice and definition of RM and compare this answer with more detailed questions about tools and techniques used. The ratio of response of RM practitioners was high (Figure 4-14); with almost half of the group (48%) using it sometimes and 49% indicated that they have always used RM. One Practitioners expressed that RM was not considered a specific factor in the projects he was involved, but recognized that RM happened in some way or other, but this practiced was not documented.

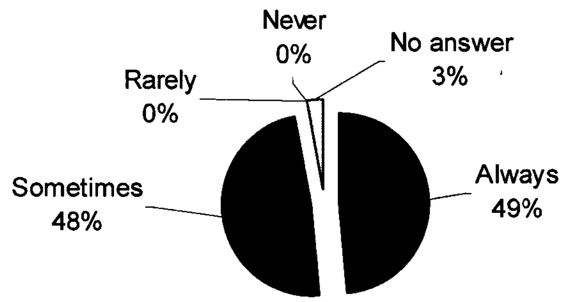

Figure 4-14 Percentage of practitioners' Companies practicing formal Risk Management (identification and treatment of risks)

The average number of years practitioners have practiced RM is 8.2, with the majority (45%) practicing it for 10 years or more. Comparing the groups of RM users with ≤20 and ≥20 years of tunnelling experience the percentages indicated that younger practitioners are using more RM (always 62%, sometimes 38%) than senior practitioners (always 33%, sometimes 67%) reflecting more use of RM practices in recent years (Figure 4-15).

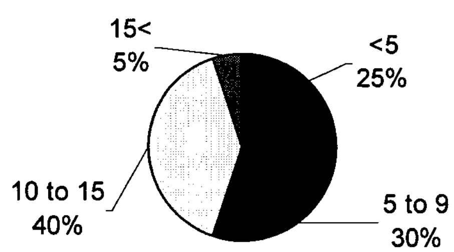

Figure 4-15 Years practicing Risk Management

67% of the group of ≤20 has practiced RM in the last ten years whereas the group of ≥20 has practiced for 2 to 25 with a mode of 5 years. This answer has two modes in 5 and 10 years as reflected in the % ranges from 5 to 9 and 10 to 15 Figure 4-15.

4.5.2 Indicate the type of Risk Identification techniques used

Risk Management can be as good as the risk identification phase. If Risk Management is conducted in a systematic manner but fails to identify any of the major risks of the project, RM fails. Practitioners were given a list of the most frequently used methods appearing in RM literature for projects as well as option for any other not mentioned. The techniques were ranked and the means provided its relative position among them as shown in Figure 4-16. Following there is a brief description of the techniques and comments related to their current practice, its results and Practitioner's comments.

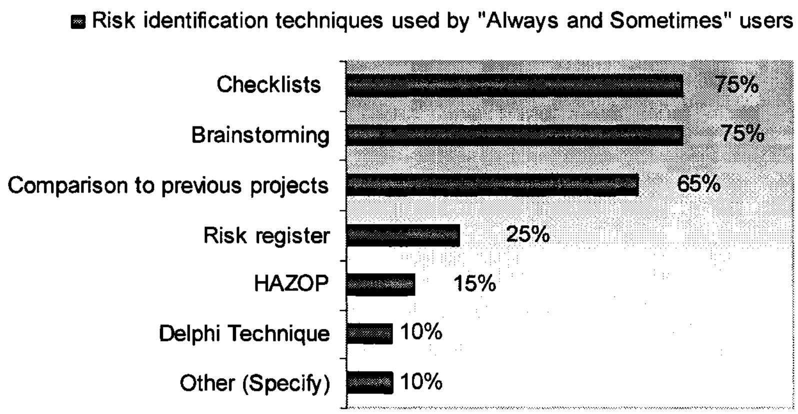

Figure 4-16 Risk identification techniques used

<u>*Checklists:*</u> They are memory aids generally developed and enriched from previous projects. They are a further step of <u>*Prompt lists*</u>, where a list of isolated words is intended to trigger ideas (Appendix B). Checklists present questions related to areas or tasks to be considered like: Are there any risk arising from the new technology of the lining system? Does TBM transportation represent a hazard? The answers provide food for thought for further assessment of risks. Checklists are an excellent trigger of ideas. On the other hand, checklists are limited and some of the important issues for a particular project might not be represented in any question at all, in this situation the new information is introduced to the checklist for future projects.

It was found that the time effort in the use of checklists in the practitioners' experience was variable in the order of hours, having a mode of 4. They are routinely used at all levels and phases, particularly during construction. This technique is one of the most popular with 75% of practitioners using it. This number is consistent with Simister (1994) findings at 76% from practitioner practitioners in different industries but related to projects.

Brainstorming workshops: They are widely used for decision-making, project creation and other applications in many disciplines, in some organizations they are performed together for RM and Value Engineering practices. After the presentation of objectives of the session, a relaxed and open environment is encouraged for the free generation of ideas where no judgment is allowed. In this stage quantity, more than quality is expected. Ideas with potential are further developed in order to be represented clearly at to the extent that risks can be evaluated.

The time effort described by the practitioners varied from few to many hours with a mode of 4. In general the people involved ranged from 6 to 12 including: the owner, geotechnical and design teams, managing consultant (project manager, tunnelling specialist), Contractor (project engineer, site engineer), outside consultants and the facilitator. As one of the practitioners stated this technique is *"very useful to get feedback from outside reviewers"*. Brainstorming is widely practiced in tunnelling with 75% of practitioners using it together with checklists over any other risk identification technique.

Risk register: A key element in the management of risks is the Risk Register. It is a live document through the project that initiates by gathering the information resulting from brainstorming a risk list. Further information of the process is added in order to make the description of risks, its possible consequences and the mitigation measures clear to stakeholders, particularly to those not participating in the brainstorming session. It includes the risks identified not only in the brainstorming session but new risks identified throughout the project. It allows the revision of status of different mitigation measures and the timely release of resources according to mitigation results. The minimum information a risk register should include is: risk's identifier or ID, risk's name, assessment in likelihood and impact (qualitative or quantitative), risk's owner, mitigation tasks, control tasks, and the date for review. Impact assessment can further be subdivided in different impact areas such as: safety, cost, time, quality, performance, etc. A Risk Register add-inn for commercial spreadsheet software is proposed by Hall et al. (2001) among many others. The adequate storage of lessons learned from past projects should be considered as part of RM implementation where the Risk Register can be the main source of information of a database. The use of databases for knowledge management, are already available to speed up the process of implementation (Tah and Carr, 2001).

The practitioners interviewed indicated the time to develop the Risk Register in its first version to be used and updated throughout the project, the mode of the time effort was 8 hrs. One of the practitioners pointed out: *"The risks have to be identified and "developed", each tunnel project is unique, a list of risk is never complete".* A risk register is a living document that plays a major role when claims arise, facilitating agreement in contractual relationships. It is the cornerstone for knowledge building in terms of RM for future projects. Information gathered at the end of the project (close down information) and the effectiveness of the methods used should be captured in the risk register for the optimization of measures in future projects. The Risk Register is the single most important RM communication tool. The results from practitioners showed that the use of Risk Registers has a low percentage, 25%, indicating a surprisingly low use. This practice is likely to change as new regulations and audit practices are introduced for tunnelling insurance purposes where the Risk Register is the first document to be audited (BTS and ABI, 2003).

Comparison with previous projects: Projects should follow a standard way for recording basic information in order to be able to transfer knowledge from project to project efficiently. Risk descriptions and elements to classify them in order to link common elements from project to project should be considered. Avoiding complexity encourages the team members to understand the value of data and its role in building knowledge for future projects. This data should be classified to facilitate information retrieval. Guiven that every tunnelling project generates a considerable amount of data, a hierarchical risk breakdown structure represents a good option accomplishing this objective. Tah and Carr (2001) presented a detailed example for its implementation compatible with a risk register.

The current practitioner's practice indicated that the time effort in the identification of risks compared to previous projects ranged from 2 to 24hrs and the mean of people involved at this stage was 8. An other practitioner pointed out that for this task *"selected individuals are assigned to improve research".* An other indicated that results of this activity are *"similar to brainstorming, both based on experience".* The comparison of previous projects for risk identification purposes is being used by 65% of practitioners. This number is likely to shift towards the percentage of Risk Registers use, as they get required for auditing purposes providing similar benefits but in a structured format.

HAZOP method (Hazard and Operability): It provides a methodology to assess the occurrence of hazards affecting the operation of a system; it is particularly suited for machinery. HAZOP could find potential in the mechanized elements involved in tunnelling construction as plants, cranes, trains and TBMs. The use of this tool was very low and almost nonexistent in the literature review for tunnelling projects. The practitioners that marked this technique expressed that *"all methods were used"*, making difficult to evaluate the extent to which they applied HAZOP.

Delphi Technique: It is a group technique aimed to gather opinion from individuals where geographical limitations exist or personal conflict needs to be avoided. The contributors can submit their ideas via E-mail, Fax or Online connection, where a facilitator provides feedback on the group's opinion avoiding the identification of the idea with the person.

The Delphi technique was not relevant among the group of practitioners (10%). Tunnelling projects normally require long periods of planning where space for meetings and workshops should not be a problem regarding time, as personal contact is crucial for effective communication. Not having the possibility for meetings or workshops is related with lack of management commitment to the RM process more than anything else.

Others: There are other techniques available (*Del Caño, A. and De la Cruz, P. 2002),* but are not popular among the group of practitioners. Practitioners identified *"Risk Management Plan Creation"* and *"Method statements"* as means of identification of risks with the participation of the owner, managing consultant and facilitator. An additional comment was that: *"Risk analysis take place one way or another on almost all projects. However these processes often are not documented"*.

Risk identification is an ongoing task that requires skill and experience, it is impossible to identify all risks but expecting the unexpected should be the mindset.

From the results obtained in this section, it is derived according to the relative importance of the techniques, together with the time and people required to perform them, that there is a preference for written aids and teamwork. When compared the answers of practitioners with ≥20 years of experience and <20 years of experience, Checklists and Brainstorming techniques have been used consistently by both groups. This indicates that both are well-established practices among old and new users of RM.

4.5.3 Type of Risk Analysis techniques used to estimate risks' probability of occurrence

Probabilities can be estimated by the ratio of the frequency of occurrence of an event in a year or the duration of a particular project or the length of the tunnel when data is available. A different situation is to estimate the probability of occurrence of an event when data is scarce and only subjective probabilities are available, this is by far the case of tunnelling projects and geotechnical engineering in general. There have been many researchers interested in the elicitation of subjective probabilities and its approximation with the real estimated probability (Reagan et. al., 1989; Ayyub, 2001; Vick, 2002). Fischoff, et. al, (1977), revealed that in general, individuals are not reliable in providing probabilities lower than 20%, Figure 4-17 explains this; where the diagonal equals the value of subjective probabilities with real frequencies. It is observed that a "well calibrated" range only occurs from 20% to 50% (probabilities higher than 50% where not studied as they were considered to be symmetric in range). Probabilities lower than 20% are highly influenced by overconfidence bias. It is possible to evaluate probabilities lower than 20% by subdivision of the problem in stages, a probability tree is a simple way to arrive at such numbers. In short, if, a model is fed with subjective probabilities <20% without a justification (a decision tree for instance), it is reasonable to doubt its validity. Involved in many of the most important Risk Analysis studies for large dams around the world, Morgenstern (1995) emphasize that:

> *"If a very small probability of failure under design loading conditions is required, the actual risk cannot be evaluated accurately by analysis. However, conducting a formal evaluation of probability of failure can help greatly in understanding the risk and what might best be done to reduce it".*

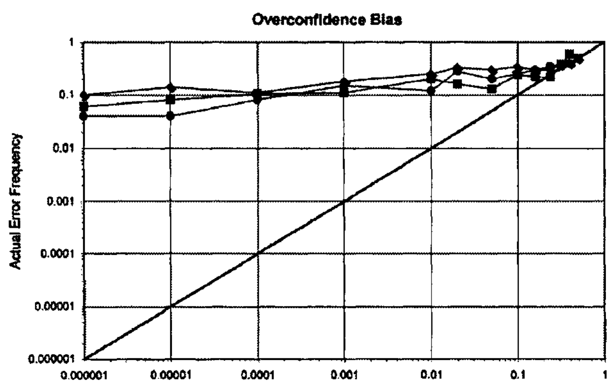

Figure 4-17 Subjective probability error (Fischhoff, et al., 1977)

Experience from many fields, not only geotechnical indicates that it is difficult to elicit information from practitioners and in most of the cases the resulting estimations reflect practitioner's overconfidence (Christian, 2004). Risk Management should not be reduced to a number, a probability or cost but on the contrary, should enlighten in the understanding of the real problem to find the better method to tackle it. Finding the probability of failure of the main bearing of a TBM is meaningless, but an analysis will help identify the measures and costs to be taken in advance to avoid such a possibility of failure.

It is not uncommon to find politicians or marketing professionals take advantage of these ambiguous concepts, the NASA and the Euro Tunnel are good examples. Table 4-1 presents the Space Shuttle probability of vehicle loss for the Challenger and Columbia missions STS-51 and STS-107. The public reports of the Challenger disaster showed that due to political issues concerning the continuity of the Space Shuttle's program a probability of failure of 1 in 100,000 was assigned to the mission opposed to the engineers estimate based on historical data near to 2 in 100 (Feynman, 1987). The consequences are known. In 2003 the Columbia disaster with a similar probability postponed the Space Shuttle program till July 2005. The Discovery launching was postponed for days till conditions were suitable and the crew operations included inspection space walks for the shuttle and the practice for repair of detached tiles in the space that was the cause of the Columbia disaster.

Table 4-1 Space Shuttle probability of vehicle loss

Space Shuttle	Mission	Crew members	Year	Probability of vehicle loss based on	
				NASA management	historical data
Challenger	STS-51	7	1986	0.000001	0.020
Columbia	STS-107	7	2003		0.019

This was an example of RM practices towards accomplishing a project not only based on a probability number that would make space exploration prohibitive but in the understanding of possible failures and its mitigation.

The other example relates to the Euro-Tunnel, which its operator declared in February 2004 a net loss of US$4.6bn. The earnings of the tunnel are 10% less of what is required to pay interests of the project. The traffic is 66% of what was forecasted. On the technical side when Eurotunnel went public in 1997, investors were told that the construction was relatively straightforward, where a 10% contingency was estimated. The real costs of the project was higher by a factor of two compared to the forecasts (Flyvbjerg et, al. 2002).

Only one practitioner commented on the techniques for the estimation of probabilities indicating that: *"All of them have been applied to varying detail in different projects".* It is recommended that prior to the use of any of these techniques a common understanding of the probabilities to be estimated are clear and calibrated with known events. Following is the description of the most common techniques found in the literature and practice for projects:

Likelihood verbal expressions (Very likely, not likely etc.): The representation of subjective probabilities by means of verbal expressions is one of the most important parts in Risk Analysis as it constitutes one of the two variables that determines the magnitude of the risk evaluated, and where Risk Analysis finds its weakest link in the chain. In the majority of the cases a coarse representation of probability of an event happening as: Low, Medium or High, might provide more reliable information for actions to take, than a detail evaluation of a misleading probability. Figure 4-18 presents the means and modes of the experiment conducted by Reagan et al. (1989). The verbal expressions shown, represents the probability ranges with the least variation of a group of expressions tested by them and other previous studies.

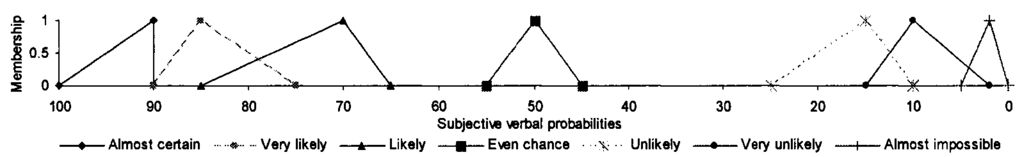

Figure 4-18 Verbal probability expressions (data from Reagan et al, 1989)

It can be observed there is a gap between 25% to 45%, and from 55% to 65%, where no expression satisfactory represents that range. This is presented here as another element to support the fact that subjective probabilities should be taken as such, where is more important to understand the rationale behind a number than the number itself. Likelihood scales are straightforward and easy to understand from practitioner to practitioner, calibration among practitioners for the same expression is required to provide reliability in probability estimation when data is scarce. In the calculation of small probabilities, it is recommended to maintain input probabilities, for probability trees for example, in the range from 10% to 90% to remain understandable. It is not surprising that Likelihood verbal expressions were preferred by the practitioners, where 70% have use them in an environment where statistical data is scarce or null.

Monte Carlo Simulation (Range estimating, Schedule Analysis): The Monte Carlo method consists in replacing a single value estimate in to a continuous distribution of the possible values of an activity or parameter depending on the data available. When data is scarce, assigned subjective values as: the lower, upper and most likely expected can be represented by a triangular distribution. A generated random number is transformed in to the value corresponding to the distribution. This is done in each of the tasks generating a total value that corresponds to one possible scenario of the output. After a large number of iterations it is possible to obtain the mean and standard deviation that allows the estimation of the result with a certain range of certainty. Monte Carlo Simulation has been systematically used for tunnelling projects by the City of Edmonton with outstanding results (AbouRizk et al, 1999). The literature presents several examples of its application in tunnelling projects (Martin and Sadek, 2004; Eisenstein et al. 1999; Bidaiah et al, 2003). The results of the questionnaire indicate that some practitioners have used it often and others occasionally. Monte Carlo was ranked second and with 55% of practitioners having some contact with it. The reliability of Monte Carlo results are directly dependent on the quality of the data provided and the model's architecture. Assuming that a model is well constructed, with reliable data, Monte Carlo provides reliable results, with poor data, the results are poor.

Event Trees, Probability Trees and Fault Trees: The construction of an *Event Tree* requires the identification of an initiating event followed by a sequence of events that might lead to an output. It is particularly useful for the recognition of series of events and possible risks in each path that otherwise are difficult to identify. When probabilities are added to each event we obtain a *Probability Tree* that helps greatly in estimating subjective probabilities smaller than 10%, helping to avoid misleading judgment. A useful algorithm for the easy calculation of probabilities based on the Central Limit Theorem was proposed by Pearson and Tukey (1965) and further extended by Keefer and Bodily (1983). *Fault Trees* are similar to probability trees but they provide the capacity of analyzing more complex sequences through "gates" ("and" and "or" gates). This feature allows considering a failure with probabilities adding ("or" gate) to an event or multiplying ("and" gate) it depending on the logical connection of them. Probability trees are more common in geotechnical engineering, in particular in the analysis of failure of Dams. The results of the practitioners show that the use of these techniques was low (15%), this could be because probability trees are time consuming and as in the case of identification techniques, time-consuming techniques are not favoured.

FMA (Failure mode Analysis): It is a qualitative technique for understanding the behaviour of physical components of a system. It helps analyze the influence of a component's failure over other components and the effect on the system as a whole. Its application is better suited to mechanized systems. Its use among practitioners was around the same value for probability trees, (15%).

Influence diagrams: They are a graphical representation of risks where each event, is represented along the different influences that contribute to it and its interrelation to other events, a popular example is a CPM network among many other examples. Influence diagrams can afterwards be enriched with probabilities. These representations have great potential introducing conditional relationships originating the *Bayesian Networks.* The use of Influence Diagrams among tunnelling practitioners is 35%, just after Monte Carlo simulation (Figure 4-19). Influence diagrams are not new and offer a good option for the representation of risks in particular to those with low probability and high consequences so common in tunnelling.

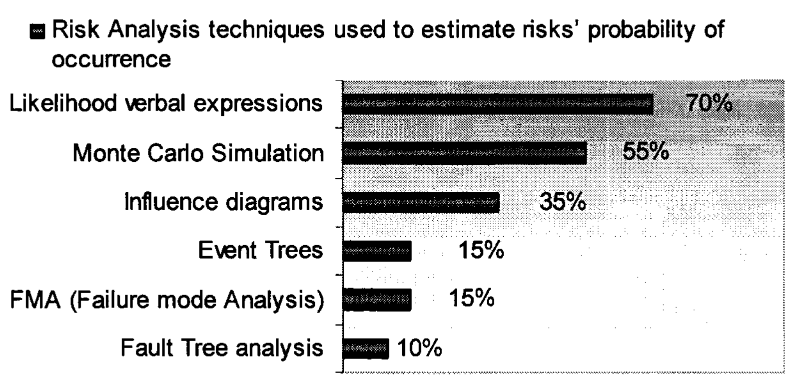

Figure 4-19 Percentage of practitioners using each Risk Analysis technique to estimate probability of occurrence

Other: Choi *et al.* (2004) presented the application for tunnelling risk analysis of *Fuzzy set.* Although a novel approach, it requires a full understanding of the model presented and flexibility to its implementation. The estimation of probabilities and impacts do not need to be exact to be useful as long as the level of uncertainty is understood and indicates a need for action.

4.5.4 Risk monitoring and control practices

The quality of a RM system can be evaluated by the level of communication of risk among participants during the project, from the conceptual stage till close down, Godfrey and Halcrow (1996) indicate that *"The biggest hazard of all is usually lack of communication"*. The monitoring practices expressed by the practitioners included different means of communication where written and site reports were the most common followed by meetings, both reports were not exclusive for RM but for normal Project Management operations like quality standards for example. The use of handbooks and databases and Risk Registers were reported for RM in particular. Some practitioners mentioned that the format for risk monitoring and control practices followed the requirements of the owner and no standard format was followed from project to project, others maintain track record of changes through claims, particularly for unforeseen ground conditions, these practices ranged from project to project and from manager to manager. Some of the best practices found was formal training sessions, supported by a structured means of control through a RM plan derived from Risk Register that outlines the mitigation items for each risk event, where each task has a start and end date. Responsibilities are assigned to team members, monitored and reported. Additional to this, full time monitoring and comparison of encountered conditions versus trigger levels are used based on the expected conditions stated on the Geotechnical Baseline Report. Finally, risk reviews are held. These can be set for certain periods of time (monthly), or at each stage where important milestones are accomplished, particularly in those where a re-evaluation of risks can lead to the releasing of contingency funds from the project. An extraordinary holistic control system is the "Systema de Auscultacion Integrado" from Madrid Metro. For a detail account of practitioner's answers refer to Appendix C.

4.5.5 Does your company have a standard way to document the daily advance rate of tunnelling?

What it is not measured, cannot be improved. The daily advance rate of tunnelling is a variable that depicts in many ways the overall progress of a tunnelling project. Advance in meters vs. days plots are a major source of information for the performance measure of the method of construction and the crew involved, specifically ground conditions. It provides information that can be retrieved for future projects to estimate more accurately costs and schedules based on past performance. This task to be useful should follow a standard documenting format in order to be able to compare project to project in general and soil conditions in particular. A simple spreadsheet with a standard nomenclature among the organization from project to project is simple and very informative. Figure 4-20 presents a daily ring production plot, where notes can be inserted where productivity falls bellow a target range. This provides a straightforward graphical reference to differentiate among risk factors affecting production or routine maintenance procedures. Soil conditions can be explicitly highlighted in order to estimate productivities for a specific type, where soil parameters, equipment and crew characteristics are known, in order to have a better estimate of the same conditions from project to project.

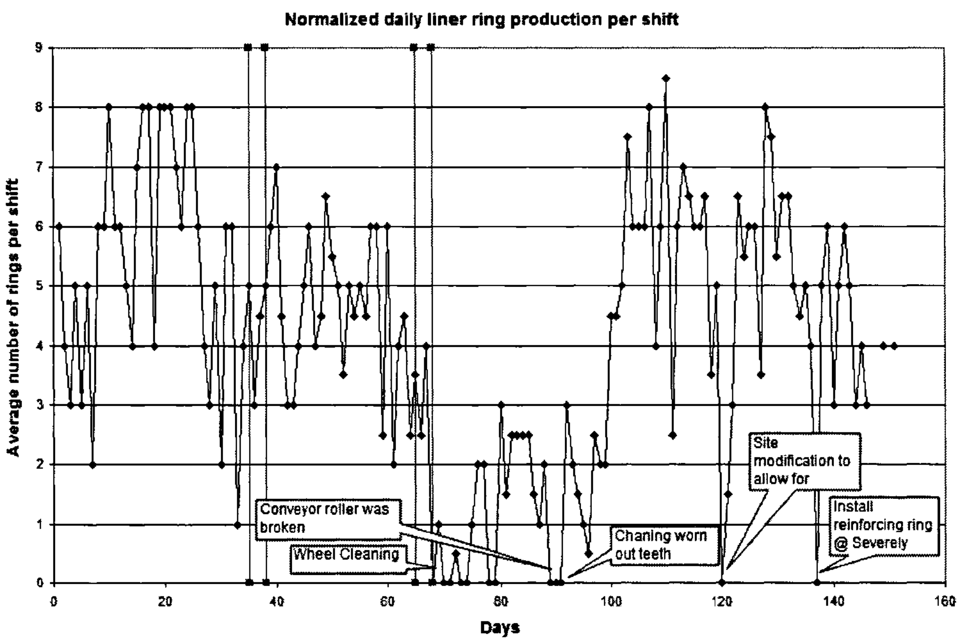

Figure 4-20 Average liner ring advance per shift (adapted from Taylor and Veloce, 2004)

The majority of practitioners (62%) indicated that they have not used or seen in their projects, a standard way of documenting the daily advance of tunnelling operations, even though all of them mentioned that this data is recorded in one way or other. In general, these data is recorded in inspector's shift reports and electronically in spreadsheets afterwards.

Collecting this data can range from a handheld electronic device (PDA) used by the supervisors in order to facilitate data entry in no time, or more sophisticated tracking systems instrumented to the TBM. The system does not need to be sophisticated to work as long as the relevant information is captured and communicated promptly. For a detail account of practitioner's answers refer to Appendix D.

4.5.6 Has your company been required to provide proof of Risk Analysis for a tunnelling project from surety or other financial entities?

Even though there has been an enormous increase of RM practice awareness for projects around the world and Europe in particular, it was surprising to find that 100% of the practitioners indicated that they have not been required to provide any proof of formal practice of RM for any project. This scenario is likely to change as the "The Joint Code of Practice for Risk Management of Tunnel Works in the UK", its international version and the European Union's Parliament Initiative, are making explicit its compliance. Issues related to Change Management would be experienced by those entities not used to RM practices. Education in the topic is urged among the tunnelling community in order to react promptly to these new trends. For novice companies in RM practices, is fundamental to resist the temptation to prepare a RM plan just as a requirement without full commitment for its implementation as becomes counterproductive. Adaptability rather than strength is what makes species and companies survive.

4.5.7 Rank the main benefits of adopting Risk Management for tunnelling projects

Practitioners were provided a list of possible benefits based on the literature in RM and from Tunnelling Consultant's input; the normalized results are shown in Figure 4-21. The questionnaire allowed practitioners to write other benefits.

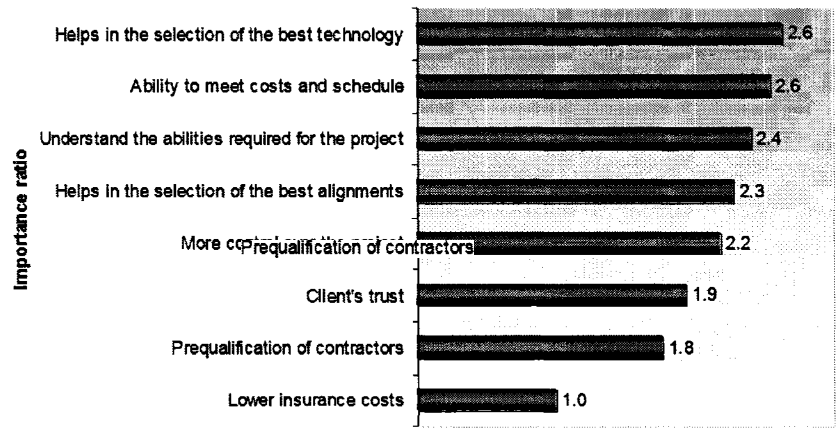

Figure 4-21 Benefits of adopting Risk Management in tunnelling projects

The information provided by the practitioners shows the relevance of RM in the <u>*Selection of the Best Technology*</u>, as this was ranked first. The selection of technology is highly dependent on the design and construction means and methods; it is a relevant fact that RM is recognized among the most important contributions in the selection of the best technology. This can be related to the fact that RM helps identify elements to guide the decision of an adequate option, even more when price might be pushing for one method, risk identification helps recognize other options that represents better value with a strong justification.

<u>*Ability to meet cost and schedules*</u> is a well recognized benefit of RM as this ranking agrees with a previous research by Simister (1993) among project managers in the construction and related industries on the benefits of the use of Project Risk Analysis and Management (PRAM). One of the practitioners indicated that this factor is a function of all others, this comment is relevant as RM contributions are not always easy to isolate from other contributors to the success of the project. Other practitioners indicated the value of RM in setting proper contingencies and was included in this category.

<u>Helps in the selection of the best alignments:</u> On "Being a Geotechnical Engineer", Conlon (1989) wrote: "I have made my greatest engineering contributions not by solving difficult problems but by avoiding them". This holds true for tunnelling projects in particular when alignments are not fixed. Detail quantification of probabilities of occurrence of many risks can be avoided by the early identification of hazards to be avoided by partial or total changes in alignments. Although selection of the best alignment was ranked forth, its importance ratio was high, additionally, from the projects

reported by practitioners, 96.5% utilizes the modification of alignments as a risk reduction measure.

More control over the project: This factor was included as it is a performance measure for project managers' performance. Projects with cost and time overruns have the potential to be blamed to Project Management regardless of the difficulties of the project if they are not documented. RM offers a structured decision support system that helps distinguish between a bad manager and a project with a high degree of uncertainties.

Prequalification of contractors: This factor although in the seventh place has the same relative distance from the fist and eight ranks, 0.8, defining a group among the highest seven factors with very low relative distance among them. Recent RM initiatives (BTS, 2003 and Eskesen et al, 2004) make emphasis in its use in the procurement process. This is favourable mainly to the Owner, but it is for the Contractor too, as they become aware of the risks to be faced in the project and have the ability to arrive better prepared for negotiations during bidding. One practitioner commented about prequalification of contractors as: *"This is independent of Risk Management*", the same practitioners indicated in another question regarding the things he would improve for future projects his priority was to *"change incompetent contractor"*. This shows how for some people RM can be extended in areas that are already causing a problem. This factor is similar to *Understand the abilities required for the project:*, this was ranked third.

Clients trust: This factor found two polarizing opinions from some practitioners, one stated: "I don't think adopting RM has much, if any, influence on client trust", while other mentioned: "Clients want risk management strategies – actually won us a job that we didn't think we would". This second practitioners provided RM where the owner was not expecting it. Being aware of the benefits of RM, can lead not only to cost savings, but in marketing advantage that others will be exploiting, is up to each organization to improve their practice to remain competitive.

Lower insurance costs: This factor was agreed by almost all practitioners to have very low importance in comparison with the others, as shown with its importance ratio. This point is expected to gain attention as auditable RM practices becomes a requirement for obtaining insurance regardless of coverage costs.

4.5.8 Rank the main reasons for not adopting Risk Management in all your projects

Lack of commitment and resources and *Complex procedures* were the main reason for not adopting RM, these findings agree in the same ranking with Simister (1994) research on the use of PRAM. Identical to Quality Management Systems, management responsibility and commitment, determines the effectiveness of the system. In this case the factor given, "*Time and cost consuming*" is directly linked with management commitment. One of the practitioners with more experience of the group indicated over this issue: "*You may spend something up front and recuperate many times later*".

Complex procedures: Risk Management does not need to be complicated to be effective. Complex models have the potential to provide deceiving information, in many cases this is a symptom that the problem was not understood in the first place. Training offers opportunities for the practice of RM and its tools and techniques at levels required, once the process is understood its practiced is accepted.

Experience covers its contribution and *Does not make any difference:* This factors are favoured by the fact that it is difficult to isolate the benefits of RM in hard results. This can discourage senior management in changing what they have been doing for years.

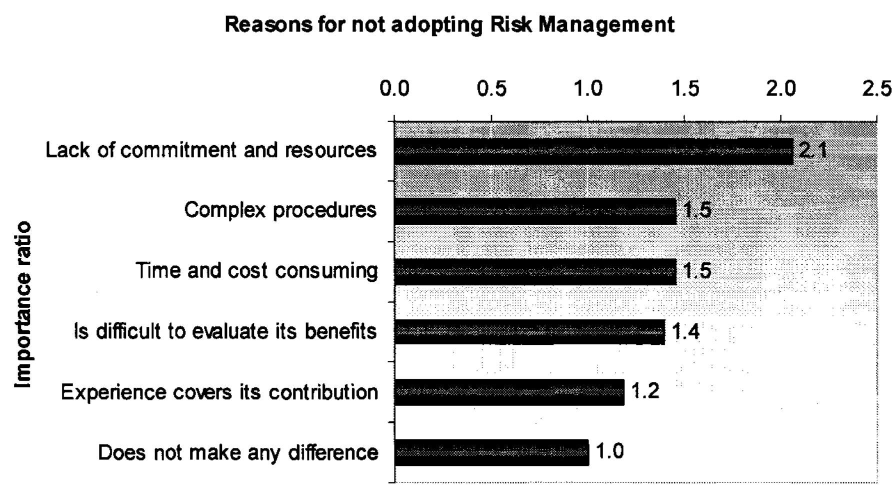

Figure 4-22 Reasons for not adopting Risk Management in tunnelling projects

4.5.9 Factors that contribute to the success of tunnelling projects

Although the factors provided to practitioners were ranked in order to evaluate its importance relative to each other, some of them are prerequisite for others, thus the interdependence is important. The values are normalized divided by the score of the least important.

Qualified contractor: One of the main objectives of RM is to assign the responsibility of risks to the best party to handle it. No doubt that a qualified contractor will increase the chances of a successful project as was ranked. One of the practitioners commented:

"My most difficult tunnel project was due to awarding the contract to an incompetent contractor, when his tender price was well below the engineer's estimate and the next lowest tender price. It was done by a selfish owner who looked only at the bottom line."

Constructability: Is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986). Constructability happens when there is involvement of construction knowledge in the design phase. It is not surprising the high importance relative to the other factors that constructability received by practitioners. Constructability is one of the axes of success in tunnelling projects. Its implementation has been systematic in the City of Edmonton, Drainage Services, with outstanding results, being a key element improving quality and reducing risk (Er. K. C., 2004). Constructability generates channels of communication among project participants such as design engineers and construction professionals, improving each step of the design to the final completion of the project. This practice reduces the chance of project failure and other related performance problems. The role of constructability in tunnelling is paramount, one example of its weight as success contributor for a 115 km tunnel is the Superconducting Super Collider presented by Gilbert, P. (2002).

Use of adequate technology: This factor was ranked second and agrees with previous results (see 4.5.7) as one of the main factors on the overall RM in Tunnelling projects.

Communication: Is a key element in the management of projects, moreover where parties in the same project can have different views of the importance or irrelevance of the same task, communication is fundamental when dealing with risk tolerance levels. Sources of misunderstanding facilitate hazards to occur. In this study two practitioners were asked to rank how important was to reduce the uncertainty in the location of shafts, while for the design project coordinator its importance was the lowest, for the owner's project manager was the highest, both practitioners referring to the same project. As tunnelling projects become more challenging, RM offers a framework to expedite communication among the parties involved. In this case both practitioners had their own reasons for prioritizing in different order some elements of the project based on their past experience. As this experience converges in the same project, a common channel of communication and agreement in their views is required. Risk Management helps to handle these differences of opinion towards a same goal. Communication is an ongoing activity inside RM practices. Planning represents the starting point in communicating needed inputs and desired outputs. Identification communicates risk from one party to the other rising concern about issues not detected by others. The assessment of likelihoods and impacts communicates the relative importance of a risk according to the collective risk appetite of the stakeholders. The decision to avoid, reduce, manage or transfer risks, communicates specific responsibilities for each project member, and indicates to be prepared and react promptly when adverse situations generate. On other hand, communication helps measure the performance of RM practices, deficient communication nullifies previous RM efforts.

Availability of Geotechnical Baseline Report (GBR): The purpose of the GBR is to provide specific contractual terms for the anticipated geotechnical conditions to be encountered during underground construction (Essex, 1997). It is the tool that communicates factual information between owner and contractor. It allows the owner to set its risk tolerance on the face of an expected underground scenario, and the contractor to measure its opportunities versus other contractors for better handling of the baseline underground conditions. According to the practitioners, its relative importance (1.3) is half of the factor ranked as the most important (2.3). Availability of GBR ranked 5th place. This indicates that it is not as widely used and its full potential might not have been achieved in Canada even though this is not a new concept (Essex, 1997). Its use was formally introduced in 1997 and was recently included as a requirement in Code of Practice. It is expected to be required as well in the near future for insurance purposes. Independently of these circumstances, its use is highly encouraged as it represents a excellent tool to manage the risk of unforeseen ground conditions from a contractual perspective where owner and contractor benefit greatly. Owners avoid paying contingencies built in bid proposals due to contractors taking risk that are not fully known. The availability of GBR benefit contractors and owners, where contractors can manage their risk tolerance and move their proposals from the base line to better management strategies providing competitive bids balanced with knowledge and expertise.

"The GBR is therefore the most important contract specification written. It is the first document that a bidder reads and it is the first document that a dispute review board (DRB) reads when a dispute is brought before them" (Essex, 2004).

The results of the research indicate that there are vast opportunities not exploited from the GBR as a current document in Canadian tunnelling contracts. The reason might rely in the fact that the costs of a GBR must be understood from the owner as one of the best investments towards a tunnel project, where possible claims, litigation and deteriorating contractual relationships above time and cost overruns are greatly avoided. It offers an objective framework for Dispute Review Boards towards a fair settlement when claims arise.

<u>*Owners experience:*</u> It represents the catalyst party in the promotion of RM practices, its contribution to the success of tunnelling projects is based on the fact that an experienced owner will be willing to invest resources upfront for RM purposes in order to increase the certainty of a successful project.

<u>*Compliance to regulatory requirements (OH&S and/or environmental):*</u> This factor was not recognized as a main contributor to project's success. This result was not expected as when safety is mentioned in RM or Value Engineering workshops it ranks first. This could be due to two perceptions: 1) regulations are most of the time perceived as obstacles and 2) safety measures are built in the project. Compliance to regulatory requirements ranked at the bottom of the list together with Partnering and Quality Management. Two practitioners included the role of a Health & Safety Committee, pointing out that it *"requires a high level of commitment and motivation"*, and about the Emergency Response Plan it is considered *"essential to safety culture and awareness"*.

<u>*Partnering:*</u> It is the relationship promoted among Owner and Contractor in lieu of the achievement of mutual goals (USACE, 1991). It promotes open communication and collaboration in improving project's environment. It requires a positive attitude to promote commitment and understanding towards excellence based on mutual trust. The practitioners ranked Partnering in the ninth place and its relative distance to the first and second factors was almost half of them. The rank given by the Practitioner shows that partnering as described by the USACE guidelines is not widely used. One of the

practitioners stated that Partnering was not relevant in its projects as *"...good contracts make good partners, particularly for low bid work"*. The contribution of Partnering in a RM system should be for those risks not identified or difficult to allocate, so called "shared risks" (Rahaman and Kumaraswamy, 2002). Some of them are character or attitude related that in a negative atmosphere can generate unpredictable consequences, or otherwise, be managed with professional maturity.

Quality Management and Risk Management: Risk Management and Quality Management Systems contribute among other practices to the success of tunnelling projects. Although their outputs are common, their inputs are not. As an example, the output of Risk Identification would be the risk itself and its treatment activities; they can become an input on the Quality system in order to assure the quality of the RM process. As these are highly interrelated, their integration should be considered at all times. They are complementary. An important advantage of Quality management Systems over RM, is that performance measurements are difficult to set in RM as uncertainty represents a permanent factor.

Other factors mentioned by the practitioners were: the role of specialists/practitioners, geotechnical knowledge and design changes. Figure 4-23 presents the mentioned factors and its respective rankings

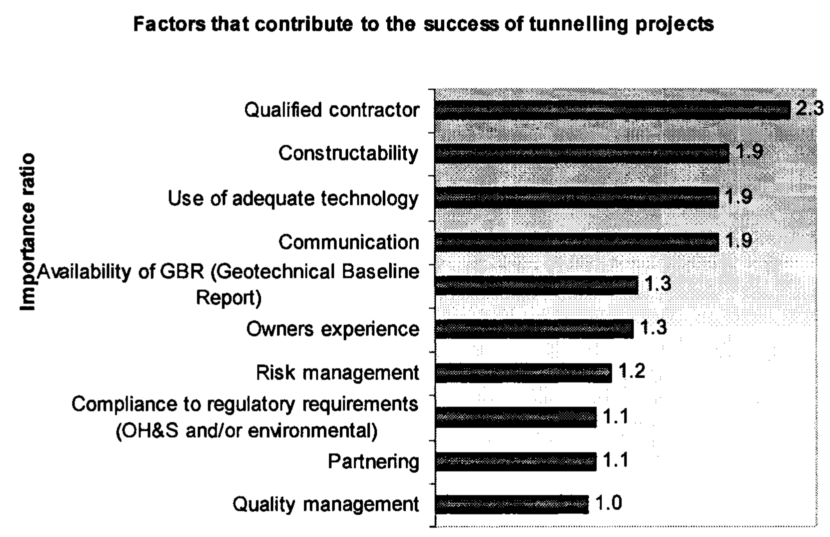

Figure 4-23 Factors that contribute to the success of tunnelling projects

4.6 Human Error

It is common that actual failure rates exceed predicted failure rates in as much as two orders of magnitude (Whitman, 1996). When this failures were analyzed through forensic engineering, it was found that most of them were the result of human error, e.g., structures not built according to plans, or materials not meeting specifications, misinterpretation of loadings, etc. *"Human error can obviously overwhelm an otherwise effectively operating system, and risk analysis that ignores or underestimate human involvement in geotechnical practice borders on naivety"* (Morgenstern, 1995). As reported by the British Tunnelling Society's "Close Face Working Party" (2003), the satisfactory TBM's operation and grouting techniques that are crucial for face stability rely heavily on the avoidance of human error for tunnelling success. Not considering human error during a risk analysis process implies that the project is error-free, which according to research in Civil Engineering construction is the most common cause of failures (Eldukair and Ayyub, 1991; Stewart, 1993; Kirwan, 1994).

Figure 4-24 presents the plot of the probability of human error in a nuclear reactor control room for a single event (Swain, A.D., 1987).

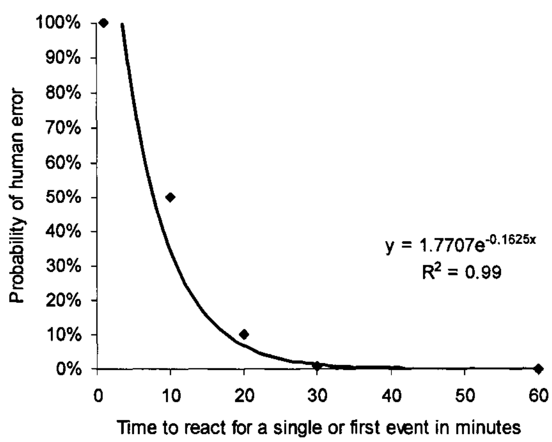

Figure 4-24 Probability of human error for a single or first event (data source Swain 1987)

It can be seen that after the threshold of 20 minutes, the probability of human error decrease greatly. This can be translated to each of the phases of a tunnelling project where activities that require intensive human interaction and prompt response should be considered as candidates for risk analysis and reduction of human error. Some examples of these activities are: the sampling of boreholes, the observation of settlements and structures, survey alignments, gas monitoring, mechanical risks, management of groundwater inflows and soil revelling control, among many others. Godfrey and Halcrow (1996) indicate that: *"The most unpredictable hazard is people*". Morgenstern (1995), in two case histories, illustrates the overwhelming influence of human and model uncertainty in Geotechnical Engineering.

The following factors in each section depend on the knowledge and the experience of the Geotechnical Engineer, Design Engineer and the contractor in each particular case. The numbers presented herein reflect the practitioners' experience. One of the Design and Geotechnical consultants contacted with over 30 years of experience, expressed that in his experienced, when he has done consulting for contractors, many things had gone wrong. Contractors experience from this perspective is preponderant on the reduction of construction human error. It is common that if some of the criteria listed go wrong then the others are likely to be off at similar level.

4.6.1 Human errors in Geotechnical Reports for tunnelling projects

Geotechnical human error includes errors that can happen from the very beginning of the soil investigation such as, selecting the adequate sampling tools and personnel to collect soil parameters, until the submission of a Geotechnical Data Report and recommended property ranges. Factors that are not self explained are commented:

Too conservative conclusions: Refers to conclusions based on the worst case scenario where excessive design would be the consequence. Generates the risk of unjustifiable excessive costs.

Misinterpretation of the geology: Refers to the inadequate representation of the geology when the average professional would not make the same error. This is different from unforeseen ground conditions.

"copy-paste": Refers to the practice of editing a report from a previous one and modifying the information to suit the new, leaving information that does not pertain to the current project.

Too optimistic conclusions: Refers to conclusions based in the best case scenario where the consequence is high risk built in the design.

Lack of system perception of the overall project: Refers to errors incurred when reducing the scope of analysis to only the geotechnical investigation phase, and not including the objective of the geotechnical investigation, which is to be to be used as a design and construction input.

Not reporting relevant parameters for the particular project: A case is the ground water conditions that vary from cycles of flood and drought (Samuels, 2002). This can vary greatly between the first soil boring program and the completion of the bid period. Geotechnical Consultants and Owners should be prepared to agree in the need of additional information if pertinent.

Table 4-2 presents the results of Geotechnical Human Error according on the frequency that practitioners have found them in their experience. Percentages in dark grey indicate that more than 1/3 of answers fall in a specific likelihood. Geotechnical errors are sorted from the most frequent to the least frequent. The 50% value in the "Cumulative %" column divides the errors from most frequent to least frequent, according to the nomenclature followed by Reagan et al (1989).

It can be derived from Table 4-2 that 79% of the practitioners consider that there is at least "Even chance" to find "Too conservative conclusions" in geotechnical reports. 37% agree that is "Likely". 58% of practitioners consider that there is at least "even chance", or equal probability to find misinterpretation of the geology.

Table 4-2 Geotechnical human error

Geotechnical human error	Almost Certain	Very Likely	Likely	Even Chance	Unlikely	Very Unlikely	lmost impossible	Total	Cumulative %
Too conservative conclusions	0	11	37	32	16	0	5	100	79
Misinterpretation of the geology	0	21	21	16	26	16	0	100	58
"copy-paste"	7	7	0	40	33	13	0	100	53
Lack of communication	0	6	22	22	33	17	0	100	50
Too optimistic conclusions	0	0	11	33	39	17	0	100	56
Lack of system perception of the overall project	0	0	13	25	50	13	0	100	63
Not reporting relevant parameters for the project	0	11	16	11	47	16	0	100	63
Wrong conversion of units	0	0	5	11	47	26	11	100	84

% < 26   26<%<32   33<%

4.6.2 Human errors in the Design Specifications for tunnelling projects that affect operations during construction

Design Human errors in the majority of cases are modeling errors. The translation of a real problem to the modeling environment to process data and then, obtain an approximation of the real problem can have fitness variations of the model, to the real problem. When a key feature of a problem is not identified and then not considered for decision making, there is a model error (Whitman, 1996). According to information from insurance companies 40% of defects in buildings are design related and 40% are workmanship related, the rest are due to components and parts defects. 80% of maintenance costs are originated in the first 20% of the design process (Flanagan, R., 2003).

The following factors are derived from literature and experienced tunnelling professionals:

Contradictory or unclear specifications: This factor is noticed once contract terms have been settled and a problem arises, where the design contradicts specifications. A case was reported where specifications contradicted the contract and indicated the use of the wrong technology (Er, 2004).

Limited working areas: are not only those required for safety requirements but additions needed to be considered in the specification of equipments that might not be possible to get to site due to limited space, a heavy tonnage crane for instance.

Unrealistic schedule: Refers to schedules that are not construction driven.

Tolerances unachievable: Including no flexibility of design

Wrong support system: Related not only to immediate support during the construction phase but for the life cycle of the tunnel as in the case of Roger's Pass tunnels in British Columbia's Rocky Mountains (Martin, 2004) where support needs to be changed before the lifecycle of the tunnel.

Wrong excavation sequence: This relates in particular to large sections in the Sequential Excavation Method where this is the cause of collapse.

Shaft location: Refers to inaccessible location or geological hazard.

Table 4-3 Design human error

Design human error	Almost Certain	Very Likely	Likely	Even Chance	Unlikely	Very Unlikely	Almost impossible	Total	Cumulative %
Contradictory or unclear specifications	0	10	30	45	10	5	0	100	85
Lack of communication	0	10	25	45	15	5	0	100	80
"copy-paste" mistakes	0	6	22	50	17	6	0	100	78
Too conservative design	0	5	37	32	21	0	5	100	74
Limited working areas	5	16	5	37	32	5	0	100	63
Unrealistic schedule	0	10	10	30	45	5	0	100	50
Lack of system perception of the overall project	0	11	17	22	39	11	0	100	50
Tolerances unachievable	0	10	20	15	50	5	0	100	55
Wrong support system	0	5	5	32	32	26	0	100	58
Wrong excavation sequence	0	0	15	20	45	20	0	100	65
Wrong technology	0	0	10	20	55	15	0	100	70
Number of shafts	0	0	6	11	33	44	6	100	83
Shaft location	0	6	6	0	56	28	6	100	89
Wrong conversion of units	0	0	5	5	47	37	5	100	89

%<26   26<%<32   33<%

Table 4-3 presents the results of Design Human Error according to the frequency that the practitioners have found them in their experience. Percentages in dark grey indicate that more than 1/3 of answers fall in a specific classification. The errors are sorted from most frequent to less frequent. The 50% value in the "Cumulative %" divides the errors from the range of most frequent to least frequent.

It can be derived from Table 4-3 that 85% of the practitioners consider that there is at least "Even chance" to find "Contradictory or unclear specifications" in design reports, where 30% consider that this is "Likely". 80% consider that there is at least "Even chance" to find errors due to lack of communication.

4.6.3 Human errors during construction operations for tunnelling project

The list of human errors in this section had more elements than the Geotechnical and Design, this is due to the fact that ground risks when happened show in construction phase of the project. "Lack of communication", "Poor ground control/ poor grouting operations" and "Poor quality control QC/QA" were the most common. Below is a description and literature reference relevant to each.

Lack of communication: The construction phase demands immediate communication of events or changes in the design as ground normally changes in short time. Communication during construction regarding unexpected ground conditions are a key element in Risk Management where control and mitigation measures need to be updated. During construction, when the unexpected happens, the time of reaction most of the time is in the range of <20 minutes, the probability of human error increases exponentially compared to the other phases.

Poor ground control/ poor grouting operations: It is possible that the expected conditions of the ground are different as could be the case of permeability impeding grouting operations. Failure to adapt grouting operations could lead to ineffective soil improvement. On the other hand poor ground control could induce damages to the tunnel and adjacent structures if overburden is insufficient and compaction grouting operations, for instance, induce undesired displacements (Terés, 1999).

Poor quality control QC/QA: This task includes instrumentation and monitoring of the ground and structures for risk mitigation and control additional to construction materials and methods.

Inability to react to unforeseen ground conditions: The stability of the excavated ground is time dependent. The excavation and support methods play an important role on this variable. For soils and weak rocks, the rate of advance determines the stand up time. It is very common to fail to recognize the need for immediate support when advance ratios slow down (Muir Wood, 1990). When the Observational Method is applied, interpretation of monitored variables normally detects the ground warnings before collapse.

Inadequate handling of water conditions: This factor refers to the selection of equipment and methods.

Modification to the specified excavation sequence: An example is the collapse of the Athens Metro, where a temporary small ditch made in the bench of a NATM tunnel section for the drainage of stream of water, induced the collapse of the whole section (Hoek, 2004).

Rework: Resulting from constructability or QC/QA failure

Lack of experienced work force, poor planning and poor site layout planning: The first factor is related to market availability of skilled labour, a current problem in Western Canada in the construction industry. The second and third are evident during construction and are generated in the procurement stage of the project.

Survey error: Refers to error or delays above a reasonable tolerance.

Wrong application of soil support system: This factor is interrelated with poor QC/QA as well as with lack of experience of the work force. Inadequate rebar connections or not applying sprayed concrete at the right angles for SEM or inadequate stacking and manoeuvring of liners are some examples (BTS, 2004).

Table 4-4 presents the results of Human Error during tunnelling construction operations according on the frequency that the practitioners found them in their experience. Percentages in dark grey indicate that more than 1/3 of answers fall in a specific classification. The errors are sorted from most frequent to less frequent, the 50% value in the "Cumulative %" divides the errors from the most frequent to the least frequent.

It can be derived from Table 4-4 that 95% of the practitioners consider that there at least "Even chance" to find "Lack of communication" in the construction process.

Table 4-4 Human error during tunnelling construction operations

Construction human error	Almost Certain	Very Likely	Likely	Even Chance	Unlikely	Very Unlikely	Almost impossible	Total	Cumulative %
Lack of communication	0	10	25	60	0	5	0	100	95
Poor ground control/ poor grouting operations	0	0	[illegible]	[illegible]	17	0	0	100	83
Poor quality control QC/QA	0	5	[illegible]	[illegible]	20	5	0	100	75
Inability to react to unforeseen ground conditions.	0	15	20	35	25	5	0	100	70
Inadequate handling of water conditions	0	5	20	[illegible]	[illegible]	0	0	100	60
Modification to the specified excavation sequence.	0	5	30	25	[illegible]	0	0	100	60
Rework	6	6	17	28	28	17	0	100	56
Lack of experienced work force	5	0	20	30	[illegible]	10	0	100	55
Poor planning	0	5	5	[illegible]	32	11	5	100	53
Poor site layout planning	0	0	15	[illegible]	[illegible]	10	0	100	50
Survey error	0	5	[illegible]	10	30	20	0	100	50
Wrong application of soil support system	0	0	17	28	[illegible]	6	0	100	56

%<26	26<%<32	[illegible]

4.6.4 Comments of respondents about the current practice of Risk Management in Tunnelling Projects

From the comments received, we present three that are representative of points of view repetitively found throughout the responses of the questionnaire:

Comment from a senior geotechnical engineer with 25 years of experience, participated in 13 tunnelling projects, 22 km of tunnels:

"As far as the projects I was involved in, RM was not a specific factor that was considered. I think RM is something that would be of greater concern to Owners. Unless they address the need, it is unlikely that a contractor would include it as part of his bid as it is a cost item. The engineering community is also restricted in this respect, since Owners set the terms of reference and scope of work for the engineering work. Again, it would be difficult for a consultant to add this into his quote for the job as it would be an additional cost item and it would be impossible to quantify the benefits without knowing more about the job. Until Owners recognize the merits of undertaking a RM approach, it is unlikely that it will gain greater acceptance in the industry."

Comment from contractor-project manager with 20 years of experience, participated in 21 tunnels with a cumulative length of 46.7 km.

"Risk management by contractors is generally carried out on all projects in an informal manner. The risks are weighed up especially at bid stage. Our company has experience in Risk Assessment and Management from projects in Europe. The main purpose was perceived to be mitigating risk to the owner, not the contractor, workforce or project. In my experience contractors have a resistance to risk assessments in the same manner as resistance to method statements, written procedures etc. This resistance may be unfounded but in my view is widespread."

Comment from Design Consultant with 15 years of experience, participated in 9 tunnels with a cumulative length of 52.2 km.

"Clients want risk management strategies – actually won us a job that we didn't think we would."

Comments reflect the different perceptions of RM in tunnelling projects, its benefits and obstacles for its implementation. In general, the current practice of RM among practitioners ranges from informal, intuitive and embedded in other processes, to well structured, high-end methodologies. In most cases, documentation and means of communication differ from project to project and a systematic use of RM is not common. Additional to these comments some practitioners expressed their interest in research of the experiences on Disputes Review Boards (DRB), projects with and without Geotechnical Baseline Reports (GBR) and its interaction with DRB and the impact on the "The Joint Code of Practice for Risk Management of Tunnel Works in the UK" in Canada.

4.7 Summary of Findings

There is a strong international activity among practitioners as 42% of reported projects are tunnels outside Canada. Practitioners' working practice concentrates in three main areas: Toronto, Edmonton and Vancouver. Toronto and Edmonton share the same geological formation, thus, they have similar geotechnical characteristics reflecting common tunnelling methods and geotechnical risks. The method most frequently used and with more km is the TBM Open face. TBM EPB is the most effective method when compared by a ratio of length vs. number of tunnels, this is likely to be due to the tunnelling density in Edmonton and Toronto in transported soils (glacial till), as well as the safety and mechanized construction advantages of the method. The majority of tunnels where practitioners participated in the last five years are for transportation purposes (38%), followed by Water (33%).

RM is practiced but this process is rarely systematic and the depth of analysis is variable, in many cases is not considered a specific task, generally this practice is not documented. When compared the groups of ≤20 and ≥20 years of experience, on their RM practices, the group of ≤20 has done it more frequently in the past years indicating a growing interest in RM.

Regarding Risk Identification techniques, Checklists (75%) and Brainstorming (75%) workshops have been used consistently from practitioners with ≤20 and ≥20 years of experience, this indicates that both are well-established practices among old and new users of RM. Risk Registers are used only by 25% of practitioners in the identification of risks, this number is expected to grow in the future as Risk Registers become a common practice as is now required in the UK and in other international guidelines.

For probability estimation of risks, likelihood verbal expressions were preferred by 70% of practitioners, this is not surprising in an environment where statistical data is scarce or null. Likelihood scales are straightforward and easy to understand from practitioner to practitioner. Calibration among practitioners for the same expressions is required in order to provide reliability in the estimation. In the calculation of small subjective probabilities when a number is provided, it is recommended to maintain input probabilities, for probability trees for example, in the range from 10% to 90% in order to avoid overconfidence of results.

The preference for Checklists, Brainstorming Workshops and Likelihood verbal expressions, indicates that the tunnelling industry does not necessarily need to apply more complicated techniques to perform RM, but to have a systematic approach to its performance.

The use of Monte Carlo simulation is moderate ranging from often to occasionally. It was ranked second and with 55% of practitioners having some contact with it. The reliability of Monte Carlo results are directly dependent on the quality of the data provided and the model's architecture. Monte Carlo Simulation running over Special Purpose Simulation Software, has been systematically used in tunnelling projects by the City of Edmonton with excellent results, this is a promising tool for tunnelling works. Influence Diagrams were the third technique used by practitioners it would be positive to see an increase in its use together with Bayesian Networks. The estimation of probabilities can become a tedious and difficult task that can make the real objective of RM be forgotten in technicalities. The estimation of probabilities and impacts do not need to be exact to be useful, what is important is to understand the level of uncertainty and identify the need for actions. When practitioners were asked about their perceptions of the importance of different factors throughout the questionnaire, it was found they have different priorities depending on their role even when refereeing to the same project or item. This difference in opinion enriches the evaluation of risks during workshops what makes Brainstorming sessions and the whole practice of Risk Analysis workshops worthwhile.

The quality of a RM system can be evaluated by the level of communication of risks among participants during the project from the conceptual stage until close-down. The monitoring and control of risks in the practitioners' experience varies greatly from project to project and from manager to manager as no standard format is followed. Site reports and meetings are the common means of risk monitoring and control practices among practitioners, where both means were not exclusive of Risk but Project Management practices in general. The format of these reports depends largely on Owners' requirements, these include: handbooks, databases and Risk Registers, others maintain track of changes through claims, particularly for unforeseen ground conditions. The majority of practitioners (62%) indicated that they have not used or seen in their projects a standard way of documenting the daily advance of tunnelling operations, even though all of them mentioned that this data is recorded in one way or other. In general, these data is recorded in inspector's shift reports and electronically in spreadsheets afterwards.

No Practitioner knew of any formal requirement by any entity, of proof of RM practices. This situation is relevant as change management will be an issue to consider for those entities not use to the practice of Systematic RM once it becomes a requirement to get insurance coverage. Education in the topic is urged among the tunnelling community in order to react promptly to these new trends. Preparing a RM plan just to comply a requirement is not only a bureaucratic obstacle but can be a dangerous option as it provides a sense of risk control, facilitating the overlook of real risks.

Selection of the best technology was ranked as the most important benefit of RM in tunnelling. This demonstrates the relevance of RM practices as the selection of adequate technology is the single most important decision in the success of a tunnelling project. RM helps decision-making when price might be pushing for one method but risk identification supports better value options. RM was identified to increase the chances of meeting budgets and schedules as well as setting proper contingencies. RM was recognized to help in the selection of the best alignments where avoiding risks was the main driver, a practice that was identified in over 96% of the projects provided by practitioners.

The main obstacle identified in the implementation of RM practices was lack of commitment. This is followed by the fact that some people identify RM to have complex procedures and to be time and cost consuming. The difficulty in evaluating its benefits represents a factor used by non-practitioners to resist its practice.

The factor identified to be the most valuable in the success of tunnelling projects was having a qualified contractor followed by: constructability, use of adequate technology and communication. These factors were followed by the availability of Geotechnical

Baseline Report. GBR represents one of the most important tools in defining geotechnical risk ownership; its use is highly recommended as a standard practice as well as the adoption of Constructability practices.

Human error is one of the recurrent sources of risk during tunnelling projects; the following list refers to the ones identified by practitioners to happen at least 50% of the time:

Geotechnical human errors: too conservative conclusions, misinterpretation of the geology, "copy-paste" mistakes and lack of communication.

Design human errors: contradictory or unclear specifications, lack of communication, "copy-paste" mistakes, too conservative design, limited working areas, unrealistic schedules and lack of system perception of the overall project.

Construction human error: lack of communication, poor ground control/ poor grouting operations, poor quality control QC/QA, inability to react to unforeseen ground conditions, inadequate handling of water conditions, modification to the specified excavation sequence, rework, lack of experienced work force, poor planning, poor site layout planning, survey error.

From the projects provided by practitioners it was derived that the most frequent ground conditions that affect the completion of tunnelling projects within schedule and budget are the presence of: boulders, saturated sands, free flow of water, wet silts, sand stone, soft clays and running sands (dry). The previous geotechnical conditions were identified by practitioners to happen at least 50% of the time.

The most common risk reduction measures used to minimize the impact of difficult or unforeseen ground conditions were the change of horizontal and vertical alignments in almost all projects provided by practitioners. This is a point where the use of Value Engineering practices can greatly enhance the results of RM practices as well as the overall outcome of the project.

The first factor that practitioners would like to change in future projects is the contract strategy. In this respect, Systematic RM offers a framework for the better allocation of risks to the parties better able to handle them.

4.8 Conclusions

Risk Management in the tunnelling industry is generally carried out on most projects in different levels of depth, from an informal manner to sophisticated use of tools and techniques. In general, the documentation of this practice differs from project to project according to owners requirements, which makes the use of historical data from previous projects a difficult task. The Risk Register is the living document that allows permanent communication among stakeholders in a systematic practice though standardized documentation during the project and for future reference. The backbone of a systematic RM system is the Risk Register.

If Risk Management objectives and procedures are not well communicated through all participants in the different phases of the project, it is expected to face acceptance difficulties as it can be reduced to a bureaucratic procedure generating a dangerous sense of risk control where in fact it increases the likelihood of risks to happen. If RM is conducted in a perfect format but fails to identify any of the major risks of the project, RM fails. Therefore, the maturity of RM depends on these two main activities: identification and communication. The most sophisticated analysis and tools can be used but overlooking important risks or not providing adequate communication for its management transforms RM in to a deceiving activity. The years of experience and RM practice of practitioners reflect an increasing use of RM practices, more awareness is expected as a result of new regulations.

Many benefits of RM are difficult to isolate from other practices such as Value Engineering, Quality and Safety Management Systems, what makes RM's role fundamental is its capability to help identify where actions are needed at the outset of the project and identify effective control measures to achieve the goals shared with other Project Management practices.

Human errors that happened at least 50% of the time in geotechnical, design and construction phases were identified. They represent areas for risk reduction that need improvement where adequate communication is a must. Risk Identification should consider this areas at all times.

Although all participants in a Tunnelling project benefit from RM, Owners have the main potential to make RM a systematic practice for their own benefit, better allocation of contingencies provides more financial flexibility for other projects, it also provides proof of good management and accountability. Risk Management practices greatly improves its contribution when practiced alongside with Constructability, Value Engineering, Quality and Safety Management systems. Its implementation should consider their systems integration, as all aim to the same performance measures: safety, cost, time and performance.

The use of Geotechnical Baseline Reports is strongly encouraged in order to optimize procurement and contracting practices. Partnering represents an ideal preventive risk control measure for those risks not identified.

Risk Management does not need to be complicated to be useful.

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Chapter 5 Systematic Risk Management for Tunnelling Projects (SRMTP) Start Up Guideline

5.1 Introduction

The following guideline consolidates Risk Management (RM) practices among different industries towards its use in tunnelling at an introductory level. The majority of RM elements are taken from guidelines focused on projects and construction. Emphasis is given to the underground nature of tunnelling works in its different stages; it includes input from best practices of RM in Canadian tunnelling works.

This guideline intends to be a first step to the adoption of Systematic Risk Management in Tunnelling Projects (SRMTP), more detailed processes and techniques are available elsewhere (AS/NZS; 2004, BTS; 2004; Eskesen et al., 2004; Godfrey and Halcrow, 1996; ICE et al.,1998; OGC, 2002; Thompson and Perry, 1992; Treasury Board of Canada, 2001; Simon et al, 1997). Owners, consultants and contractor starting in the practice of SRMTP would find it useful as the content is intended for projects that do not have enough data and the evaluation is based on expert opinion as the main source of information. The risk analysis section of the guideline focuses on qualitative and semi-quantitative analysis. A variation of the methodology proposed by Godfrey, (1996) and the ICE, (1998) has been successfully used for drainage (S. M. A. Consulting Ltd., 2002) and transportation (Becker and Griffith, 2004) tunnels in Edmonton, Canada.

Appendix G presents the elements of different RM standards and guidelines. In general, all standards follow the same structure but some standards classify the elements in different areas and place different emphasis depending on its orientation (Financial, IT, Public Works, Aerospace, etc), this guideline is aimed for Tunnelling Projects (planning, design, procurement and construction). The guideline focuses on 14 steps that make explicit rather than implicit its role in the process as follows:

	Step	RMTP elements
Establish context		
	1	Management responsibility
	2	Establish context
Risk Identification		
	3	Plan and initiate Risk review
	4	Identification
Risk assessment		
	5	Evaluate Risks
	6	Mitigate Risks
	7	Secondary risks evaluation
	8	Cost contingency
	9	Ownership
Risk Treatment		
	10	Implement mitigation actions and Emergency response
	11	Communicate Strategy and plans
Risk Review and Monitoring		
	12	Monitor review and update ongoing Risk Register
	13	Control Risks
Close Down	14	Close Down review RM process

These steps are structured towards the construction of a Risk Register as the centre of the process on communication and documentation.

5.2 Elements for the Implementation of Systematic Risk Management for Tunnelling Projects

Companies are required to comply with different management systems (quality, environmental, OH&S, etc.) where Systems Integration becomes an important issue (Karapetrovich, 2003; Wilkinson and Dale, 1999). This guideline is structured over Demming's model, Plan-Do-Check-Act (PDCA) (Deming, 1982) adopted by ISO in its standards. The terminology and structure follows in general the proposed IEC-ISO 2001 Project RM guidelines (IEC, 2001). The elements required by "The Joint Code of Practice for RM of Tunnel Works in the UK" for which an international version is being prepared have been included (BTS and ABI, 2003), (Mellors and Southcott, 2004). This format is intended to provide an incentive in the implementation of SRMTP as a management improvement tool rather than a bureaucratic procedure.

Figure 5-1 presents the holistic concept of SRMTP. The outer circle represents the project in question. The upper left arrow represents input to the project from external management resources, where management responsibility starts the motion of the system together with the context of the project. This follows the PDCA components adopted for Quality Management Systems in order to provide parallel procedures avoiding redundant documentation that commonly generate communication bottlenecks. A feedback loop is represented with the "Permanent Improvement" arrow at the end of each PDCA cycle where the process is reviewed as new information is known through the project. The inner circle represents the Risk Register and permanent communication; this element is the main bearing of the model and determines the efficiency of the system. The arrows represent the information coming in and out of the Risk Register providing permanent communication. The upper right arrow represents the close down review process commonly forgotten in Project Management practices. This element is the "lesson's learned" generator for future projects, where the evaluation of appropriate RM decisions can be reviewed for future implementation, modification or elimination. Finally the centre right arrow, "External Auditing", represents the stage at any point in the project where audit takes place; this audit can be conducted within the company or from other stakeholders like insurance auditors or public inspectors.

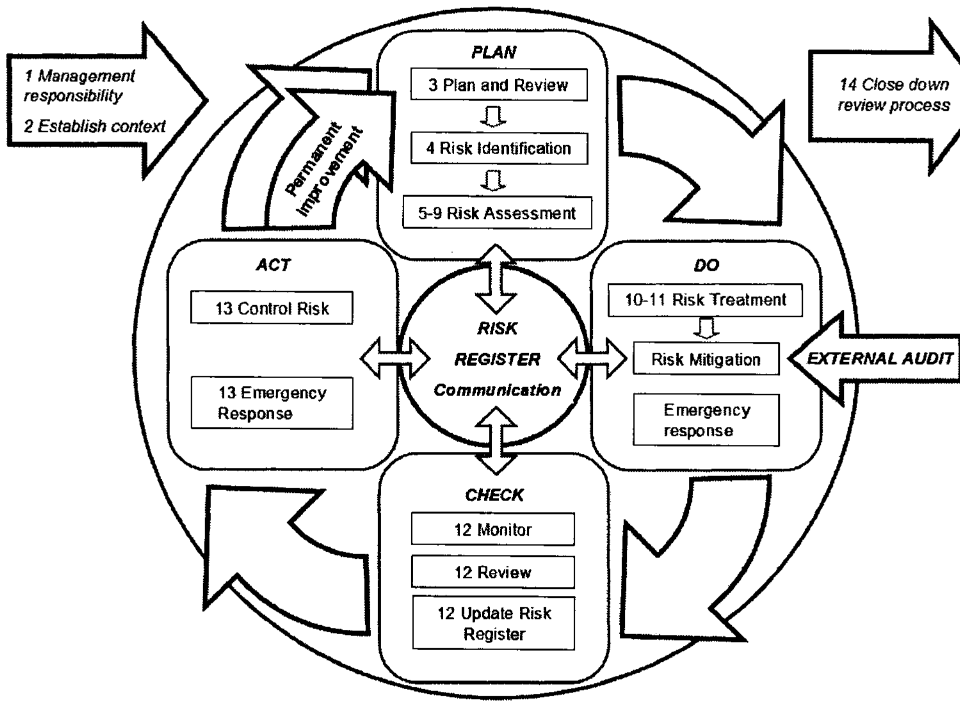

Figure 5-1 Systematic Risk Management in Tunnelling Projects

Following is a description of the 14 elements and its development through a project.

5.2.1 STEP 1: Management Responsibility

For the Risk Management System (RMS) to be effective, the involvement and commitment of the Owner's top management is required with some of the following responsibilities (adapted from ISO/FDIS:9001, 2000):

- Promote the creation of the Risk Management (RM) process by assigning a representative to lead a team through the RMS
- Communicate through all the project participants the importance of meeting RM requirements for: safety, third parties, schedule, environment, regulatory and legal.
- Establish the Risk Policy
- Provide adequate resources for the operation of the RMS
- Conduct management reviews of the operation of the RMS

5.2.2 STEP 2: Establish context

Risk Policy: The owner of the project shall ensure that the Risk Policy (adapted from ISO, 2000):

- Fits the purpose of the organization and its risk tolerance levels and of other stakeholders, in particular to third parties
- States commitment to comply with the requirements needed to maintain a satisfactory development of the RMS
- Provides a framework for the management review of RM Objectives
- Is communicated and understood within its organization and partners in the project (consultants, designers and contractors)

Risk Management Objectives: Risks are not equally consequential and every person has different perception for a particular risk. Risk Management Objectives should be defined in order of importance. The priority depends on which entity is conducting the assessment in the different stages of the project. For instance a contractor will be interested only in the risks that it might face during construction, while the owner might be interested in the ones that will remain in its ownership. Not all performance measures can be represented with monetary value, for instance, damage to third party property might involve a small percentage cost of the project, but can have important social and political adverse consequences. For the initial Qualitative Risk Assessment the following variables are to be ranked (Appendix H):

- Safety
- Time
- Cost
- Quality
- Environment

For each, a performance indicator should be established in order to measure its fulfilment, some examples are:

- Completion of the project with 90% cost certainty

- Minimization/Maximization of objectives like: minimize third party exposures
- Targets to be met and required actions to make it happen like: finishing the project earlier than a certain date
- Reduce risks "as low as reasonably practicable" (ALARP)
- Conduct RM at a level where its value is maximized (avoid "paralysis by analysis")
- Allocate each risk to the best party to handle it
- Fix risk tolerance limits
- Further analysis of "low probability-high consequence" events
- Further analysis of the 20% of risks that account for 80% of the uncertainty (Pareto's rule)

Management strategy: In order to maximise the RM process, different Risk Assessment cycles should be run during the phases of the project at different depths depending on the information available at least at the following stages:

- Planning and Development
- Conceptual design
- Detail design and Procurement
- Construction

The Risk Management Strategy defines the steps to perform the RM process, from its initial stage to its close down including, among others: tasks to be done to achieve objectives at the different phases of the project and ownership of risks and tasks, monitoring, audit and review procedures. It establishes timing for risk reviews, as well as the number of Risk Assessment cycles and phases in the project and finally a budget for the RM process and the way to be used phase by phase.

At this stage a meeting among the Owner and Risk facilitator or leader, defines the level of Risk Analysis to be undertaken that could range from a single Project Manager going over a checklist, to the planning of an agenda and people involved for Risk Analysis Workshops, this guideline is structured in a workshop format. The level of analysis (qualitative or quantitative) is defined according to the information available for the analysis. Figure 5-2 presents the Systems Integration of Risk and Project Management practices. Project Stages of the process and its respective RM cycles are represented together with Value Engineering studies as both are complementary. The elements presented in Figure 5-2 contribute all to the project's risk reduction.

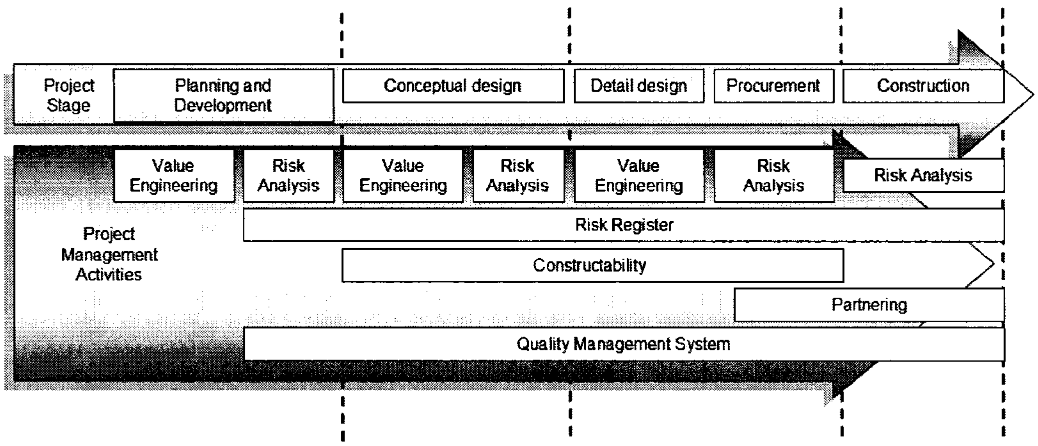

Figure 5-2 Risk Management cycles and Systems Integration of Project Management practices for tunnelling projects

<u>*Risk Management Team:*</u> The blend of people to participate in the RM process should ideally:

- Maximise synergy and minimise biases
- Be objective
- Be knowledgeable of projects objectives and constraints
- Have each of the disciplines represented
- Be small enough to facilitate effectiveness without sacrificing valuable input
- Be flexible
- Tend to think not only in the obvious (devil's advocate role)
- Develop a partnering spirit

- Excel in communication

It is recommended to maintain meetings in a relaxed atmosphere to facilitate open and direct communication towards the integration of the team to make it aware that they are the originators of the RM System and are all collectively achieving the success of the project.

5.2.3 STEP 3: Plan and initiate Risk review

Level of detail to be undertaken: At the early design stage a Qualitative Risk Assessment to identify and prioritize the main risks would be the principal objective. Later in the project when more information is available the process is reviewed at the same level of detail, or if necessary and sufficient information is available, with a more sophisticated analysis (AbouRizk, et al. 1999; Einstein et al, 1999). It is imperative to recognize early in the practice of RM that the main objective is to identify risks and actions to be taken to manage them. The process should not waste resources in complex modelling if sufficient and reliable data is not available.

People involved: The Risk Assessment should have at least representatives of the Owner, Geotechnical and Design teams. The presence of an experienced contractor, as a consultant, is indispensable in order to gather ideas from all the stages of the project and from the construction stage in particular, as this is the point where the majority of risks materialize. Constructability should always be present during design (Muir-Wood, 1990).

Project Brief: This document contains the available information of the project to be delivered to the participants at least a week before the Risk Workshop or earlier, in order to provide introductory information previous to the meeting. If at this stage a Value Engineering study has been conducted, it should be included in the brief.

Risk Review: This stage establishes at each of the RM cycles the status of risks in order to define new and ongoing risks and tasks, as well as the close down of each until the RMS fulfils its purpose and close down. This is the point in the process where contingency is re-evaluated to be augmented if emergency response needs it, to transfer it to the base cost if the risks already materialized or to release it partially or totally from the project. This is of particular importance as cash flow is always an issue for any Owner.

5.2.4 STEP 4: Identification

Some of the risks in the project will not be known and some others that will materialize will not be foreseen. With this in mind, the challenge is to identify all risks that might have a considerable impact to the project objectives. Brainstorming sessions and Checklists have been successfully used in tunnelling practice in Canada. The recommended structure to follow is to provide to the participants with the programme of activities and breakdown structure of the project and ask the participants to write statements for each risk. The Risk Statement should be clear and concise providing a full description of the risk. The following condition-consequence format is recommended:

"Given the <condition> there is a possibility that <consequence> will occur" (NASA, 2002). It can be supplemented with additional information to put the risk in the context associated with its statement (assumptions associated with the risk, supporting information). Other option for the description of risks is for the participants to ask themselves the questions: "What can go wrong?", "What can change and adversely affect to achieve the project objectives?" and write their input as follows:

Activity	Spoil removal
What can go wrong?	Spoil removal can slow production
Description:	Spoil can freeze in car during winter time in the portal area and be difficult to extract Mud difficult to pump Conveyor belt breakdown

The use of a *Prompt List* (Appendix B) facilitates specific risk identification; these lists can be augmented as experience is built within the organization. Prompt lists are single words or short expressions intended to trigger ideas towards risk identification

With the elements in writing each of the participants are ready to collaborate in the brainstorming session. Risk Identification is the principal element that sets the bar for the RM process as the risk recognized would be the only ones to be managed properly, the rest of the process can only be as good as the identification phase. No criticism is fundamental to promote creativity.

Once risks have been identified the use of *Checklists* help verify that topics or areas that are common form project to project have been covered, its use is encouraged only after prompt lists have been reviewed and before the closing of the brainstorming session. Checklists effectively sabotages creative thinking, they should be used as what they are, a verification tool. This is a convenient point to provide a brake for the session in order to avoid exhausting creativity.

The next step after the brake is to classify risks by groups in a format to avoid duplication and classify the risks as independent of each other as possible. Risks that have strong dependency should be considered as one risk group where further analysis might be required. Independency among risks is a must for their estimation. Once risks have been identified, briefly described in the "What can go wrong?" format and listed as independent as possible, this information is recorded in a Risk Sheet (Appendix I) for each risk. The individuals identifying the risks are the best to start the description of them including: Risk Name, ID, Author, Status, Last update, Date identified, Date approved, Risk Description, Cause or source, Impact to project objectives (Safety, Time, Cost, Quality, and Environment). After this exercise all risks are discussed and the Identification section of the Risk Sheet complemented.

5.2.5 Risk Register

The Risk Register contains the list of recognized risks recorded in each Risk Sheet. The risk register can be managed in a spreadsheet or in a database. The information related to the other elements of the RM process is documented and updated in the risk register. The risk register is a live document and is the cornerstone of communication throughout the process

5.2.6 STEP 5: Evaluate Risks

Risk has two components: The frequency of occurrence or likelihood and the consequence or impact:

$$\text{Risk} = (\text{Likelihood})\,(\text{Impact})$$

To assess risk, both must be evaluated. Risk Management is a dynamic process as risks change through time, a risk today might not be a risk tomorrow and vice versa. There are two analysis levels for the estimation of risks depending on the data available: Qualitative and Quantitative analysis.

The objective of the *Qualitative Analysis* is to allow the Risk Management team to prioritize risks in a straightforward and quick manner without paying much attention on the exact value of the risk but in meaningful rough approximation. The estimation of risk is made through *Likelihood and Consequence scales*, their multiplication generates a *risk matrix* for the assessment of risks. Qualitative scales are determined by the risk tolerance of the Owner varying the number of classifications and values of the scales. It is recommended that each organization define their own and use them systematically to allow comparison of historical data, different approaches can be found elsewhere (ICE et al, 1998) (AIRMIC et al., 2002), (NASA, 2002), (OGC, 2002), (PMI 2002), (RICS, 2003), (BTS, 2004), (Eskesen et al. 2004). Tables 5-2, 5-3 and 5-4 present three examples of different criteria for the evaluation of Likelihood, Consequence and Risk Assessment.

Table 5-1 Likelihood /Probability scales (modified form Godfrey, 1986)

Description	Guidance	Scale 1	Probability (Godfrey, 1986)
Very likely	Likely to occur frequently, many times during the period or section of concern (e. g. project duration, project length).	5	100/T
Likely	Several times in the period of concern.	4	10/T
Unlikely	Some time in the period of concern.	3	1/T
Very unlikely	Unlikely but possible in the period of concern (e. g. once in ten times the project duration)	2	1/10T
Almost impossible	Just possible but very surprising	1	<1%

T could be defined as the project duration, km or % of works

Table 5-2 Consequence scales (modified form Godfrey, 1986)

Description	Guidance	Scale 1	Cost $ (Godfrey, 1986)
Catastrophic	Death, system loss, criminal guilt, bankruptcy	5	100V
Critical	Occupation threatening injury or illness, major damage, substantial damages, exceeds contingency, dividend at risk	4	10V
Serious	Lost time injury or illness, damage causing down time of plant, consumes contingency, requires an insurance claim	3	1V
Marginal	Injury or illness requiring first aid at work only, minor damage that can await routine maintenance will only require an apology letter, accommodated as part of contingency or insurance excess	2	V/10
Negligible	So minor as to be regarded as without consequence	1	V/100

V value determined by owner's risk tolerance

The V value of scale "Cost $" in Table 5-2 is determined by the owner's risk tolerance. The owner needs to decide of a nominal value of V, this can be the estimated monetary value that fits the "Serious" description: "Lost time injury or illness, damage causing down time of plant, consumes contingency, requires an insurance claim".

Table 5-3 Risk Assessment for Scale 1 (modified form Godfrey, 1986)

Likelihood	Probability	Consequence Catastrophic 5	 Critical 4	 Serious 3	 Marginal 2	 Negligible 1
Frequent	5	25	20	15	10	5
Probable	4	20	16	12	8	4
Occasional	3	15	12	9	6	3
Remote	2	10	8	6	4	2
Improbable	1	5	4	3	2	1
		Intolerable	20-25			
		Significant	10-19			
		Tolerable	4-9			
		Negligible	0-3			

Throughout the literature, likelihood/probability and consequence scales vary widely; this is due to the different risk tolerances from project to project or among organizations. Scale 1 offers simplicity having identical scales (from 1 to 5) for Probability and Consequence what make them straightforward in prioritizing risk value (NASA, 2002). It should be noted that when scales are the same, low consequence - high probability events have the same value as low probability - high consequence events as shown in Table 5-4.

Table 5-4 Comparison of high and low consequence events

Risk	Likelihood	Consequence	Risk Value	Assessment
Water inflow	5	1	5	Tolerable
Death	1	5	5	Tolerable

Although both risks have the same value, any potential catastrophic event, even with an improbable occurrence should be further reviewed at a reasonable level. The relevance in this is that RM focuses in measures to reduce the impacts as probabilities are more difficult to control or not at all. Awareness of the possible extremes of risk is much more important than accuracy of details. Combining linear scales for probability and logarithmic scales for impact, helps differentiate the ambiguity described above (ICE et al, 1998).

If the impact is to be subdivided by each of the objectives (safety, time cost, quality and environment), the scales together with the objective criteria generate a "Qualitative Risk Assessment for Risk Prioritization" (Table 5-5).

This approach provides a risk rank where the assessment combines the weighting vector values obtained from the objective criteria (Appendix H). It allows a clear, fast and straightforward assessment of the importance of the risks analysed regardless of the detail of the real probability or consequence in monetary terms of risks. This list can be easily modelled in a spreadsheet and then risks be sorted by rank and then by the presence or not of High impact from the rightmost column. The Pareto rule can be applied where, 20% of the risks generate 80% of the total value of risks. This prioritization helps focus on the risks that have more effect on the project.

Table 5-5 Qualitative Risk Assessment for Risk Prioritization with Scale 1 values

Risk ID	Risk Name	Probability 1 Low 5 High	Impact on objectives 1 Low 5 High					Rank see formula	
(A)	(B)	(P)	Safety (D)	Time (E)	Cost (F)	Quality (G)	Environment (H)	(I)	Any High impact?
Rank = P • (D•WVS + E•WVT + F•WVC + G•WVQ + H•WVEn)								WVS	Safety
Weighting Vector Value on:								WVT	Time
								WVC	Cost
								WVQ	Quality
								WVEn	Environment

Another option when monetary value is to be used is proposed by Godfrey and Halcrow (1996), in columns "Probability" and "Cost $" in Tables 5-2 and 5-3. These scales generate the Risk Matrix in Table 5-6:

Table 5-6 Risk Assessment for Probability-Cost $ scale

Likelihood	Probability	Catastrophic $100V	Critical $10V	Serious $1V	Marginal $V/10	Negligible $V/100
		Consequence				
Frequent	100/T	10000V/T	1000V/T	100V/T	10V/T	V/T
Probable	10/T	1000V/T	100V/T	10V/T	V/T	V/10T
Occasional	1/T	100V/T	10V/T	V/T	V/10T	V/100T
Remote	1/10T	10V/T	V/T	V/10T	V/100T	V/1000T
Improbable	<1%	V/T	V/10T	V/100T	V/1000T	V/10000T

T could be defined as the project duration, km or % of works

V value determined by owner's risk tolerance

Comparison of results with risk acceptance criteria

The values of Tables 5-2, 5-3 and 5-6 can be grouped in the classification shown in Table 5-7 in order to determine the actions to follow in the management of each risk. The ranges presented are just examples as each are defined by the Owner.

Table 5-7 Acceptance Risk Criteria

Description	Meaning	Scale 1	Probability-Cost $
Unacceptable	Intolerable, must be eliminated or transferred	15-25	100V/T-10000V/T
Undesirable	To be avoided if reasonably tractable, detailed investigation and cost benefit justification required, top level approval needed, monitoring essential	5-14	V/T-10V/T
Acceptable	Can be accepted provided the risk I s managed	3-4	V/100T-V/10T
Negligible	Not further consideration needed.	1-2	V/10000T-V/1000T

Semi-Quantitative Risk Analysis

Quantitative Risk Analysis can be performed when enough data is available to represent the risks analyzed in terms of probability and consequence. In tunnelling the availability of this information is rare and a Semi-Quantitative Risk Analysis is presented instead.

The Semi-Quantitative approach consists of asking practitioners the true value of probability of a certain event between 0 and 1, where this number is used in the actual calculation of risk together with the real monetary value of the impact (Ayyub, 2001). In this case different subdivisions of risks can be applied. One risk can present different scenarios in combination of different probabilities and impacts as presented in the following description (Table 5-8) derived from the probability tree (Figure 5-3):

Table 5-8 Risk probabilities derived by tree

Risk	Case	Probability	Description	Cost basis	Cost $000	Risk $000
Building settlements due to dewatering	No event	0.8			0	0
	Low	0.16	6 properties with minor cracking	$5,000	30	4.8
	Medium	0.036	12 properties with minor cracking and 2 with major cracking	$60,000	100	3.6
	Severe	0.004	As above plus one property with severe cracking	$500,000	200	0.8
				Average value of risk		9.2

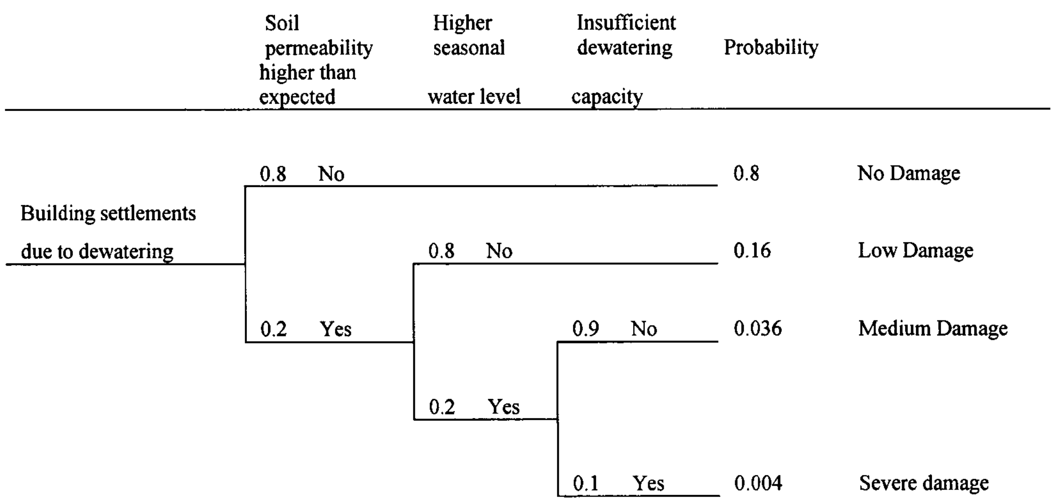

Figure 5-3 Probability tree

The multiplication of probability and consequence of each option of each risk and the addition of all of them provides the average risk value of the assessment. In order to provide a detailed representation of the uncertainty involved, Monte Carlo simulation can be used to provide not only the average value of the risks but the standard deviation of the assessment. This method is not in the scope of this guideline.

5.2.7 STEP 6: Risk Mitigation

Once risks have been assessed and prioritized it is possible to establish the risk mitigation measures to manage them, typical actions involve: avoid, reduce, transfer, insure or accept. Each risk can have one or all of the options available. Consideration in the evaluation should be done in order to optimize the measures to provide the best value for the actions to be taken.

Avoid risks is a preferred action in underground engineering, this is most of the time accomplished by providing different horizontal and vertical alignment options when available. Alignment selection is one of the most important decisions that can be further detailed through Value Engineering workshops in order to provide the optimum option. In some circumstance alignment constraints does not allow flexibility and further measures should be consider, in any case the final decision depends on the optimum balance of risk and cost/benefit of the action taken.

Reduce: Risk reduction aims to lessen the impact of risks or its probability of occurrence through: design modifications, adding or increasing safety features, including warning devices. Regarding human factors risk reduction can be accomplished by implementing procedures and training in order to attract the attention of the people involved within the activity of their responsibility and its control. Flexible design plays a major role, allowing when possible, modification through construction making use of the Observational Method (Peck, 1969; Powderham, 1998). Instrumentation plays a major role, as preventive and remedial measures can be set prior to construction and to be in action once trigger levels are reached. The whole process should be assessed in order to provide measures that are less costly than the risk itself. Risk reduction is particularly important for risks having potential catastrophic consequences. When reducing risks special care should be taken in order to re-evaluate the generation of new risks as a consequence of design modifications.

Transfer: Transferring risk should be considered only when the receiving party is better suited to cope with the risk, as transferring risks does not eliminate it. The risk may return to the originator in the event that the receiving party goes bankrupt or the contract is found to be unfair. Contractual terms define the responsibilities on the management of transferred risks. It is strongly encouraged the use of Geotechnical Baseline Reports in order to provide a clear scope of responsibilities when transferring underground risk with respect to unforeseen ground conditions (Clayton, 2001).

Insure: Insuring tunnelling projects has become a stringent process. Insurers are reducing coverage extensively and premiums have increased to levels never seen before. Insurance should be perceived as an uncertainty reduction measure in return for a premium. On the other hand, there are limitations as not all risk are insurable or they are but only up to a certain amount. For these reasons is important to consider insurers as the last resource for risks that have a low probability of occurrence but potential catastrophic consequences.

Accept: Risks are retained: when its value is low enough that does not pose any significant threat to the organization, when after a cost/benefit analysis is found to be worth to retain them or when we fail to identify them. From this description we find the active and passive acceptance of risks. Active risks are those we identified and consciously accept and we are willing to pay if they arise. Passive acceptance of risks includes risks that were not properly assessed in terms of impact, risks inadequately managed and those not identified.

It is a fact that not all risks in a project will be identified, thus; they will have a passive acceptance. Many of them will arise during the course of construction and will need to be dealt professionally in order to accomplish overall objectives from stakeholders. *Partnering* is the RM practice that helps in dealing with unidentified risks strengthening the working relationship and avoiding adversarial conflict that can escalate in adverse results. Figure 5-4 presents some of the elements that contribute in the risk reduction with partnering practices.

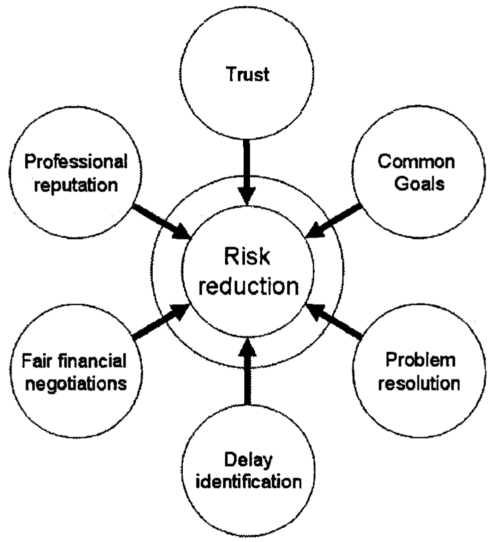

Figure 5-4 Partnering elements for Risk Management

The adoption of Partnering practices is not straightforward as the construction industry is highly adversarial. Trust is one of Partnering's pillars and is the fundamental driver that helps in the resolution of conflicts before they escalate. The adoption of Partnering practises in tunnelling projects is highly recommended. For further literature on Partnering refer to (USACE, 1991). Figure 5-2 presents the role of partnering around the integration of Project Management Systems.

5.2.8 STEP 7: Secondary risks evaluation

Once mitigation measures are proposed and the specific risk reduced it is important to identify if the measures introduce any new hazards to the project or impairs any part of the system's performance, if this is the case, a new countermeasure is required. As the organization's resources are limited, resources to control risks are limited, from this perspective it is considered that a solution operates beneficially only if its risks are more than offset by its benefits; in the same manner a measure is "safe" only to the degree that its risks are acceptable (Simister, 1994). Overall, risk measures should be analyzed for their effectiveness, feasibility and cost.

5.2.9 STEP 8: Cost contingency

There is extensive literature related to the common underestimation of costs in construction (Heat, 2004; Flyvbjerg et al, 2002, 2003; Gilbert, 2002), as well as the important role of adequate estimation of contingencies in project management (Flanagan, 2003; Klien, 2004). There is a variety of methods to approach to this problem (Lichtenberg, 2004; Edwards, 1995; Martin and Sadek, 2000), as well as software for this purpose (Hall et al. 2001; Reilly and Brown, 2004). What is important is to raise awareness of the factors that affect the bottom line. The components of an estimate when using risk analysis are:

Fixed costs (no variability)	$000
Uncertainty contingency (three point approximations)	$000
Risk contingency (probability • $impact)	$000
Total	∑$000

Fixed costs: Composed of the elements that are known with certainty and its monetary value are not expected to change significantly during the project and can be assumed to have one value throughout the project.

Uncertainty contingency (Range Estimate): Contains the items that have uncertainty in their estimate and its value can not be precisely established. When data is scarce this estimate can be approached with three point estimates elicited from the estimator based on past projects. The results of the process are highly dependent on the quality of the data provided by the estimator.

Risk Contingency: Derived from the addition of all risks cost estimated with the method chosen in the Risk Assessment, this can be easily calculated among others, with the root mean square method used in the "Estimating with Risk Analysis (ERA)" method by Barnes (Edwards, 1995).

5.2.10 STEP 9: Ownership

A RM rule of thumb is that each risk should be assigned to the best party to handle it. The ownership of risk should be clearly defined in the contract (Melvin, 1998; Rahaman and Kumaraswamy, 2002; Samuels, 2002; Faber and Stewart 2003). During the first cycles of the RM process prior to the preparation of the contract, consideration should be given to the adequate assignment of risks where each risk should be clearly explicit. A natural companion for RM in tunnelling projects and contractual arrangements is the Geotechnical Baseline Report (GBR) as it provides explicit limits of risk acceptance from the owner and this provides opportunity for contractors to provide competitive bids (Figure 5-4) benefiting owners and contractors (Essex, 1997, 2004; Essex and Bartholomew, 2004).

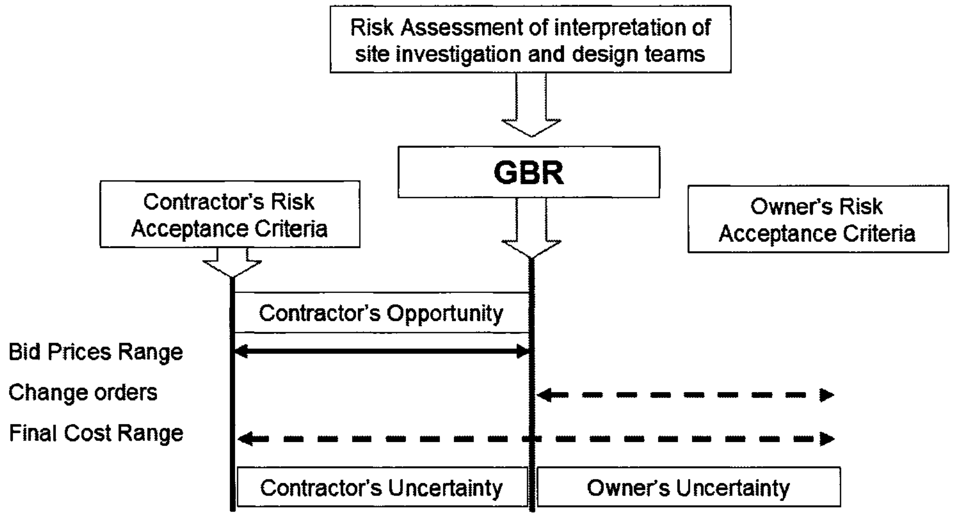

Figure 5-5 Geotechnical Baseline Report and uncertainty ownership

The GBR is an excellent communication tool to express the ownership of geotechnical risks and the terms of the contract in the event of unforeseen ground conditions, the most common source of uncertainty in tunnelling projects (Morgenstern, 1995; Kangari, 1995; Christian, 2004; Choi et al, 2004). The GBR provides uncertainty reduction in contractual terms that provides grounds for conflict resolution and avoids the owner to pay contingencies built in contractor's base estimates. The GBR helps avoiding unfair contractual relationships that most of the time affects participants in the project leaving no winners.

5.2.11 STEP 10: Implement mitigation actions and Emergency response

A Risk Response Plan should be generated with the results of the risk assessment and the respective ownership of risks. Its implementation should be verified where countermeasures should be in place. The Risk Response Plan should contain:

- Plans for the minimization and control of risk's impacts
- Instrumentation measures and trigger levels
- Contingency budgets
- Levels of authority and responsibility matrix during eventual crisis management

5.2.12 STEP 11: Communicate Strategy and plans

Risk should be communicated; it is important to verify that each risk owner is aware and have knowledge and understanding of the risks under its responsibility. A risk to be properly managed should be understood, a detailed description of the means and methods for the containment of risks should be provided by the risk owner. Basic information emanating from this stage should be reflected in the Risk Register for permanent communication.

5.2.13 STEP 12: Monitor, review and update ongoing Risk Register

This stage reviews the risk register activities and records new risks and its assessment. The systematic monitoring of performance measures allows trend analysis in order to control and react in a timely fashion when trigger levels are reached. The Risk Register re-evaluation and update feeds the report of out-turn costs at each RM cycle. This report should provide information on the availability of resources committed for the current stage of the RM cycle. It should be updated with the new information available, transferring allocated contingency that has already been used to be part of the base cost or released when risks are no longer a threat. This information should be present during weekly meetings and updated to the Risk Sheet and briefly described in the Risk Register.

5.2.14 STEP 13: Control Risks

Controlling risks involves putting in action the decisions made based on the information gathered during monitoring and review. Corrective actions if needed should be documented and assessed for effectiveness. The Controlling stage close the RM loop that will continue if further cycles are needed or be finished in the Close Down stage.

5.2.15 Audit

Project audit (internal or external) can take place at different stages of the project. One branch relates to the procedure of the RM System in itself, particularly verifying that risk reduction measures are being taken and that monitoring is being performed according to plan. The other branch relates to the risk budget and its allocation in order to assure that resources are in place to maintain the RM System current. These audits can take place at each of the cycles of the RM system (see Figure 5-1).

5.2.16 STEP 14: Close Down review Risk Management process

Close Down review of the process provides the learning lessons generator for future projects. This stage should be conducted by the Project Managers with help from other participants of the project that grasp the whole process from beginning to end as the evaluation focuses on expected and actual results. It is important to validate that all risks are closed and no pending activities exists. This evaluation can be straightforward by the assistance of a Closedown Checklist (Appendix J) where relevant information should be added for future use. An analysis of key performance measures of the objective criteria set at the beginning of the project should be compared with the actual results in a systematic manner from project to project. It is important to report the relevant factors of the project that consumed up to 80% of resources and the mitigation actions used as well as its effectiveness. The following points should be addressed:

- Comparison of actual risk with those anticipated
- Assess effectiveness of the process vs. objective criteria
- Assess the adequacy of analysis' level of detail (qualitative - quantitative)
- Lessons learned

- Improvement proposals
- Communicate results to stakeholders

A description of the comparison of the risk impacts with those anticipated should be recorded and updated for future reference.

5.3 Conclusion

The present guideline presented a basic framework with the steps needed to conduct Systematic RM for Tunnelling Projects. It described the main elements that constitute the process and its documentation through a Risk Register and its role as a live document throughout the project. This guideline provides the launching scenario for further upgrade of RM practices as detailed as a project might require. Its structure follows the Plan-Do-Check-Act model widely used in Total Quality Management and the ISO management systems standards, to facilitate system's integration in order to avoid communication bottlenecks and bureaucracy. It can be said that Risk Management is "rocket science" as this methodology is used to place astronauts in the space, but its procedures are straightforward and based mainly in common sense. The present guide illustrates that Risk Management does not need to be complex to be effective.

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Chapter 6 Conclusions

6.1 Research Summary

The present research analysed the practice of Risk Management in Canadian tunnelling projects in three main streams:

- In the impact of "The Joint Code of Practice for Risk Management of Tunnelling Works in the UK" in the international insurance market and the immediate impact to Canadian tunnelling owners, contractors and consultants. This information was gathered through interviews with Canadian and European brokers and underwriters on their corporate practices towards tunnelling projects in Canada.
- In providing insightful information about the current practice of RM in Canadian tunnelling projects as well as some perspectives on the international practice based on literature. This study was based on practitioner's opinion in a case based format through a questionnaire filled by experienced members of the Tunnelling Association of Canada as well as other international practitioners. The findings reveal the variation in RM practices among the Tunnelling Industry, and the gap to be filled to comply with the regulations to be required in Canada in terms of the implementation of auditable and systematic RM practices.
- Finally, the information gathered from the research previously described was consolidated in the start up guideline: Systematic Risk Management in Tunnelling Projects (SRMTP). This guideline consolidates the current practice of RM for projects in different areas and industries. The elements of the SRMTP were adapted to provide a succinct, no bureaucratic procedure to help the Canadian Tunnelling Industry shorten the gap between the current practice, to a systematic and auditable procedure. The implementation of this guideline would allow the Canadian tunnelling industry to better manage and retain more risks and have access to insurance, as well as improving the overall performance of the Tunnelling Industry in Canada.

6.2 Conclusions and Contributions

Following are the conclusions and contributions of each of the three main areas of this research:

6.2.1 Insurance in Canadian Tunnelling Projects: Current Practice

Insuring tunnelling projects has become a challenging process around the world as auditable RM procedures are becoming mandatory. The former is happening in an environment where the insurance industry is limiting coverage extensively; moreover, while the Code of Practice has already been required for Canadian tunnelling projects seeking insurance headquartered in Europe. It is expected that its full compliance will soon be required in Canada in less than two years. There is currently a lack of knowledge among the Canadian insurance and tunnelling industries on the requirements being asked in Europe and its impact in Canada. This is an area where the Tunnelling Industry will experiment very important Change Management challenges. Compliance with insurance requirements is becoming an important competitive factor.

It was found that there is an inconsistent approach perceived by brokers on the criteria established by insurance companies towards premium estimates for tunnelling projects. The Code of Practice would help the Tunnelling and Insurance industry to standardize requirements providing a uniform evaluation of the RM practices from companies seeking insurance. This should provide benefits in the long run not only to contractors and owners but to the Tunnelling industry in general. The practice of RM benefits owners and contractors in allowing more control over their projects, retain and control more risks, get insurance only for those risk that have minimal predictability and can have catastrophic consequences, as well as to maintain business operation. The high cost and requirements of insurance represents an incentive to improve the focus of RM and direct resources, not to high premium costs, but better planning, exploration, design, and construction practices and perceive insurance as a last resource. The path to follow by the tunnelling industry to achieve Risk Management maturity depends on the awareness of stakeholders of the risks involved and the capacity to handle them. Risk financing options should be optimized as RM maturity of the organization is gained. Contractors should inform brokers when positive standing is present in terms of their experience with past claims and RM practices in order to provide better terms for premium negotiation; the use of systematic RM practices provides a valuable performance tool for this evaluations.

6.2.2 Risk Management in Canadian Tunnelling Projects: State of Practice

Tunnelling practice concentrates in three main Canadian cities: Toronto, Edmonton and Vancouver, but Canadian consultants have a strong international activity too (42% of reported projects were abroad). Edmonton and Toronto lie beneath transported soils (glacial till), this fact explains that TBM-Open face is the method most frequently used and TBM-EPB to be the most effective method when compared by a ratio of length vs. number of tunnels due its safety and mechanized construction advantages.

Regarding practitioner's experience with Risk Management, it was found that these processes are neither systematic nor documented and the depth of analysis is variable. When RM is practiced, checklists (75%) and brainstorming (75%) workshops are well-established as Risk Identification techniques; while for probability estimation Likelihood verbal expressions are preferred by 70% of practitioners; this is not surprising in an environment where statistical data is scarce or null. Calibration among practitioners for probability elicitation with the same verbal expressions is required in order to provide reliability in the estimate. The preference for checklists, brainstorming workshops and likelihood verbal expressions, indicates that the tunnelling industry does not necessarily need to apply more complicated techniques to perform RM, but to have a systematic approach to its performance.

The Code of Practice makes reference to various Project Management practices, recommendations, and documentation that the Canadian tunnelling industry does not consistently conduct, leaving a gap to be shortened in the immediate future. The data presented here reflects an inconsistent approach of the tunnelling industry to RM. The need for systematic RM practices is evident. As auditable RM practices becomes mandatory, the temptation of preparing a RM plan just to fulfil a requirement is not only a bureaucratic obstacle but can be a dangerous option as it provides a sense of risk control, facilitating the overlook of real risks.

According to practitioner's opinion, the most important benefit of RM in tunnelling is the selection of the best technology. This demonstrates the relevance of RM practices as the selection of adequate technology is the single most important decision in the success of a tunnelling project; on the other hand RM, was identified to increase the chances of meeting budgets and schedules as well as setting proper contingencies. RM is recognized to help in the selection of the best alignments, where avoiding risks was the main driver, in fact in 96% of projects. The factor identified to be the most valuable in the success of tunnelling projects was having a qualified contractor followed by constructability, use of adequate technology and communication.

Even though the former benefits reported by practitioners, there are important obstacles found in the implementation of RM practices, being lack of managerial commitment the main one. This is followed by the fact that some people identify RM to have complex procedures and to be time and cost consuming. The difficulty in evaluating RM benefits represents a factor used by non-practitioners in resisting its practice. Regarding the projects provided by practitioners, it was derived that the most frequent ground conditions that affect the completion of tunnelling projects within schedule and budget are the presence of: boulders, saturated sands, free flow of water, wet silts, sand stone, soft clays and running sands (dry). These geotechnical conditions were identified by practitioners to happen at least 50% of the time.

Human error is one of the recurrent sources of risk during Tunnelling projects; the following list refers to the ones identified by practitioners to happen at least 50% of the time:

- *Geotechnical human errors:* too conservative conclusions, misinterpretation of the geology, "copy-paste" mistakes and lack of communication.
- *Design human errors:* Contradictory or unclear specifications, lack of communication, "copy-paste" mistakes, too conservative design, limited working areas, unrealistic schedules and lack of system perception of the overall project.
- *Construction human error:* Lack of communication, poor ground control/ poor grouting operations, poor QC/QA, inability to react to unforeseen ground conditions, inadequate handling of water conditions, modification to the specified excavation sequence, rework, lack of experienced work force, poor planning, poor site layout planning, survey error.

6.2.3 Systematic Risk Management in Tunnelling Projects (SRMTP)

Risk Management for tunnelling projects effectively promotes the practice of quality and safety management as well as adequate value engineering, project controls and monitoring systems. Its integration with Partnership, represents an ideal RM practice in dealing with risks not previously identified that develop during the course of construction. The integration of these elements is presented explicitly within a systems integration framework in the proposed SRMTP guideline.

Owners should be aware that soil investigation is one of the main variables that influence the bottom line of underground construction. Previous studies have shown the chronic tendency to invest less than enough in soil investigation that resulted in costly remedial measures during construction; for this reason, the guidelines make specific emphasis in the fact that owners are the driving force in establishing contract terms where Geotechnical Baseline Report and appointment of Dispute Review Boards are specified. Regarding the estimation of probabilities can become a tedious and difficult task that can make the real objective of RM be forgotten in technicalities. The estimation of probabilities and impacts do not need to be exact to be useful, what is important is to understand the level of uncertainty and identify the need for action. Finally, the quality of a RM system can be evaluated by the level of communication of risks among participants during the project from the conceptual stage until close-down, in this terms, the guidelines promotes expedite communication.

6.3 Recommendations for Future Research

Following are recommendations for future research derived form the present work:

- It is desirable to have the questionnaire applied for this study in the future, 5 and 10 years time to provide a comparative study on the improvement of RM practices of the Tunnelling Industry. Due to the fact that this initiative requires the support of the Tunnelling Association of Canada (TAC), it is recommended to have this initiative moved from within the Association.
- The local governments of the Canadian cities that have a soil boring network performed by the National Research Council, would find advantage to have geostatistical characterization and simulation of the subsoil to help in the assessment of the likelihood of encountering differing site conditions and help in

the decision making on the extent at which soil investigation campaigns should be undertaken.

- The use of Influence Diagrams was the third technique used by practitioners, it would be positive to see an increase in its use together with Bayesian Networks as these techniques are particularly useful in the calculation of subjective probabilities supported by limited experimental data. The use of Bayesian Networks is in the same train of thought of the observational method and the practice of geotechnical engineering.
- The efforts of Lukajik in the making of the first Canadian Tunnelling Catalogue should be continued by the tunnelling community in order to provide historical information to help improve the overall practice and knowledge of the tunnelling industry. A database accessible to members to post information of new projects as well as to providing retrieval would enhance the knowledge management of the tunnelling community.
- There is limited information about the benefits and obstacles that the Canadian tunnelling industry has encounter with the use of Geotechnical Baseline Reports (GBR), a study on its results would be beneficial to evaluate the cost/benefit of its practice.
- A database of results from Dispute Review Boards would provide a valuable source of knowledge in the better management of tunnelling projects towards the avoidance of litigious outcomes.
- It is recommended that insurance companies developed a key performance index in premiums/claims index in order to better assess owners and contractors and reflect this performance in premium price and avoid the scenario developed in the UK in 2001. Good practice or RM should be rewarded by Insurance companies.
- The SRMTP guideline encourages the use of a “Close Down Form” which contains a summary of the performance of the RM procedure in a specific project. This practice will provide information that can be compared in the future in the evaluation of the performance of construction companies, and owners (municipalities).

Appendix A: Questionnaire

Risk Management in tunnelling projects

(For an overview of the objective and expected contributions of this research, press the Ctrl key and this line, or refer to the last section)

Respondent experience

1) **Information of respondent:**

Ref#		
011	Name (optional):	
012	Company (optional):	
013	Position:	
014	City:	
015	Province:	
016	Phone:	
017	E-mail (optional):	
018	Tunnelling Experience (years):	

2) **We appreciate if you allow us to contact you in the near future in regard to this study. A summary of our findings will be available to you:**

021 [ ] Yes, I would like to provide more information regarding my experience in tunnelling.
022 [ ] No

Your comments are very valuable for the study; please develop your answer where you consider appropriate.

3) **Cities where you mostly worked in tunnelling projects in the last five years:**

Ref#	City	Province	Number of projects
031			
032			
033			
034			

4) **How many tunnelling projects have you been involved with?**

Ref#	Tunnelling method	Number of tunnels	Total length of all tunnels in km:	Comments
041	TBM open face			
042	TBM EPB			
043	NATM/SEM			
044	Drill and blast			
045	Other (specify)			

Most recent project

5) What is/was your role in your most recent tunnel project?

051 [ ] Owner
052 [ ] Geotechnical Engineer
053 [ ] Design consultant
054 [ ] Project Manager
055 [ ] Contractor
056 [ ] Other (specify) ______________________

6) What is the intended use of the most recent tunnel project in which you are involved in?

061 [ ] Transportation
062 [ ] Drainage (sewerage)
063 [ ] Water
064 [ ] Utility
065 [ ] Storage
066 [ ] Others – specify______________________

7) Specify the characteristics of your three most recent projects

Ref #		Project name	Diameter m	Length m	Depth m	Estimated productivity rate m/day	Actual productivity rate m/day	Total number of boreholes	Number of shafts	Value of project CAN$
071	Project 1									
072	Project 2									
073	Project 3									

If the project had different sections consider as different projects.

8) Specify with an (X) tunnel location

			Project 1	Project 2	Project 3	Comments
081	urban setting	Residential				
082		Downtown				
083		Other (Specify)				
084	Open field	through ravine				
085		mountain range				
086		river crossing				
087		Other (Specify)				

9) Provide a brief description of the general ground conditions of your current or most recent tunnelling project:

9.1 City:
9.2 General Ground conditions:
9.3 Describe possible difficulties/challenges pertaining to the underground conditions:

If you would like to provide information for additional projects please refer to "Optional questions 9 for additional projects"

10) Mark with an (X) the method employed to overcome the difficult ground conditions referred above?

Ref #	Method	Project 1	(Optional) Project 2	(Optional) Project 3	Comments
101	Mud stabilizers				
102	EPB				
103	Micro fine cement grouting				
104	Chemical grouting				
105	Jet Grouting				
106	Jackhammer (for boulders)				
107	Other (specify)				
108	Other (specify)				
109	Other (specify)				

Last two years or most recent experience to present

11) Based on all the tunnelling projects you have been involved in recent years, indicate with an (X) how often you found the following ground conditions:

Ref #	Ground condition	Always (5)	Almost always (4)	Often (3)	Almost Never (2)	Never (1)
111	Running Sands (dry)					
112	Saturated sands					
113	Wet silts					
114	Contaminated ground					
115	Methane					
116	Coal mines					
117	Land slides					
118	Free flow of water					
119	Boulders					
1110	Sand stone					
1111	Swelling ground					
1112	Soft Clays					
1113	Other (specify)					
1114	Other (specify)					
1115	Other (specify)					

12) For the three most frequent ground conditions indicated above, what mitigation measures would you commonly apply to reduce any negative impact?

Ref#	Ground condition	Comments
121		
122		
123		

13) What would you improve or change from your most recent project to reduce the factors that affected your schedule or budget? Rank in order of importance: (1 most important, 8 less important)

Ref#	Restrictions	Rank	Comments
131	Additional Boreholes		
132	Different contract strategy		
133	Different TBM		
134	Different tunnel support		
135	Different partners		
136	Other (specify		
137	Other (specify		
138	Other (specify		

14) Rank the factors that most influenced the final location of shafts in your most recent tunnelling projects. Rank in order of importance: (1 most important, 9 less important)

Ref #	Restrictions	Rank	Comments
141	Protected areas		
142	Limited work site		
143	Stakeholders concern		
144	Restricted work hours		
145	Geological hazard		
146	Difficult access		
147	Other (specify		
148	Other (specify		
149	Other (specify		

15) Indicate with an (X) the decisions that were applied in order to mitigate underground risks or risks pertaining to infrastructure facilities in your three most recent projects.

Ref #	Decision	Project 1	Project 2	Project 3	Comments
151	Change of partial vertical alignment				
152	Change of total vertical alignment				
153	Change of partial horizontal alignment				
154	Change of total horizontal alignment				
155	Preventive soil treatment				
156	Remedial soil treatment				
157	Relocating work site				
158	Other (specify)				
159	Other (specify)				

16) What was the method or methods of construction used in your last tunnelling project?

	Method of construction	Project 1	Project 2	Project 3
161	TBM open face			
162	TBM EPB			
163	NATM			
164	others (specify)			
165	others (specify)			

Risk management

17) Does your company conduct formal Risk Management (identification and treatment of risks) for tunnelling projects?

171 [ ] **Always in the past_____ years**
172 [ ] **Sometimes in the past_____ years**
173 [ ] **Rarely**
174 [ ] **Never**

Continues in next page.

18) Rank the main benefits of adopting Risk Management for tunnelling projects (1 highest rank- 9 lowest) :

Ref#	Benefits	Rank	Comments
181	Ability to meet cost and schedule		
182	Prequalification of contractors		
183	Understand the abilities required for the project		
184	More control over the project		
185	Lower insurance costs		
186	Clients trust		
187	Helps in the selection of the best technology		
188	Helps in the selection of the best alignments		
189	others (specify)		

19) Rank the main reasons for not adopting Risk Management for tunnelling projects (1 highest rank- 7 lowest) :

Ref#	Disadvantages	Rank	Comments
191	Time and cost consuming		
192	Complex procedures		
193	Does not make any difference		
194	Lack of commitment and resources		
195	Experience covers its contribution		
196	Is difficult to evaluate its benefits		
197	others (specify)		

20) Indicate the type of Risk Identification techniques used and approximate time effort:

Ref#	Risk Identification technique	Time effort in hrs	Team, people involved: Construction manager, Project managers, Inspectors, Engineers etc.)	Comments
201	Checklists			
202	Brainstorming sessions			
203	Risk register			
204	Comparison to previous projects			
205	HAZOP method (Hazard and Operability)			
206	Delphi Technique			
207	Other (Specify)			

21) Type of Risk Analysis techniques used to estimate risks' probability of occurrence

Ref#	Risk Analysis Techniques	X	Comments
211	Likelihood verbal expressions: Very likely, not likely etc.		
212	Monte Carlo Simulation: Range estimating, Schedule Analysis		
213	Event Trees		
214	Influence diagrams		
215	Fault Tree analysis		
216	FMA (Failure mode Analysis)		
217	Other (Specify)		

22) Once your projects have been analyzed through a risk management process, which are the most common residual risks you manage:

Ref#	Residual Risks	%	Risk management measures
221			
222			
223			
224			
225			

23) Does your company have a standard way to document the daily advance rate of tunnelling? (Example: Every tunnel data is recorded in the same formatted spreadsheet and stored in a common place to be used for the next project as historical data). If yes, explain your answer, if No, how is the data stored (inspector logbooks, etc).

Ref#		X	Detail your answer
231	Yes		
222	No		

24) Have your company been required to provide proof of Risk Analysis for a tunnelling projects from surety or other financial entities?

241 [ ] **Yes** **Required by** ______________________
242 [ ] **No**

25) If you have participated in a difficult tunnelling project due to unforeseen ground conditions that had been successfully completed from the stand point of the Owner, Designer, and Contractor. Rank the factors that you consider contributed to the success of the project. (Rank: 1 most important - 10 less important)

Ref #	Factor	Rank	Comments
251	Constructability		
252	Risk management		
253	Partnering		
254	Quality management		
255	Compliance to regulatory requirements (OH&S and/or environmental)		
256	Communication		
257	Owners experience		
258	Qualified contractor		
259	Use of adequate technology		
2510	Availability of GBR (Geotechnical Baseline Report)		
2511	Other (mention)		
2512	Other (mention)		
2515	Other (mention)		

26) Based on you experience how likely is to find the following human errors in Geotechnical Reports for tunnelling projects.

Ref #	Geotechnical human error	Almost certain	Very likely	Likely	Even chance	Unlikely	Very unlikely	Almost impossible
261	Misinterpretation of the geology							
262	Wrong conversion of units							
263	Too optimistic conclusions							
264	Too conservative conclusions							
265	Lack of system perception of the overall project							
266	Lack of communication							
267	Not reporting relevant parameters for the particular project							
268	"copy-paste"							
269	Other (specify)							
2610	Other (specify)							

27) **Based on you experience how likely is to find the following human errors in the Design Specifications for tunnelling projects that affect operations DURING construction.**

Ref #	Design human error	Almost certain	Very likely	Likely	Even chance	Unlikely	Very unlikely	Almost impossible
271	Limited working areas							
272	Wrong support system							
273	Contradictory or unclear specifications							
274	Wrong technology							
275	Wrong conversion of units							
276	Too conservative design							
277	Lack of communication							
278	Lack of system perception of the overall project							
279	Wrong excavation sequence							
2710	Tolerances unachievable							
2711	Shaft location							
2712	Number of shafts							
2713	Unrealistic schedule							
2714	"copy-paste" mistakes							
2715	Other (specify)							

28) **Based on you experience how likely is to find the following human errors during construction operations for tunnelling projects.**

Ref #	Contractor human error	Almost certain	Very likely	Likely	Even chance	Unlikely	Very unlikely	Almost impossible
281	Poor quality control QC/QA							
282	Inadequate handling of water conditions							
283	Poor site layout planning							
284	Wrong application of soil support system							
285	Poor ground control/ poor grouting operations							
286	Lack of communication							
287	Survey error							
288	Inability to react to unforeseen ground conditions							
289	Modification to the specified excavation sequence							
2810	Lack of experienced work force							
2811	Rework							
2812	Poor planning							
2813	Other (specify)							
2814	Other (specify)							

29) Please state any points of view not included in this questionnaire that you consider pertinent to be included in this study in order to better account for underground conditions in tunnelling projects:

Appendix B: Prompt List for Tunnelling Project

- ☐ Accident to workers
- ☐ Adequate interaction among tunnelling technology and labor (TBM, lining, etc.)
- ☐ Adequate number of shafts and location
- ☐ Adequate space and conditions for launching pad
- ☐ Advance rate not achieved
- ☐ Archaeological material found
- ☐ Boulders
- ☐ Bursting ground
- ☐ Coal mines
- ☐ Constructability
- ☐ Contaminated ground
- ☐ Contaminated groundwater
- ☐ Contractor experience and capability
- ☐ Contradictory or unclear specifications
- ☐ Copy-paste mistakes
- ☐ Delay in obtaining lining segments
- ☐ Delay in obtaining permits (construction, blasting, structures)
- ☐ Delay in obtaining TBM
- ☐ Delay in obtaining utility survey
- ☐ Delays, including problems at portal, shaft and station areas
- ☐ Differing ground conditions
- ☐ Difficult ground control
- ☐ Difficult grouting operations
- ☐ Difficulties in maintaining alignment
- ☐ Limited portal lay down areas
- ☐ Limited shaft lay down areas
- ☐ Limited working areas inside tunnel
- ☐ Methane
- ☐ Misinterpretation of the geology
- ☐ Mobilization time not achievable
- ☐ Modification to the specified excavation sequence
- ☐ Muck handling and disposal.
- ☐ Occupational health and safety compliance
- ☐ Open cut stability
- ☐ Pollution of groundwater with grouting operations or other means
- ☐ Poor planning
- ☐ Poor quality control QC/QA
- ☐ Poor site layout planning
- ☐ Problems completing final interior lining
- ☐ Regulations imposing technical or logistical limitations
- ☐ Rework
- ☐ Roof collapse
- ☐ Running sands (dry)
- ☐ Sandstone
- ☐ Saturated sands
- ☐ Saturated Sands/Silts
- ☐ Saturated soil
- ☐ Shaft location

- ☐ Difficulty obtaining insurance
- ☐ Environmental impact from blasting (noise, dust, vibration, etc)
- ☐ Environmental impacts (public, structures, traffic, etc)
- ☐ Existing utilities
- ☐ Fault zone
- ☐ Fire in tunnel
- ☐ Free flow of water
- ☐ Handling of slurry muds
- ☐ Inability to react to unforeseen ground conditions
- ☐ Inadequate handling of water conditions
- ☐ Labour disputes
- ☐ Lack of communication
- ☐ Lack of experienced work force
- ☐ Lack of system perception of the overall project
- ☐ Land slides
- ☐ Larger than expected settlements
- ☐ Leakage between tunnel segments
- ☐ Soft Clays
- ☐ Squeezing soils
- ☐ Subsidence (Heavy ground)
- ☐ Support system difficult to assemble
- ☐ Survey error
- ☐ Swelling Ground
- ☐ TBM assemble problems
- ☐ TBM bearing failure
- ☐ TBM seal broken
- ☐ Tolerances unachievable
- ☐ Too conservative design
- ☐ Unanticipated obstructions
- ☐ Unrealistic schedule
- ☐ Water inflows
- ☐ Wet Sands, Wet Silts
- ☐ Wrong application of soil support system
- ☐ Wrong conversion of units
- ☐ Wrong excavation sequence
- ☐ Wrong technology

Adapted from: BTS, (2004), Choi et al., (2004), Clayton, (2001), Gilbert, (2002), Melvin, (1998)

Appendix C: Risk Monitoring and Control Practices

- *Checklists or report for site geotechnical engineer's reference; periodic review by designer; periodic review by External Reviewers (either owner's or engineer's review board)*
- *Meeting of the construction supervision with the contractor. Quality Manual for each site. Contents depend on the particular project.*
- *Shift reports, inspections, meeting minutes, specialists on site, etc.*
- *Database system*
- *By reviewing the risks through site meetings and trying to mitigate them*
- *Handbooks to the site*
- *Varies from project to project. A lot depends on how the Client perceives the risk!*
- *Full time monitoring of encountered conditions*
- *By written communication*
- *Write GBRs, on-site construction observations*
- *Depends on the project and on the project manager*
- *Depends completely on the client. Typically there is a different process for each risk, ie: Claims from unforeseen ground conditions, Action: Develop GBR.*
- *Project develops a RM plan that outlines the mitigation items for each risk event. Each task has a start and end date. Appropriate team members area assigned monitoring and reporting of task. Management team reviews plan monthly to review, modificate*
- *Written procedures and formal training sessions*
- *Meetings, as required, to review status of recognized risks.*
- *Through claims*
- *Risk Register*
- *Risk plan/Method statements*

Appendix D: Advance Rate Documentation Practices

Does your company have a standard way to document the daily advance rate of tunnelling?

Yes (38%):

- *Inspection and shift reports*
- *Daily log and digital log*
- *Inspector log book, spread sheet*
- *Each advance is observed and recorded throughout the day. Contractor submits details of daily tunnelling progress reports.*
- *All information is stored electronically as well as in printed format.*
- *Daily logs*
- *Project close-out report prepared by Resident Engineer*
- *Normally as built records are made and can be referenced at a later date*

No (62%):

- *Generally varies from project to project; a project specific document will be prepared. For some projects, the Construction Manager may mandate the from to be used.*
- *Most projects are different. Newer Projects are stored on spreadsheets.*
- *It changes from project to project according to the client!*
- *Not sure of the answer to this one. Personally utilize spreadsheets which are fed by data from inspection reports*
- *Tunnel inspectors, contractors records, real time monitoring with TBMs*
- *Log books and field reports*
- *Ground movements are recorded and reported by independent consultants.*
- *Critical information is shared immediately with the Contractor.*
- *I have my own system - not a company system spreadsheet.*
- *Data from EPBM record digitally, survey and ground instrumentation readings record approximately once per advance, detailed shift reports, specific EPBM data plotted graphically each day*
- *We rarely get involved with construction management*

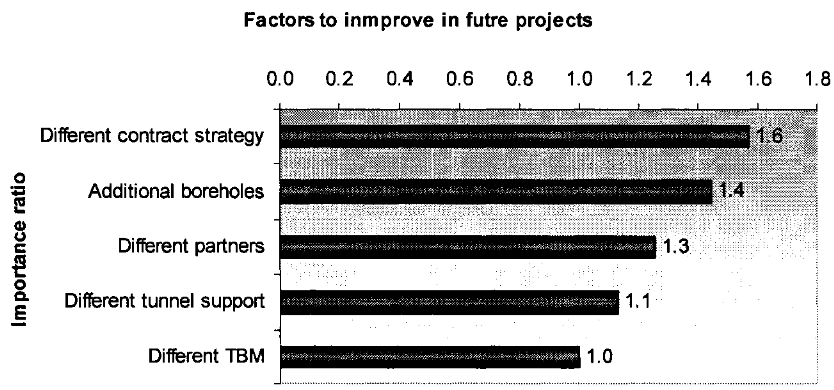
Appendix E: Human Error Checklist

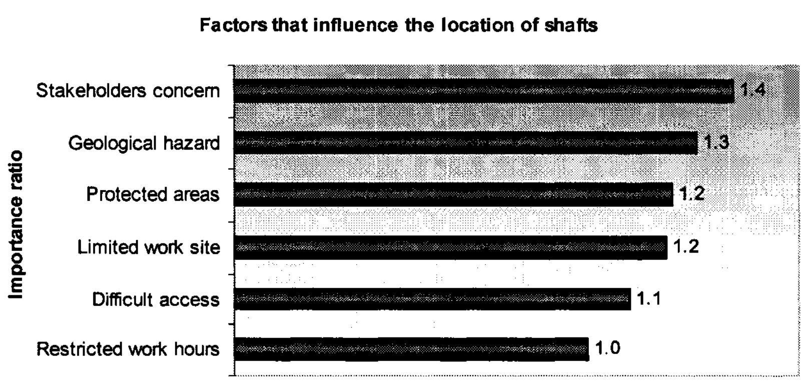
Geotechnical human error	
Too conservative conclusions	☐
Misinterpretation of the geology	☐
"copy-paste" mistakes in reports	☐
Lack of communication	☐
Design human error	
Contradictory or unclear specifications	☐
Lack of communication	☐
"copy-paste" mistakes in reports	☐
Too conservative design	☐
Limited working areas	☐
Unrealistic schedule	☐
Lack of system perception of the overall project	☐
Construction human error	
Lack of communication	☐
Poor ground control/ poor grouting operations	☐
Poor quality control QC/QA	☐
Inability to react to unforeseen ground conditions	☐
Inadequate handling of water conditions	☐
Modification to the specified excavation sequence	☐
Rework	☐
Lack of experienced work force	☐
Poor planning	☐
Poor site layout planning	☐
Survey error	☐

Human errors reported by tunnelling practitioners to happened at least 50% of the time

Appendix F: Tunnel Characteristics of Recent Projects

Measures applied to mitigate underground and infrastructure risks	% of projects
Change of total horizontal alignment	35
Change of total vertical alignment	28
Preventive soil treatment	20
Change of partial vertical alignment	17
Change of partial horizontal alignment	17
Appropriate selection of tunnelling methodology	10
Remedial soil treatment	10
Relocating work site	7
Change of partial vertical alignment	3
Change support from rock bolts to steel sets	3
High frequency blast monitoring	3
Replaced incompetent contractor	3
Selection of alternate construction method	3
Strengthened TBM face	3





Frequency of different ground conditions

Ground conditions	Always	Almost always	Often	Almost Never	Never	Total %	Cumu -lative %
Boulders	0	10	70	20	0	100	80
Saturated sands	5	14	57	10	14	100	76
Free flow of water	0	30	35	35	0	100	65
Wet silts	5	10	48	19	19	100	62
Sand stone	5	16	37	42	0	100	58
Soft clays	5	10	38	38	10	100	52
Running sands (dry)	10	0	40	35	15	100	50
Swelling ground	0	0	30	60	10	100	70
Methane	0	5	21	37	37	100	74
Contaminated ground	0	0	11	57	32	100	89
Land slides	0	0	5	58	37	100	95
Coal mines	0	0	0	42	58	100	100

Appendix G: Elements of Risk Management in Different Standards

PDCA	Step	RMTP	Code of Practice	ITA RM Guidelines	RAMP	CIRA 125	M_o_R	NASA	IEC 62198	ASAS/NZS 4360:2004	PRAM	PMBOK
		Establish context										
	1	Management responsibility							•			
	2	Establish context	•	•	•	•	•		•	•	•	•
		Risk Identification										
PLAN	3	Plan and initiate Risk review			•						•	
PLAN	4	Identification	•	•	•	•	•	•	•	•	•	•
PLAN		**Risk assessment**										
PLAN	5	Evaluate Risks	•	•	•	•	•	•		•		•
PLAN	6	Mitigate Risks	•	•	•	•		•		•		
PLAN	7	Secondary risks evaluation			•	•	•		•		•	
PLAN	8	Cost contingency	•			•						
PLAN	9	Ownership	•			•	•					
		Risk Treatment										
DO	10	Implement mitigation actions and Emergency response			•	•	•		•	•		•
DO	11	Communicate Strategy and plans			•							
		Risk Review and Monitoring										
CHECK	12	Monitor review and update ongoing Risk Register			•	•	•	•	•	•	•	•
ACT	13	Control Risks			•		•	•		•		•
		Close Down										
	14	Close Down review RM process			•			•				

Appendix H: Criteria Weighting Matrix Sample Calculation

	B	C	D	E
A	A 2	A 2	A 2	A 2
B		B C	B 2	B E
C			C D	C E
D				D E
E				

Total	Weighting vector
8	0.40
4	0.20
3	0.15
2	0.10
3	0.15
20	1.00

A	Safety
B	Time
C	Cost
D	Quality
E	Environment

Importance	Description
4	Major preference
3	Medium preference
2	Minor preference
1	Slight, no preference (letter-letter)

The process consists in, listing the objectives at random and assign a letter to each, then a comparison ob objective A made to B. If a major preference exists from A over B, it is written A4, if there is medium preference from B over A then it is written B3. If both have the same preference to the evaluator it is written AB. This comparison is made horizontally from A against the rest of the objectives. After this comparing A, B is compared and the same happens with the rests of the objectives.

From the results of all rows we add all numbers related to A, as: A2=2, or AC=1. This addition is done for each of the objectives generating the first column of the weighting vector. The values of this column are added, for this example, total= 20. The next column is the % of the value of each objective relative to the total for this example A=8/20=0.40.

Appendix I: Risk Sheet

Risk Sheet								
Identification								
Risk Name:								ID
								Author
								Status
								Last update
Risk Description:								Date identified
								Date approved
Cause or source:								
Impact to project objectives (Safety, Time, Cost, Quality, Environment)								
Risk Analysis								**Risk Assessment**
Probability of occurrence (during period of project)	Probability	Impact						Severity
		Safety	Time	Cost	Quality	Environment		
Risk Management								
	Cost of treatment	Description of possible Risk reduction measures:						
☐ Avoid	$							
☐ Reduce	$							
☐ Transfer	$							
☐ Accept	$							
☐ Insure	$							
Risk reduction action:								Risk owner:
								Completion date:
Risk Analysis of Residual Risk								**Risk Assessment**
Probability of occurrence (during period of project)	Probability	Impact						Severity
		Safety	Time	Cost	Quality	Environment		
Comments:								
Emergency response								
Activity response in case of emergency describing trigger levels:								
Specific Risk Management Tasks								
Specific tasks			Task owner:				Task reviewed:	
Close Down								
Lessons learned								

Appendix J: Risk Management Closedown Checklist

1. **Risk Management Process**

1.1. How many RM workshops where conducted and at which stages?

[ ] Panning and Development [ ] Conceptual design [ ] Detail design

[ ] Procurement [ ] Construction [ ] Other________________

1.2 The Risk Management process adequately addressed the 14 elements of the SRMTP Guidelines (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

Phase	Elements	RMTP	Mark
Establish context	**1**	Management responsibility	
	2	Establish context	
Risk Identification	**3**	Plan and initiate Risk review	
	4	Identification	
Risk assessment	**5**	Evaluate Risks	
	6	Mitigate Risks	
	7	Secondary risks evaluation	
	8	Cost contingency	
	9	Ownership	
Risk Treatment	**10**	Implement mitigation actions and Emergency response	
	11	Communicate Strategy and plans	
Risk Review and Monitoring	**12**	Monitor review and update ongoing Risk Register	
	13	Control Risks	
Close Down	**14**	Close Down review RM process	

1.3. [ ] Was RM part of the normal project meetings? (Should be documented with minutes)

1.4. Provide a table with the base cost estimate, contingency value for each RM stage.

1.5. Provide a table with original estimated and final values of objective criteria (safety, time, duration, quality, environment)

2. **Risk Identification**

2.1. How were risks identified?

[ ] Prompt lists [ ] What can go wrong list [ ] Brainstorming session

[ ] Checklists [ ] Comparison to previous projects [ ] Risk Registers [ ] Other_________

2.2. [ ] Risk Identification was effective (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

3. **Risk Analysis**

3.1. How were risks analyzed?

[ ] Likelihood-Consequence scales [ ] Fault Tree Analysis

[ ] Monte Carlo Simulation [ ] Other__________

3.2. [ ] The level of detail of the analysis was adequate (qualitative - quantitative), it efficiently addressed the important risks (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

3.3. Were risks prioritized? Yes [ ] No [ ]

3.4. [ ] Risks were updated at different intervals of the project. (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

4. **Risk Planning (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?**

4.1. [ ] Risk ownership of each risk was assigned and notified to each responsible person

4.2. [ ] All mitigation plans were adequately implemented

4.3. [ ] Adequate resources were assigned for effective implementation of the risk mitigation plans

5. **Risk Monitoring**

5.1. How were risks and risk monitored?

5.2. [ ] Mitigated and monitored risks were regularly tracked to ensure that trigger levels were not exceeded (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

5.3. [ ] Risk monitoring was effective (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

6. **Risk Documentation (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?**

6.1. [ ] The Risk Register was updated continuously

6.2. [ ] The Risk Register was communicated continuously

6.3. [ ] Risk sheets clearly documented all risk acceptances

7. **Risk Communication**

7.1. [ ] Risk status was regularly presented to the Owner. (Copies of PM presentations should be requested), (rank from 1 to 5, 5=totally agree, 1=disagree). Detail your answer, why?

7.2. The risk register was available as:

7.3. [ ] Spreadsheet file [ ] Database [ ] Internet accessible database