University of Alberta

Fuzzy Logic Application in Risk Analysis of Construction Management

BY

Mahsoo Naderi ©

A thesis submitted to the
Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

Department of Civil and Environmental Engineering

Edmonton, Alberta

Fall 2008

Your file Votre référence
ISBN: 978-0-494-47372-6
Our file Notre référence
ISBN: 978-0-494-47372-6

Abstract

The uncertainty of construction environments has made them one of the most highlighted fields in risk management. Although recently the construction industry has started to benefit from risk management and risk analysis, it has been discovered since the 1980s that construction is one of the industries most in need of applying risk management. Risk management is a procedure to control the level of risk in projects and to mitigate its consequences; therefore construction projects which deal with high level of uncertainty due to geographical factors, weather conditions, type of project, economical impact, subcontractor availability, political factors, construction delivery methods, etc. should follow an effective risk management and analysis plan. Risk analysis and assessment, one of the important steps in risk management, involves analyzing identified risk factors using a qualitative or quantitative method to determine the severity of the risk factors. This research reviews some models and methods in construction engineering literature and makes an original contribution to developing a quantitative risk analysis method based on fuzzy logic. This research seeks to develop a model based on fuzzy logic and fuzzy set theory to fill in some of the gaps between real construction environments and scientific approaches. Fuzzy logic plays a key role as the converter of natural verbal human thoughts to computational comprehensive intervals. Fuzzy logic and fuzzy set theory have been used as the foundation of this new methodology. Fuzzy intervals were used for input data in order to create more realistic assumptions than those derived from a set of crisp numbers; this leads to better results, fewer failures, and a lower tolerance for risk in construction project planning.

Acknowledgements

I would like to express my gratitude to all those who gave me the possibility to complete this thesis. I want to thank the Department of Civil and Environmental Engineering of the University of Alberta for giving me the chance to commence this thesis in the first instance, and for providing the facilities to do the necessary research work.

I am really thankful to my supervisor Professor Simaan M. AbouRizk, head of the Construction Engineering Management group, whose help, constructive suggestions and encouragement assisted me in conducting my research and writing of this thesis.

I appreciate Clark Builders for providing me with data and facilitating my work by sharing their knowledge in a friendly manner.

John Lunan	Tim James - Business Development
Paul Verhesen - Company President	Gerald Clark - Human Resources Manager
Aftab Jessa – Estimating Maneger	Scott Duncan – Safety Manager
Brian Lacey – Operations Manager	Donna Smith – Program Coordinator

I would like to thank Dr. Mohamed Al-Hussein from constriction management group of University of Alberta who kindly encouraged me in many occasions. I also thank Dr. Aminah Robinson in helping me to learn and understand fuzzy logic. I like to mention the people who helped me in technical writing, Ms. Andrea Hasenbank, and Mr. Jonathan Tomalty.

Especially, I need to thank my family and friends. I am deeply indebted my parents and my brother, Misagh, who supported me by all means. My very special thanks go to Milad Monshipour, who was a great support during my studies and defense.

Table of Contents

List of Figures

List of Tables:

Chapter 1 Background and Introduction

1.1 Background

In recent years, intensive research and development have been carried out in the area of project risk management, widely recognized as one of the most critical procedures and potential areas in the field of project management.

Voetsch (2004) found a statistically significant relationship between management support for risk management processes and reported project success. Cheng (2001) remarks that shortcomings and opportunities in this field have been identified. He also mentions that some of the deficiencies are related to the ever increasing complexity of construction projects. Subcontracting is expanding since many companies are focusing solely on their core business, which results in more complex project networks and greater numbers of project participants; therefore conflict of interests will result in higher risk level. Construction projects are characterized as very complex projects, where uncertainty comes from various sources (Miller 2001). Many research and practical techniques have been applied to manage all these uncertainties and their consequences; however, there is a gap between risk management techniques and their practical application by construction contractors and involved parties.

This study tries to find a quantification method for risk analysis and assessment based on fuzzy logic and fuzzy arithmetic. This method has been developed to meet the practical concerns of construction and to enhance the benefits of the procedure.

1.2 Problem Statement and Objectives

Construction environments are one of the most highlighted fields in risk management as the nature of the industry carries uncertainty. Every new project, even identical ones such as residential developments, office buildings, or chain stores, has new constrains. In a risk analysis and management procedure, one of the important steps is to calculate and quantify risks in a comprehensive and meaningful way. Different methods have been developed in this area, and all various approaches have their own advantages and disadvantages.

Despite different terminologies and definitions in the risk management literature the main goal and concept is almost the same, but different approaches are involved in gaining the best practice. In this research, many valuable methods are reviewed and a contribution in using the Fuzzy Logic methods and arithmetic for Construction Projects Risk Management has been made. The goals of this research are as follow

1. To conduct an extensive review in literatures and current practices in Construction Risk Management systems

2. To develop a systematic quantification method using Fuzzy Logic in risk analysis and assessment for Project Risk Management

3. To verify the method by applying the data from an existing project's risk analysis and to demonstrate the results of their comparison

1.3 Research Methodology and Organization

The present thesis is organized in six chapters starting with the Background and Introduction in Chapter 1, Literature Review in Chapter 2, Background of Risk Management Procedure presented in Chapter 3, a Fuzzy Quantification method in Chapter 4, the Case Study in Chapter 5, and finally the Conclusion and Recommendations in Chapter 6.

Chapter 2 mainly includes an extensive review in applied risk management practices for construction projects. The evolution of methods and systems is presented and discussed.

Moreover, this review tries to cover the works which has been done in the area of fuzzy logic applications in risk analysis and quantification.

Chapter 3 demonstrates a complete procedure to undertake a risk management plan for a generic construction project. In this part, the risk analysis is followed step by step with a presentation of different methods. In addition, a hierarchical chart has been produced as a useful checklist or guide for identifying risk factors This Chapter is the outcome of interviews with experts, questionnaires which are set to evaluate the practiced risk management methods in a general contractor company, and use of historical surveys.

Chapter 4 focuses on the development of a quantifying system for calculating the risk severity of different risk factors affecting a project. The concept of fuzzy variables and fuzzy arithmetic has been used in this part. A defuzzification method is addressed to compute a number as a final score for rating and prioritizing the risk factors.

Chapter 5 adopts data from an existing project risk analysis and applies the discussed method to identify risk severity of each risk factor. In this chapter a new chart has been introduced to prioritize the risk factors in a categorized way.

Chapter 6 is a summary of other chapters with conclusions derived from this research and at the end with some recommendations for future research.

Chapter 2 Literature Review

2.1 Introduction

This chapter will review the literature, introducing the concepts, terminologies and definitions in risk management with a focus on construction projects. Although recently the construction industry has started to benefit from risk management and risk analysis, it has been discovered since the 1980s that construction is one of the industries in need of applying risk management.

Much research has been conducted on this topic which tried to find a systematic process to overcome the issues taking place in construction projects. Risks associated with construction projects are due to the inherent nature of construction jobs. A variety of issues has been considered such as budget overruns, time schedule extensions, technical problems, safety issues and so on.

The first three sections of this chapter demonstrate what the literature says about uncertainty as the origin of risks and opportunities, risk as a result of uncertainty and some practiced methods to measure it. Afterwards, in part 2.5, the literature about fuzzy logic and fuzzy set theory are mentioned. The methodology for the quantitative part is based on fuzzy logic, fuzzy sets and related terms; therefore, fuzzy logic and fuzzy set theory and its application and terms in risk assessment are reviewed as well. Part 2.6 reviews more literature on risk management. Additionally, a few risk management standards are introduced in the last section.

2.2 The Nature of Uncertainty in Construction Industry

The Construction Industry Institute defines *Uncertainty* as "the gap between the information required to estimate an outcome and the information already possessed by the decision maker" (CII 1989). El-Cheikh (2007) suggests that "the nature of uncertainty in any problem is a vital point; scientists in general and engineers in particular should be able to determine this nature before choosing the suitable methods or models to express and address that uncertainty." In practice, the uncertainty in construction may arise from many possible sources such as geographical factors, weather conditions, type of project, economical impact, subcontractor availability, political factors, and construction delivery methods.

To have a deeper understanding of uncertainty, the nature of uncertainty should be reviewed. As a common example, Teres (2005) compared two origins of uncertainty by explaining throwing dice versus playing dominos. He discussed that if we throw a dice an infinite number of times and record the frequency with which each number appears, we will find that the probability of any of the numbers (1 to 6) appearing is 1/6. Knowing this for a fact, the next time we roll the dice we are uncertain as to 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 events, also known as *Aleatory Uncertainty*. Krinitzsky (2002) also remarks that "aleatory knowledge is predicted knowledge. It is satisfactory or unsatisfactory, depending on the nature of the prediction and the use that is made of it."

Terese (2005) clarifies the other form of uncertainty by explaining the game of dominos. The game starts with shuffling the pieces and distributing them between players. The fact is the pieces' arrangement is fixed while the values are unknown. By examining the pieces, we can discover the exact pieces each player has, but this is what the game is all about. The key to winning the game is to find the values of the pieces through observation during the game. In this scenario, uncertainty is due to a lack of knowledge. The more pieces we are allowed to see, the lower the uncertainty in guessing the value of the remaining pieces. This sort of uncertainty is known as *Epistemic Uncertainty*. Krinitzsky (2002) also defines epistemic knowledge as interpreted knowledge; he mentions that"it may or may not be uncertain. Interpreted knowledge has been certain enough in the past to constitute a highly rational basis for the development and growth of engineering, or there would be no engineering or much of anything else on a creative level."

These definitions denote that when more information becomes available, epistemic uncertainty tends to reduce, while aleatory uncertainty will not. It can be inferred that most engineering practices relate to epistemic uncertainty more than to aleatory uncertainty, as the risks involved in projects lessen through the end of them. This concept is shown in Figure 2.1. As the project proceeds the level of uncertainty decreases relatively. At the time of starting a project during feasibility studies through the end as the information and knowledge about tasks is clarified, the level of uncertainty and fuzziness of the project decreases.

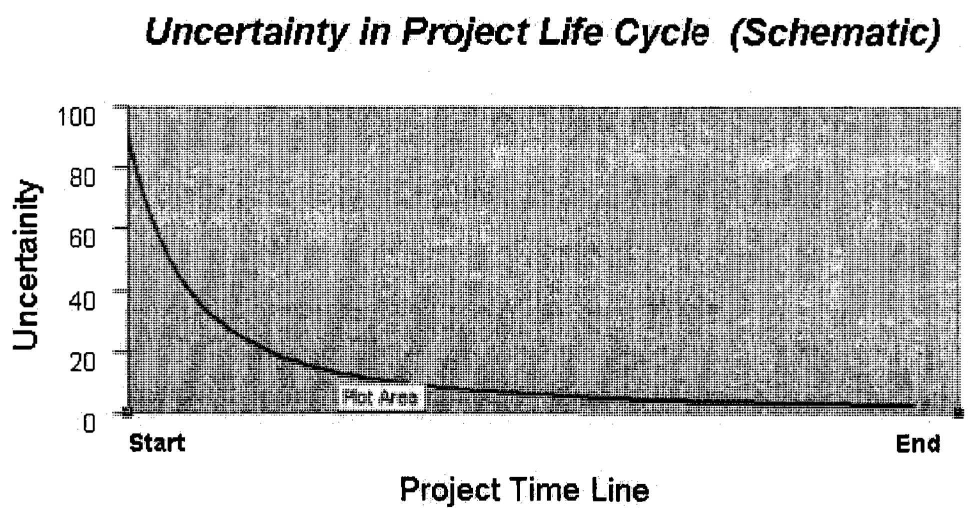

Figure 2.1 The uncertainty schematic chart during project life cycle

Stern & Fineberg (1996) discuss in their paper the fact that uncertainty is more a subject of judgment and agreement than a matter of measurement. Still, the next step after finding the origin of uncertainty would be to determine how we should deal with that in a global comprehensive method. The answer would be provided by searching for a proper measuring system.

2.3 *Measurement of Uncertainty*

Uncertainty measurement has kept the human mind busy since the 17^{th} century. The history of the calculation of uncertainty leads us to the curiosity of gamblers in the 17^{th} century who tried hard to find a mathematical solution to evaluate the risk and probabilities in throwing dice. Finding a way to convert the concepts of luck and chance to a comprehensive Figure has been a serious concern by for centuries, but the first attempt to formulate it as a mathematical method did not take place until 1965 after a gambler's dispute.

Based on the literature, one of the best ways to express uncertainty is to use probability as the measure of uncertainty. Lindley (1987) mentions in his paper that "the only satisfactory description of uncertainty is probability." He strongly believes that every statement should be in the form of probability and that every uncertainty statement must be in the form of a probability, and he also believes that by using the rules of probability, several uncertainties can be combined together. He concludes that "calculus of probabilities is adequate to handle all situations involving uncertainty; in particular, alternative descriptions of uncertainty are unnecessary."

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

Teres (2005) summarizes Vick's two schools of thought in his review of uncertainty measurement and describes "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." This state of nature could be explained by conducting experiments and observations. He continues with the other school of thought and remarks that

> 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. Judgment plays a paramount role in this evaluation as many things that appear evident for an expert, might be difficult to evaluate for another. (3)

The mathematical analysis of uncertainty has its origins in probability theory. In classical probability theory, precision and likelihood are in conflict as the higher the precision the less likely it is to happen. Using the classical probability theory, a theory has been developed at the University of Bristol called the *Interval Probability Theory.* This theory represents the probability as an interval number. The probability of some tasks to take place or their possible consequences might be defined fairly well while others are impossible or difficult to define.

Still there are many arguments on the approaches used in measuring uncertainty. Some scholars discuss the measurement of uncertainty in the possibility theory and there are more who prefer other methods and a third group who link all these theories to achieve their goal. Jamison (1998) explains in his paper that "it is shown that possibility distributions can be formulated within the context of probability theory and that membership values of fuzzy set theory can be interpreted as cumulative probabilities." Sometimes uncertainty is recognized but cannot be measured, quantified or expressed in statistical terms. In such cases, all that can be done is to examine various possible hazard scenarios and subjectively rank them in terms of probability and consequence (Sun 2002). That is the link between uncertainty and fuzzy logic. The relationship between these two concepts is explained more in section 2.5.

2.4 *Risk: Result of Uncertainty*

Kirchsteiger (2005) defines *Risk* as the" possibilities that technological activities or natural events lead to consequences that affect what human values." While the risk definition in RAMP (1998) explains "risk is the likelihood of variation in the occurrence of an event, which may have either positive or negative consequences." The latter definition matches more the concept of the author of this research. Hillson (2002) mentions in his paper that "the traditional view of risk is negative, representing loss, hazard, harm and adverse consequences. But some current risk guidelines and standards include the possibility of 'upside risk' or opportunity." Opportunities are circumstances in which an uncertainty leads to a benefit or positive effect on the project. Despite recent considerations for upside risks, most risk analysis and management process still focus on managing hazards and threats, and the area of opportunities needs more work. While the concept of risk might bring only negative issues to most people's mind, it includes all kinds of risk like opportunities; the risk management process is considered as a *Risk/Opportunity Management analysis,* called ROM in current research.

AbouRizk (2008) explains the *Risk Factors* as "every possible event or issue that may cause harm to the project, "and the Risk Analysis would be the approach to identify these factors and the methodology used to quantify them. *Risk Analysis* is defined as the process of identifying risk factors and using a qualitative or quantitative method to calculate the severity of those factors in order to manage them. The need for early conduction of Risk Analysis in the engineering curricula has been suggested by Whitman (1996), Morgenstern (1995), Faber and Stewart (2003), and others. The risk in projects is a direct result of uncertainty from different aspects, either because of the nature of project as Frequentist point of view or judgmental uncertainty. Therefore it is important to state the approach adopted in the characterization of risk, and what is assumed of the associated uncertainty, when the risk factors are communicated to the concerned parties or the decision makers.

Risk Severity is an index for demonstrating the level of risk to be dealt with in the project. In this research it has been assumed to be the product of the likelihood of a risk or opportunity taking place and the magnitude of the risk-consequence impact. Obviously the first step to find the risk severity would be calculating or estimating the likelihood and impact of the risk factors.

Severity = (likelihood of occurrence a risk)* x *(magnitude of impact)

Likelihood, in other words, can be the probability of a risk factor happening. The *Impact* can also be defined as the magnitude of the risk's result, which can be described in terms of monetary value, time or other values. In this research, all the terms are considered to be dimensionless in order to unifying them.

2.5 Fuzzy Logic and Fuzzy Set Theory

Fuzzy Logic has emerged out of Lotfi Zadeh's (1965) developments in theory of fuzzy sets by Lotfi Zadeh (1965). *Fuzzy Sets* are sets with partial membership function. Fuzzy sets have been introduced by Zadeh as an extension of the classical set theory. In other words, a classical or standard set can be considered as a subset of a fuzzy set. In classical set theory, the membership of elements in a set is bivalent: an element pertains or does not pertain to a set. It is not allowed to be included and in a set and its complementary set simultaneously. Based on the classical theory, many real situations cannot be handled. On the contrary, fuzzy set theory allows the gradual membership of elements in a set; this is described with the term called membership function, which has a value in real interval of [0, 1].

A good example is in the situation of using imprecise and vague and propositions like "this person is smart" (handsome, rich, etc). In Figures 2.2 and 2.3 below a non-fuzzy set (crisp set) and a fuzzy set are illustrated. In Figure 2.2 an interval of 10 to 30 degrees centigrade is considered as absolutely cool whilst other temperatures are not cool at all. It is obvious there are sharp edges on end points, which is not realistic at all. In the real world we cannot even distinguish between 30 ℃ and 31 ℃, but in a crisp set demonstration there is a sharp edge dividing these areas. Comparing Figure 2.2 and Figure 2.3 shows clearly the difference of using fuzzy concepts instead of crisp methods. The partial membership function for members of a set showing the temperature for instance makes more sense.

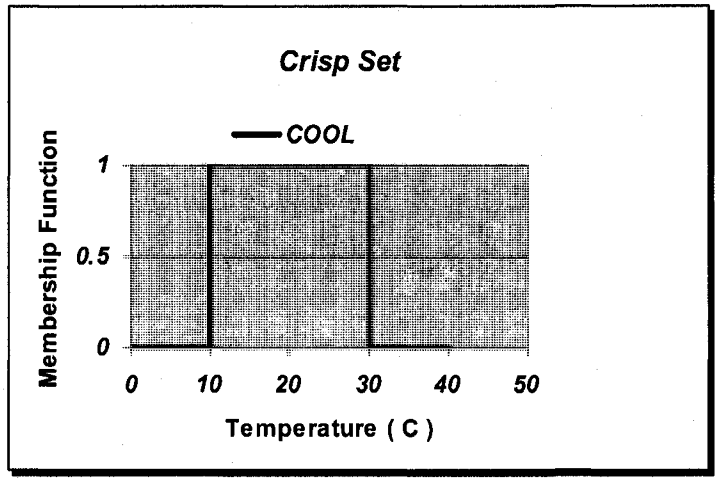

Figure 2.2 Crisp set of members demonstrating "cool temperature"

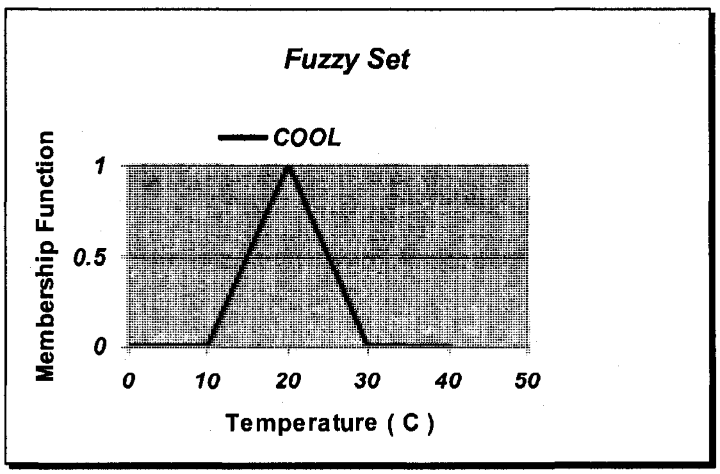

Figure 2.3 Fuzzy set of members demonstrating "cool temperature"

Kosko (1997) mentioned that the difference between fuzzy sets and classical sets is called the law of the excluded middle. Denoting the definition of a classical set in which an object either belongs or does not belong to the set, he brings an example that a number fully belongs to the set of even numbers and not at all to the set of odd numbers and vice versa. Kosko (1993) summarizes the origin and history of developing fuzzy logic in a paragraph:

> The modern study of fuzzy logic and partial contradictions had its origins early in this century, when Bertrand Russell found the ancient Greek paradox at the core of modern set theory and logic. According to the old riddle, a Cretan asserts that all Cretans lie. So, is he lying? If he lies, then he tells the truth and does not lie. If he does not lie, then he tells the truth and so lies. Both cases lead to a contradiction because the statement is both true and false. Faced with such a conundrum, classical logic surrenders.

In fuzzy logic, this statement can be analyzed: the answer is actually partially true and partially false. He mentions that 50 percent of the time the Cretans lie and the other half they do not lie. In the 1920s a Polish logician, Jan Lukasiewicz, evolved the principles of multi-valued logic, in which statements can take partial true values between the interval zero and one of black or white logic. In 1937 quantum philosopher Max Black brought up the term "Vagueness" and applied multi-valued logic to sets of objects; therefore the first fuzzy set curves emerged. It was 30 years later that Lotfi A. Zadeh, the chair of the electrical engineering department at UC Berkeley at that time, published the paper "Fuzzy Sets," a remarkable literature which gave the field its name. Zadeh applied Lukasiewicz's logic and developed a complete algebra for fuzzy sets. Despite all, fuzzy sets have not been used until the mid 1970s, when Ebrahim H. Mamdani of Queen Mary College in London designed a fuzzy controller for a steam engine. He used the term 'fuzzy logic' in his developed system and since then it has stand for any mathematical or computer system that reasons with fuzzy sets.

Zadeh (1994) divides fuzzy logic into two main directions:

1. Fuzzy logic in the broad sense
2. Fuzzy logic in the narrow sense

The latter one is a relatively new discipline of generalized classical multivalued logic. On the other hand, fuzzy logic in a broad sense is used to convert the vagueness of linguistic terms, in analysis of natural language statements. Vagueness is a form of epistemic uncertainty that is not due to lack of knowledge but because of imprecise meanings of linguistic terms (Hajek 2006). In this research the fuzzy logic in the broad sense has been used, to analyze of vagueness in natural language and convert the opinions of managers and participants in a construction project to a mathematical index that can be dealt with in computational systems like programs or simulators.

Computers do not reason as brains do. Computers understand determined facts; they can analyze the information which has been reduced to strings of zeros and ones and statements that are either true or false. The human brain can reason with vague assertions or claims that involve uncertainties or value judgments: "He is handsome," or "That car is fast," or "She is slim." Unlike computers, humans have intuition that enables them to reason in a world where things are only partially true. Kosko (1993) explains: "fuzzy logic is a branch of machine intelligence that helps computers paint gray, commonsense pictures of an uncertain world." Logicians in the 1920s first broached its key concept: everything is a matter of degree.

Fuzzy Logic filled many gaps in scientific and practical problems .The concept of fuzziness is something that we deal with in our daily life. Simple examples about a fuzzy description can be our idea about the weather such as "Cold" "Hot," or "Nice": without necessarily mentioning the degree or humidity we can recognize these explanations as a human being. Obviously, different interpretations could be made by these explanations depending on the context or environment and group of people, but it still makes sense when people talk about these terms in every day tasks and events. As a good example portfolio theory mentioned by Eldukair (1990) in his paper, is one of the areas which cannot be dealt with classical logic. This theory seeks for a correlation between projects due to their several factors which have different importance and level of contribution to projects. He states that:

> The importance and the level of contribution of each factor can be estimated based on experience and judgment. Experience and judgment may easily be expressed in subjective measures rather than mathematical terms. Classical portfolio theory fails to incorporate subjective information. The subjective measures can be translated into mathematical values using the fuzzy set theory.

Construction is not apart from this concept as it is about people, communication, human skills, and qualitative technical issues. Ross (2002) divides the information world into some regions with different effects on the approach to calculate the risks caused by uncertainty.

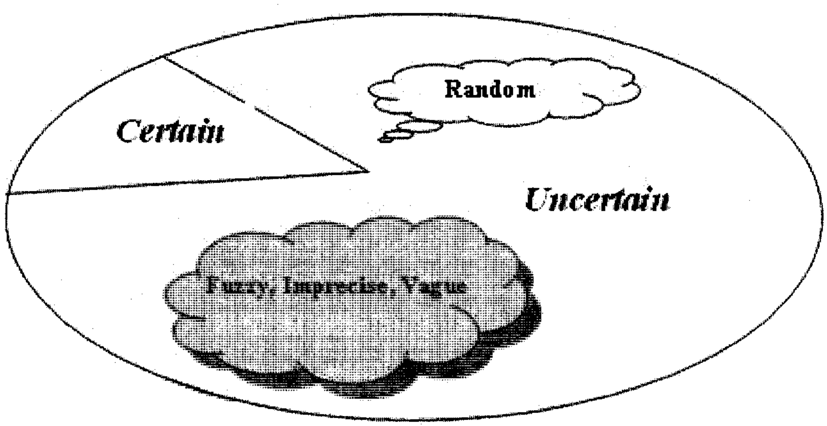

Figure 2.4 Forms of uncertainty in the information world, (Ross 2002)

As it is shown in the Figure 2.4 the whole information world is divided into "Certain" and "Uncertain" zones. The uncertain part which causes the risk factors includes two major types of uncertainty: "Randomness" and "Impreciseness & Fuzziness." The randomness part of uncertainty is a concept related to probability and percentages while the fuzziness deals with degrees of membership- they are not the same Probabilities measure whether or not something will take place while fuzziness measures the degree to which something happens or exists. The statement, "There is 70 percent chances the weather will be cool" conveys the probability of cool weather happening, but saying that the morning feels "70 percent cool" means that the air feels cool to some extent. Conversely, the statement can mean that the weather feels just right and warm to a different extent (Kosko1993).

It was discussed before that the origin of uncertainty affects the risk and risk factors, and consequently the approach to analyzing them. The random part of the uncertainty deals with the fact that in some events like tossing a dice the possible results are definite but the answer is based on randomness. This type of uncertainty can be calculated based on the probability theory. The other part of uncertainty that seems to have a larger portion in uncertain environment is a result of vagueness, impreciseness, and fuzziness. It can be a consequence of lack of knowledge, inadequate data, judgmental opinion, etc. This type of uncertainty is communicated easily between people. All these vague expressions such as "Low," "High," or "Medium" can be sufficient for understanding between human beings, but they are not effective for communicating with computers and programs like scheduling or simulation programs. Fuzzy logic is defined as a proper way to carry this translation from the subjective verbal form of judgments to the numeric, mathematical solutions.

Risk analysis is used to assess projects' risk data in a qualitative process or a quantitative process in which risks are measured by the use of probabilities. However, since being unique is one of the characteristics of every new project, it is clear that no previous data can be provided in advance. Decisions taken and the actions that may be carried out are highly subjective due to the nature of the risk. The risk management approach discussed in this literature identifies the risks, and assesses the likelihood of occurrence of each risk and the magnitude of their impact by using linguistic variables through fuzzy logic and fuzzy sets. The use of linguistic terms is a departure from conventional methods in risk analysis that mainly rely on statistical assessment to quantify the severity of risks in projects. The risk analysis process, using fuzzy logic, is found to be a better way to handle project risk management which is highly subjective, and varies substantially from project to project.

2.6 Risk Management

A systematic concern with risk assessment methodology was raised in the Aerospace sector following the Apollo test in January 1967, in which three astronauts were killed. In April 1969, NASA formed a space shuttle task group. The task group developed "suggested criteria" for evaluating the safety policy which contained quantitative safety goal. (Bedford 2001). Later on, these studies and new probabilistic risk analysis were undertaken in the nuclear sector. The first full-scale application of these methods, including an extensive analysis of the accident consequences, was undertaken in the Reactor Safety Study in 1975. Flanagan (2004) explains the necessity of applying risk management in construction industry and mentions that "the construction industry, because of its nature, is subject to more risk and uncertainty than perhaps any other industry. Yet, managerial techniques used to identify, analyze and respond to risk were not applied in the industry until the 80s."

Risk/Opportunity Management is a constructive way to increase the likelihood of successful completion of the projects while avoiding cost and time overruns. Risk management is defined as a procedure to control the level of risk and to mitigate its effects (Toakley 1989). Risks for which there are ample data can be assessed statistically (PRAM 1997). However, no two projects are identical. Often things go wrong for reasons unique to a particular job condition, time constraints, or working environment. When data is available, a fair estimation of probabilities and consequences of risk factors can be provided. This analysis may bring us to reasons why conditions differed and to what extent, and also how things could have been changed if it was possible to minimize the risk factors and/or their magnitudes. The historical case analysis can help us identify the patterns of hazards and their likelihood in specific cases. This approach relies on data collected in the risk register. (Teres 2006)

The probabilities that can be obtained should be looked at 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 to experts without probability trees, for example (Fischoff et al. 1977). Because of projects' engineering, innovations, strong technical or strategic content, a systematic procedure seems preferable to an intuitive approach. This process should not be considered only as a set of tools and techniques but as an integrated part of the project management. (PRAM 1997). Although projects are unique, and therefore their environments and surrounding hazards and risks are different, a generic pattern can be applied to lead the projects in a meaningful complimentary process of controlling risks. Raftery (1994) well explains this underlying pattern in his book with simple words, as he believes that: "Many books and papers in the economy of constructions, estimating and forecasting contain ritual declarations of the 'uniqueness' of construction:

- Each project is different
- There are special problems in construction
- The future cannot be forecasted
- Construction is a high-risk business

These pleas are sometimes accompanied by suggestions that ...'different rules'... should apply." (Raftery 1994, 4) Then he continues by arguing this idea and mentions that it is obvious that each industry has their own special characteristics, but few of them are so special that they cannot be understood by an outsider.

2.7 *Risk Management Best Practices in the Construction Industry*

Many companies and institutes have made efforts to develop numerical or non-numerical processes in order to conduct proper risk management. The most comprehensive project risk management processes today are as follows:

- ***PRAM***

Project Risk Analysis and Management Guide, Association for Project Management, U.K, 1997.
This booklet has been updated and republished by APM, The Association for Project Management, and it is introduced by them: "This Guide provides an introduction to the processes involved in Project Risk Analysis and Management, offering a simple but robust and practical framework to help new users get started" (PRAM 2000)

- ***RAMP***

Risk Analysis and Management for Projects is a comprehensive framework within which risks can be managed effectively and financial values placed upon them. It aims to achieve as much certainty as possible about a long term and uncertain future. In the case of a new project, the RAMP process covers the project's entire lifecycle, from initial conception to eventual termination. The process facilitates risk mitigation and provides a system for the control of the remaining risks.
This guideline has been provided by Institution of Civil Engineers (ICE), Faculty of Actuaries, Institute of Actuaries, and London. (RAMP 1998)

- ***PMBoK*** (Risk management chapter)

Project Management Body of Knowledge, Project Management Institute (PMI).The ***PMBoK*** is the standard reference for terminology and processes in project management. It provides the core "body of knowledge" for studying for the Project Management Professional certification. Most changed in its last revision in 2000 (updated from the 1996 original version) is Chapter 11 on Project Risk Management. This has been rewritten and thereby much improved. Based on this guideline Project Risk Management has been expanded into six functional areas:

- Risk Management Planning
- Risk Identification
- Risk Assessment
- Risk Quantification
- Risk Response Planning
- Risk Monitoring and Control

Chapter 3 Risk Management: A Systematic Approach

3.1 Introduction

The construction industry has not typically been a venue for pioneering initiatives in applying risk management techniques, despite the considerable frequency of risks encountered within the industry. Uher et al. (2002) have identified "cultural issues" as the main reason for not using risk management, specifically risk analysis, effectively in construction. These cultural issues include a lack of knowledge, negative attitudes, and mistrust of risk analysis. The surprising point is the significant presence of uncertainty and risk in the construction environment in every phase of a project. The financial implications and time restrictions of the key project stakeholders are often underestimated or even disregarded due to the neglect of an advanced risk analysis system. As previously discussed, risk management should not be considered only as a set of techniques, but should be built within a company's culture and integrated into the project's body.

In this chapter the general steps in conducting a risk management plan are followed, and some quantitative methods are also described based on current practice and general knowledge in risk management. The modifications and developments of previous ideas are made considering the major points involved with regard to the construction industry in general and the contractor's point of view in particular. As has already been mentioned in section 2.4, the whole process of Risk and Opportunity Management is referred to as "ROM" in current research. Before beginning to review the major steps involved in risk management, the main benefits of conducting risk management in construction are summarized here. There are many reasons for using risk/opportunity management, but the main reason is that it can provide significant benefits far in excess of the cost of performing it. These benefits are listed below:

- a better understanding of the project, which leads to more realistic plans in terms of cost estimating and time scheduling

- a clear vision of the risks in a project and their possible consequences, which might lead to the mitigation of risks or their impacts for a party and/or the allocation of risks to another party which is better able to handle them
- a better selection of contract type based on existing risks
- the formulation of a more appropriate contingency plan based on considering a more realistic situation with a variety of risks and discouraging the acceptance of risks with a higher level of failure
- encouraging of greater, but more rational, risk taking which leads to increased benefits in a project

3.2 ROM General Steps and Strategies

For a systematic ROM approach the following steps are generally mentioned in the literature. There may be differences in the terms used but the goals and ideas remain consistent:

- Risk Management planning
- Risk Review
- Risk Management and Response
- Risk Monitoring and control
- Closure

3.2.1 ROM Planning

The integrated ROM plan provides guidance in order to adopt a more holistic approach to managing risk. It enables managers and employees to better understand the nature of risk, and to better plan to manage it systematically. The risk management strategy and plan define the steps involved in executing the risk management process—from its initial to final stages. It includes all the tasks to be performed in order to achieve goals at different phases of the project as well as ownership of risks and tasks, monitoring, and auditing and reviewing 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 risk management process and the way it is to be used phase by phase. Below is a summary of the various components that should be included in the plan:

• Methodology	(how)
• Roles & responsibilities:	(who)
• Timing	(when)
• Scoring & interpretation	(risk assessment scales)
• Thresholds	(when to initiate action)
• Reporting formats	(how to report)

3.2.2 Risk Review

3.2.2.1 Risk Identification

Risk identification attempts to identify all uncertainties that the company may be exposed to. This requires an intimate knowledge of the project objectives; client needs; stakeholders' concerns; the market in which the company operates; the legal, social, political, and cultural environment in which the company exists; as well as the factors critical to its success and the threats and opportunities related to the realization of these objectives. A systematic risk identification program should ensure that all significant activities are considered, and in this regard ROM leads the management committee to consider all possible hazards that are contributors to time and cost overruns. Meanwhile, all possible opportunities which can improve the project outcome should be discovered. In any project there will be risks and uncertainties of various types as illustrated by the following examples:

- Resources may not be available at the required level
- The management and financial authority structure are not yet established
- A technology is not yet proven
- Industrial relations problems seem likely

This stage is the primary and most important step in risk review, and risk identification is essential in order to have a structured approach to risk management. In order to establish a complete risk profile, a general understanding and awareness of the current risk tolerance of each stakeholder is a key component. The environmental scan may identify stakeholders affected by the company's decisions and actions, and their degree of comfort with various levels of risk. Risks and opportunities can be identified through consultation with involved parties, considering the fact that they may change over time as new information and data become available.

Risk identification can be accomplished by different means such as prompt lists, checklists, interviews, workshops, questionnaires, and brainstorming sessions, for instance. This process is usually accompanied by some form of assessment which includes the description of risk factors and their consequences and which estimates the probability of those risks to take place and the magnitude of their impact either numerically or subjectively. The use of a Prompt List facilitates specific risk identification; these lists can be extended as experience is built within the organization. Prompt lists are single words or short expressions intended to trigger ideas towards risk identification. Once risks have been identified through brainstorming, workshops and/or prompt lists, the use of checklists can be helpful as a reminder to identify certain topics or areas that have not been covered. Its use is encouraged only after prompt lists have been reviewed and before the closing of the brainstorming session. Checklists tend to decrease group creativity and push the participants to pre-assigned risks. They primarily include the project's common risks.

Two different approaches are recommended for risk identification—internal inspection and external inspection. Internal inspection means that the personnel directly involved in the project are the only ones utilized to provide the project's identified risks, which is ideal since they are the experts in the topic and its consequences. On the other hand, there may be parties who are barely involved or are entirely uninvolved in a project, and whose ideas and opinions are unbiased. In any event, the project management team should be closely involved in the analytical process in order to ensure the validity of the analysis as well as to instill confidence in the results. The next step after the break is to classify risks into groups in such a format as to avoid duplication and classify the risks as independently from each other as possible (Teres 2005).

3.2.2.2 Risk Classification

Risk classification is an important step preceding the risk assessment process, as it helps to structure the various risks that may affect a project. There are a number of different methods for classification suggested in the literature.

Perry and Hayes (1985) have provided an extensive list of factors collected from several sources, which have been classified based on the relevant party holding the risk such as contractors, consultants, and clients. Cooper and Chapman (1987) have classified risks according to their nature and magnitude, dividing risks into two major groups—primary and secondary risks. Tah et al. (1993) have used an RBS (risk breakdown structure) to classify risks considering to their origin and the location of their impact on the project. Wirba et al. (1996) have adopted a synergistic combination of the approaches of Tah et al. and Cooper & Chapman. In current research based on Tah (2000), risks have been classified using the hierarchical risk breakdown structure developed in Tah et al. (1993). Moreover, the following categories can be used as a basis considering all the types of risks included. This chart can serve the group as a checklist to make sure that all areas are considered, and should be updated from time to time.

- Internal Risks
  - ✓ Local
  - ✓ Global
- External Risks
  - ✓ Economical
  - ✓ Physical
  - ✓ Political
  - ✓ Technological

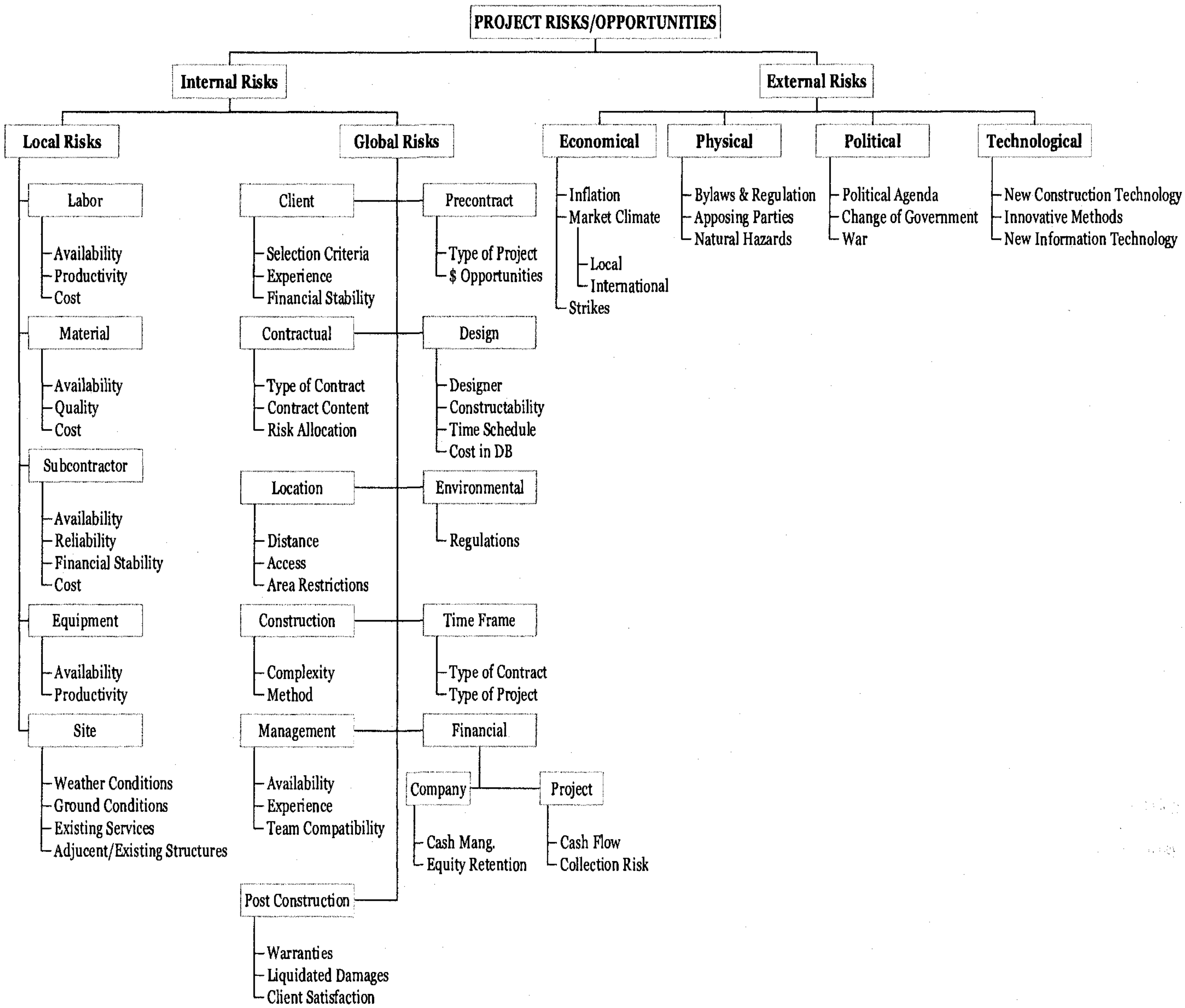

Figure 3.1 Hierarchal risk breakdown structure

This chart has been developed based on interviews and questionnaires conducted for the targeted company in the industry of construction as part of this research. The results are represented in Figure 3.2 below, which shows the different areas with specific risk/opportunity centers or fields. This chart is also presented in a table format in Appendix A.

3.2.2.3 Risk Analysis & Assessment

This stage will specify how these areas of uncertainty can impact the performance of the project, either in duration, cost or in meeting the users' requirements regarding quality, technical aspects, or safety.

The risk analysis process can be conducted qualitatively or quantitatively depending on the type, size, and nature of a project.

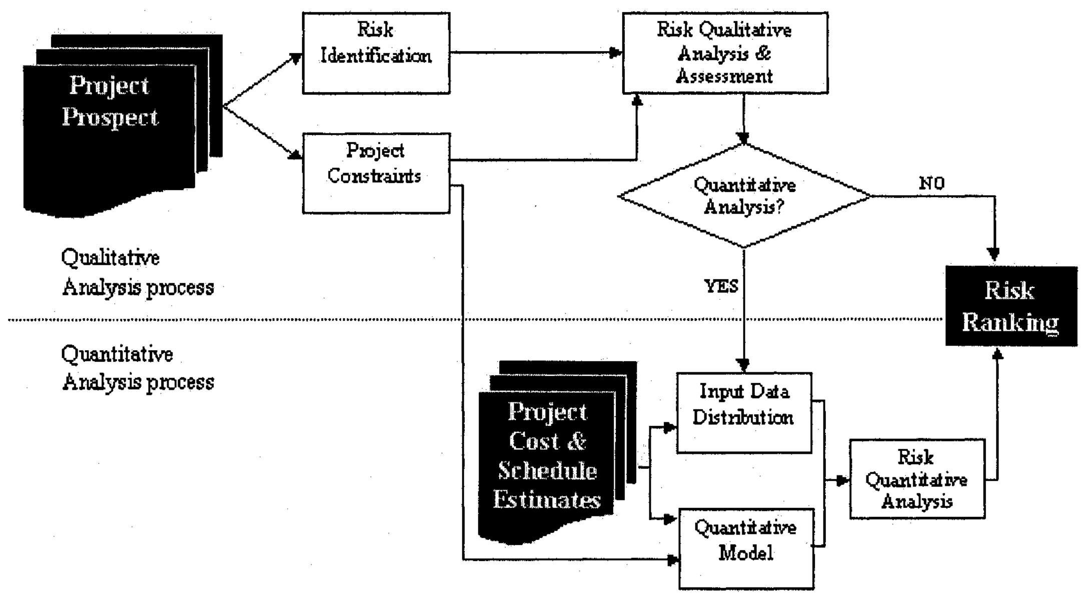

Figure 3.2 Risk management chart

In Figure 3.3 a flowchart is presented to walk us through the various stages of risk management including qualitative and quantitative assessment. It shows that how qualitative analysis always precedes quantitative process if necessary. The final product of this process would be a list of prioritized risks. This list is the prerequisite for managers to start mitigating and managing the risks in order of importance.

Qualitative Risk Analysis

Qualitative risk analysis is the baseline for risk assessment, either in qualitative evaluation or in any quantitative analysis and assessment. All methods mentioned for identifying risks—such as interviews, questionnaires, etc.—basically represent a qualitative method in risk assessment. The most common qualitative risk analysis tool is the Likelihood/Impact Matrix. Each identified risk should be allocated in the following matrix considering the probability of the event happening and the impact of its occurrence.

Depending on the ROM respond plan, different strategies can be applied to different segments. The figure below is an example of one of these matrices along with possible strategies. In this format, likelihood and impact are divided into three or more segments. Likelihood ranges from low to high and impact from minor to significant, for instance. Different terminologies and definitions have been used in different references.

As is demonstrated, different levels of risk are categorized and variable strategies should be applied. In Figure 3.4 the colors show the intensity or severity of the risk result. The darker areas represent a higher level of risk while the lighter parts represent a tolerable level of risk. One thing to be pointed out here is the difference between the areas with low likelihood but high impact and areas with high likelihood but low impact. Some companies treat both in a similar manner while others take different actions toward these two scenarios. The other thing to be mentioned is the scales. Scales are only important in better understanding the process; it is a subjective matter that depends on the users and involved parties.

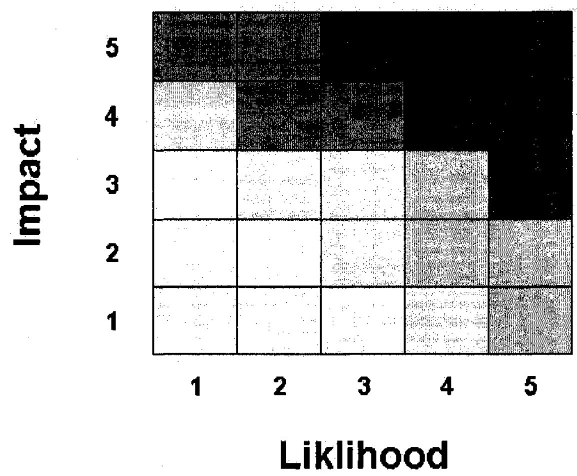

Figure 3.3 The impact-likelihood matrix

One of the most comprehensive risk assessment approaches considers risk as the result of the event's likelihood multiplied by its consequences. This definition is probably derived from the elementary mathematical concept of expectation of an event. Expectation for a given event is defined as the product of its probability of occurrence and its impact value (in a generalized sense) if it does occur. Risk assessment in a broad sense involves a combination of analytical methods and an assessment of social values rather than a simple use of the physical scientific methods with which engineers tend to be familiar. It can be described as a framework within which an iterative process can take place. Quantitative risk assessment is just a part of this entire process and not necessarily the most important part.

Slovic (1999) has stated that "risk assessment is inherently subjective and represents a blending of science and judgment with important psychological, social and political factors." As has been mentioned, risk assessment basically distinguishes between qualitative and quantitative processes, such that the former one should precede the latter if any quantitative method is applicable.

Quantitative Risk Analysis

Quantitative risk analysis (QRA), also called Probabilistic Risk Analysis (PRA), is currently used in numerous fields, including construction, chemical engineering, aerospace, military, financial management, etc. The trend in all areas is for QRA to support tools for management decision making. Quantitative risk analysis is constructed based on the prioritized risks from qualitative analysis, studying the effect of a given risk event and deriving a numerical value.

Quantitative risk analysis is applied in order to obtain the numerical probabilities or frequencies of the consequences and the likelihood of those risks occurring. The methods used at this stage are normally mathematically- and/or computationally-based, and serve to modify the assumptions or decisions made in the qualitative assessment. The values used in these techniques are obtained from historical databases, or they are estimates which still contain an element of subjectivity (Thompson and Perry 1992). In cases where the ROM committee finds it necessary and useful to apply a quantitative risk analysis, the following methods can be implemented in order to carry out a quantitative risk assessment.

A total of eight techniques—expected monetary value (EMV), expected net present value, algorithms, decision matrix, decision tree, break-even analysis, scenario analysis, and simulation—are mostly regarded in literature as being frequently used. The mean values for their relative rates of success reflect the frequency of use of the techniques.

Two of the techniques mentioned above, EMV and simulation, have shown success values rated substantially higher than their respective frequency values, indicating the possibility for continued use in the future (Baker 1999)

For construction, four of the techniques—expected monetary value (EMV), break-even analysis (Eschenback 1992), scenario analysis (Flanagan and Norman 1993), and Simulation—have been widely used. Break-even and scenario analyses are more commonly used together and are collectively referred to as sensitivity analysis (Singhvi 1980; Hayes et al. 1986; Ho and Pike 1992).

A Summary of Quantitative techniques

✓ ***Expected Monetary Value (EMV)***

Expected monetary value analysis calculates the average outcome when the future is not entirely certain. In order to calculate the EMV, the monetary value of a possible outcome is multiplied by the probability that it will occur. EMV analysis is commonly used in conjunction with decision tree analysis.

Example: Suppose someone offered you two envelopes. Envelope A contains $1,000 and envelope B has a 50/50 chance of containing $2,500. Which would you choose? Looking at the EMV of each:

A is 100% certain and so has a probability of 1; therefore,

A = 1 x $1,000 ➔ EMV = $1,000

B has only a 50% chance of occurring therefore

B = 0.5 x $2,500 ➔ EMV = $1,250

In theory, you should take envelope B, as the EMV is still higher. In practice your decision will depend on how badly you need the $1,000 and whether or not you are prepared to take a gamble.

✓ ***Decision Tree Analysis***

Decision tree analysis is a detailed review of the information available to evaluate different outcomes. Decision trees facilitate a consideration of the probability and impact of every branch of the decision under analysis. Solutions are based on alternatives, which provide the greatest expected value when every implication, cost, reward, and subsequent decision is considered.

Example: Suppose there is a factory already manufacturing a product. The business development of the company is considering the idea of developing a new product. Now the question is, "Should we develop a new product or consolidate?" Different scenarios are inspected in the EV chart presented in Figure 3.5, and the created values are based on market reaction. The following process shows the calculation of uncertain outcome nodes. Suppose, for instance, that one calculation process is performed; the expected value of developing the new product can be calculated as follows:

0.4 (probability of good outcome) x $500,000 (Value)	= $200,000
0.4 (probability of moderate outcome) x$25,000 (Value)	= $10,000
0.2 (probability of poor outcome) x $1,000 (Value)	= $200
Total Value	**= $210,200**

The same calculation should be applied to all other branches to get the expected value of different scenarios. The whole calculation is demonstrated in two steps. Figure 3.5 shows the calculation for making profit out of various options and Figure 3.6 shows the net values earned from each scenario by subtracting the amount of investment from the earnings to find the net profit.

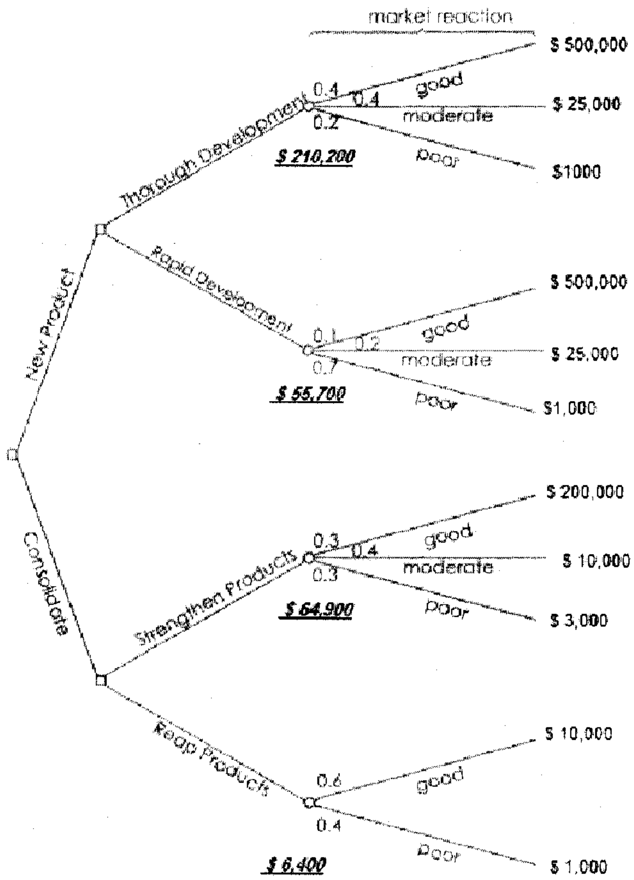

Figure 3.4 The expected value for different scenarios

Then the net value would be the difference between the product value in the market and the finished cost of the good.

Net value = Value – Cost **Equation (3.1)**

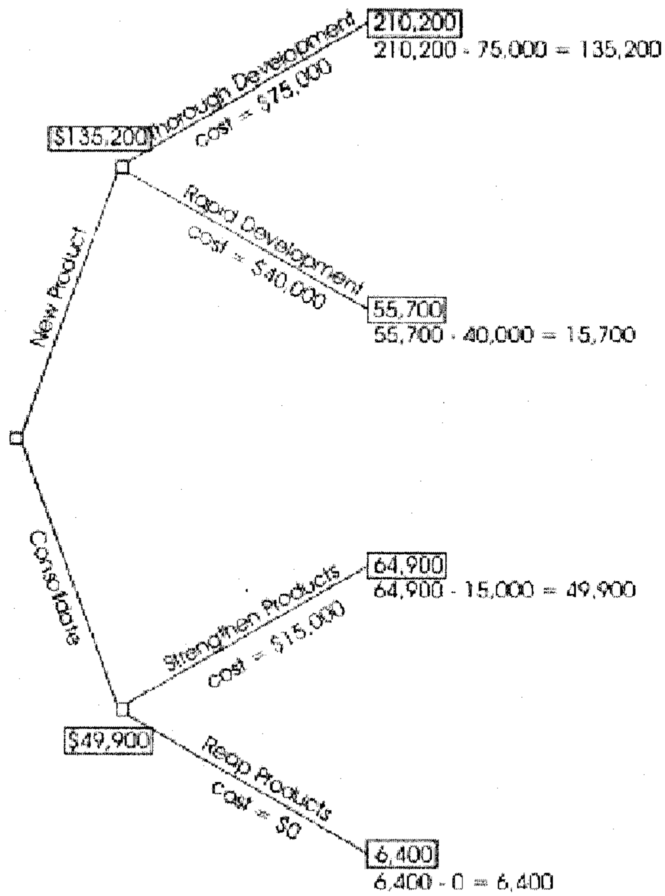

Figure 3.5 Expected net values

Result: By applying this technique we can see that the best option is to develop a new product. It is much more valuable to take enough time to get the product right than to rush the product through to market. Furthermore, it is better to simply improve an existing product rather than botch a new product, even though the latter may cost the company less.

✓ ***Sensitivity Analysis***

Sensitivity analysis measures the impact of one risk against all other variables on a level plane. The risk currently being analyzed is assigned variable values based on the possible outcomes. This is an excellent method by which to ascertain the impact of a single risk; however, the method does not yield a combined effect for risk analysis.

✓ ***Modeling and Simulation***

A model can be understood as a mock-up of a system or problem; a simulation imitates functionality. There are numerous computer simulation packages currently available such as BRISK, Opera, Sonata, Crystal Ball, Ohrat, Geostatistics, and Monte Carlo. A common model and simulation combination is the Monte Carlo Analysis. This approach effectively illustrates how processes can occur under different conditions without risk to the production systems and data.

The steps involved in performing a Monte Carlo Analysis are first to establish a range of values for each task and determine the probability distribution for it, and then to choose random values for the simulation. Then the simulation and analysis of the data should be performed for the end phase.

3.2.2.4 Risk Prioritizing

The previous section described the process of assessing risks. Unfortunately, most organizations have limited resources by which to manage all risks equally for a project. In order to overcome this problem, the organization can assess and prioritize the level of each risk factor so that an appropriate level of effort can be applied to their management. In particular, resources will be directed in order to manage the risk factors with the higher risk ranking.

Ranking risks, considering risk tolerance, using existing or developing new criteria and tools, are all tasks involved in this step. The prioritization of risk is based on assessed risks, and the most critical/beneficial Risks/Opportunities are considered as high priority. It is important to remember that all ROM processes should be as effective as possible such that the creativity and talent of managers and decision makers stand as the most important factors. Furthermore, none of these steps should restrict the user in a negative way.

3.2.3 Risk Management and Response

This stage of the process involves the formulation of management responses to the main risks/opportunities. Risk management may start begin during the review and analysis phase as the need to respond to risks may be urgent and the solution fairly obvious. Iteration between the risk review and risk management stages is also likely.

Project risk/opportunity management identifies and assesses the prioritized risks that significantly affect the completion of the project. Techniques are then formulated and applied to address the risks, and especially to leverage those risks which present opportunities and effectively reduce the potential impact of downside risks. The overall goal of this stage is to ensure that:

- Clients receive their product/service within their specifications (quality, cost, and time).
- Contractors deliver the project without budget and time overruns while making a good profit and keeping the customers satisfied.
- All other stakeholders' concerns are taken into consideration or managed within proper lines of communication.

As such, it is important that management be fully aware of the risks inherent to their company, projects, operations, and processes. In general, situation changes may from time to time cause concern for management, stakeholders, and staff regarding the effectiveness of operations and possible responses. The solution is to be proactive by undertaking the risk assessment and finding the best response to allocated risks.

Possible response options

Once risks have been assessed and prioritized it is possible to establish the risk mitigation measures needed to manage them. Typical actions are:
(1) Eliminate, (2) Reduce, (3) Transfer, or (4) Accept; each risk can have one or more of the options available. Consideration should be taken in the evaluation in order to optimize the measures in such a way as to provide the best value for the actions to be taken.

- ✓ *Risk Elimination*: Avoid the risk factors by choosing different strategies or alternative methods.

- ✓ *Risk Reduction*: Reduce the level of uncertainty through re-evaluation of the situation, either through further investigation or by reducing the impact of that event on the project.

- ✓ *Risk Transfer*: Transfer the risk element to a third party by sub-contracting or using insurance, or even by moving it from one of the involved parties to another. Transferring of risk should be considered only when the receiving party is better suited to cope with the risk, given that transferring the risk 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 responsibility with regard to the management of transferred risks.

- ✓ *Risk Acceptance*: Develop a plan response for residual and otherwise acceptable risks. Risks might be retained due to different reasons, some of which are listed here: when its value is low enough that it does not pose any significant threat to the organization; when after a cost/benefit analysis it is found to be worthwhile to retain it; or when we fail to identify it. From this description we can identify the active and passive acceptance of risks. Active risks are those which we identify and consciously accept and are willing to sustain the costs of if they arise. Passive acceptance of risks includes risks that were not properly assessed in terms of impact, were inadequately managed, or were never identified. In fact, it is a reality that not all risks in a project will be identified; some, alternatively, will have a passive acceptance. Many risks will arise during the course of construction and will need to be dealt with professionally in order to accomplish the overall objectives of stakeholders. (Teres 2005).

As mentioned in the *risk hierarchical breakdown*, risks/opportunities are generally divided into internal and external categories. Internal r/os are the most tightly controlled, while the external ones are for the most part outside of the project manager's authority. As a result, different strategies should be taken

3.2.4 Risk Monitoring and Control

After risk reduction activities have been implemented, the partners and other stakeholders will review what risk management activities have been implemented and how effective they have been. Evaluation is critical to accountability as well as in ensuring the prudent use of scarce resources. The tools used for evaluation will need to be as flexible and diverse as the risk reduction activities themselves. Organizations may vary the basic steps and supporting tasks most suited to achieving common understanding and implementing consistent, efficient, and effective risk management. In any case, the following steps are generally taken. Each step is explained afterward.

- Manage the agreed risk mitigation
- Assess the effectiveness of the process and its application
- Revise the ROM plan periodically

Manage the agreed risk mitigation

In this stage the managers and senior managers should make sure that the mitigation plan for each significant risk is applied and managed properly. At the end of this stage the risk register list should be updated and any new risks or residual risks should be modified. The owner of each risk should be responsible to the project manager to monitor his or her risk, and to either take appropriate action to prevent it from continuing or to take recovery action if the problem does occur.

Assess effectiveness of process and its application

Nothing can be controlled which cannot also be measured in some way. In any given project there are three things elements which can always be measured—the schedule, the cost, and the users' satisfaction. Moreover, by assessing these three factors, the ROM committee would obtain a favorable result out of their performance.

Revise ROM plan periodically

As each project is a new experience for the company and the ROM committee, after finishing each project the ROM plan may be revised in order to encounter better performance in future projects.

3.2.5 Closure

As with any project or process, the whole ROM process should have a closure stage, and in this stage the entire process needs to be reviewed.

- Review Risk Analysis Process
- Draw lessons learned
- Propose improvements to process
- Communicate the result

Review Risk Analysis Process

We can consider a process successful when what has been anticipated matches the project reality to an acceptable degree. In this way, comparing the results to ROM documents would be an appropriate guide for current and future decision making.

Draw lessons learned

This component is the most important and the most ignored aspect of process closure. The lessons learned can be considered as benchmarks for similar future projects as well as a tool to update risk register lists. A unified format for keeping records and dates is essential in order to increase the efficiency, as it is easier to find specific data than to search for any possible important cases. Furthermore, new knowledge and information technologies have opened a vast venue for making useful databases.

Propose improvements to process

The ROM committee should update and improve their policies and processes from time to time since risk/opportunity management is a dynamic mechanism requiring proactive measures.

Communicate results

Depending on the culture of the company, this may include reports circulating among managers, meetings, emails, or any other line of communication among the ROM committee members and stakeholders who need to be informed about the results.

3.3 "When" and "Where" Should ROM be Applied ?

Risk / Opportunity Management is a continuous process that can be applied in almost any stage in the project life-cycle, and which can be logically sustained until the costs of using it begin to exceed the potential benefits to be gained. As time progresses, decreasing uncertainty means the effectiveness of using Risk/Opportunity Management tends to diminish; therefore, it is most beneficial to use it in the earlier stages of project. The process of decreasing uncertainty in a project life cycle has already been demonstrated in Figure 2.1.

3.3.1 When to Apply ROM

There are five points in a project where particular benefits can be achieved by employing ROM.

- ✓ Feasibility study: This is the most flexible stage of the project in that the reduction of more obvious risks can be achieved at a relatively low cost. It is beneficial for making choices between different alternatives.

- ✓ Pre-tendering: This is where the client can view the risk exposure associated with the project and make sure that all possible steps have been taken to reduce or manage the risks. A quantitative analysis can clearly demonstrate the chance of achieving the project objectives (cost, time and performance) for the client.

- ✓ Budgeting tendering: The contractor can make use of ROM in order to ensure that all risks have been identified and to assist the ROM committee in setting a proper risk contingency.

- ✓ Contract award: The client can check to ensure that the contractor has identified all risks and assessed the likelihood of various programs being achieved.

- ✓ At intervals during implementation: Identifying and managing risks and opportunities help the project to stay on track.

3.3.2 Which Projects Should be Considered?

As all projects contain risk and risk analysis and management, ROM should be an integral part of all projects. As it was mentioned before, this process would be carried out until the benefits exceed the costs. Regarding the cost of analysis, some projects have a higher priority for ROM application. The following list presents a number of examples:

- fast-tracked projects
- innovative, new technology projects
- projects requiring large capital investment
- projects involving unusual agreements (either legal, insurance, or contractual)
- projects with sensitive issues (environment/ relocation)
- projects with stringent requirements (regulatory/safety)
- projects with important political/economical/financial parameters

Chapter 4 Fuzzy Quantification Method

4.1 Introduction

The construction industry is now increasingly applying innovative computer modeling techniques to assist decision makers in finding better answers regarding cost estimates, time scheduling, performance, and quality control. As described in Chapter 2, fuzzy set theory and fuzzy logic are practical in the areas where little deterministic data are available or where the information is represented in subjective verbal forms.

Nguyen (1985) has stated that "fuzzy set theory was originally devised to model uncertainty associated with human perception or subjective probability judgments." Because of the uncertain inherent nature of construction, fuzzy logic seems a nice fit for many construction applications. This uncertainty might be due to a lack of knowledge or experience, unavailability of data, or improper historical analysis. Any construction project bears a number of risk factors which affect it in different ways, including time, cost, safety, and quality. All these factors are important, but they vary in terms of impact depending on the situation or the perspectives of different parties.

4.2 Fuzzy Arithmetic

The quantitative process is explained here step by step, followed by an example, for the purpose of clarification, of a solution formulated using this method. As discussed in Chapter 2, the level of severity is the result of multiplication of likelihood and impact.

Severity = (Likelihood) x (Impact) **Equation 4.1**

Considering all of the factors above, a weighted method is applied in this research where risk severity calculations take place in a fuzzy environment. Probability and impact charts are assumed as fuzzy variables.

Step 1: Conversion of verbal judgments to a numerical scale

The likelihood and impact can be quantified in a number of different ways. In the context of this research, these terms are based on expert opinion in verbal form. A fuzzy variable set is assumed for each one for which the scales and amounts can be adapted based on each project's specifications and the involved parties' opinions.

These charts should be provided by the ROM committee through meetings, previous similar jobs, company databases, expert interviews, or any other appropriate way. As this portion of the process is not of particular concern to the present research, a rational common chart is assumed for probability and impact as the base.
The following are the probability and impact assumed charts.

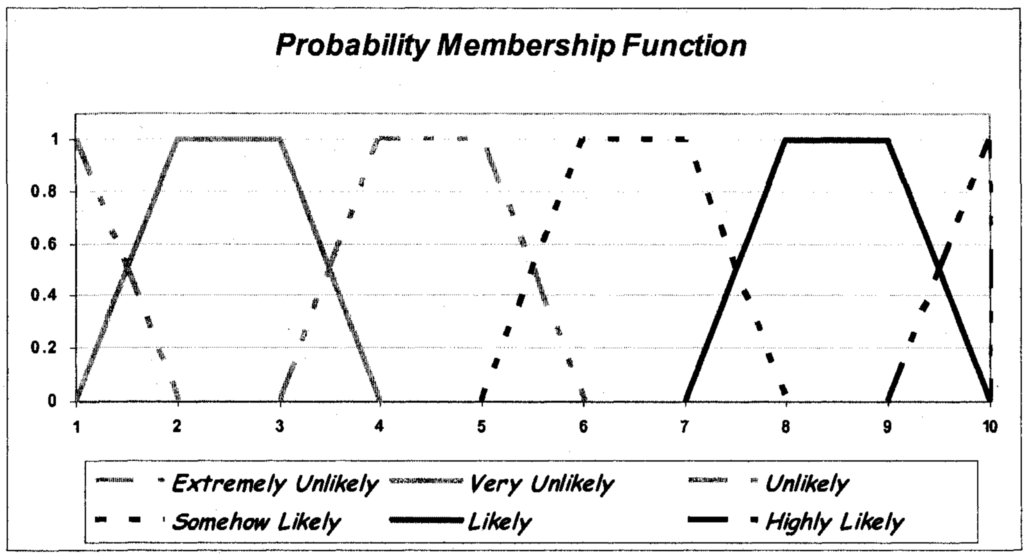

Figure 4.1 The probability fuzzy variable

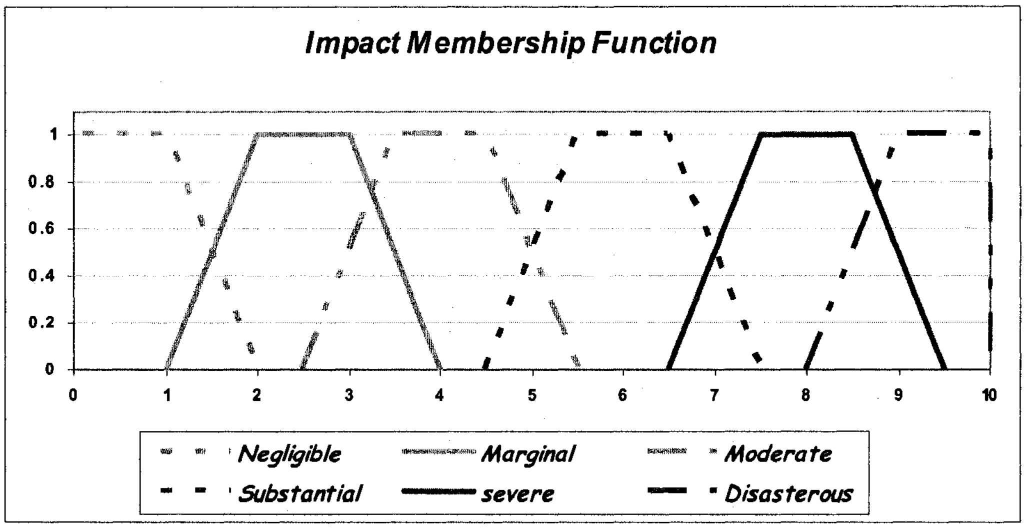

Figure 4.2 The impact fuzzy variable

The probability is scaled from "Extremely Unlikely" to "Highly Likely" in six intervals which are distributed almost evenly. The impact functions are considered from "Negligible" to "Disastrous," again in six intervals. The input for an analysis would be a verbal opinion of an expert or a group of experts about the probability of a risk factor to take place and the possible impact of that risk factor on each area.

Step 2: Finding α-cuts equations

One of the most important concepts of fuzzy sets/fuzzy relations is the concept of an alpha level set and its variant, a strong alpha level set. The alpha level set of fuzzy set is the crisp set, which contains all the elements of universal space, and whose membership grades in set are greater than or equal to the specified value of alpha. The strong alpha level set of fuzzy sets is the crisp set that contains all the elements of universal space and whose membership grades in set are greater than the specified value of alpha. The set of all alpha levels that represent distinct alpha-cuts of a fuzzy set / fuzzy relation is called a level set of set / relation. For example, in Figure 4.3 a fuzzy set is shown demonstrating warm temperature, and an alpha-cut for α= 0.5 is pictured. The interval [20 , 40] is the alpha cut of 0.5 for this set, which includes all the members of this set which have a value exceeding or equal to 0.5.

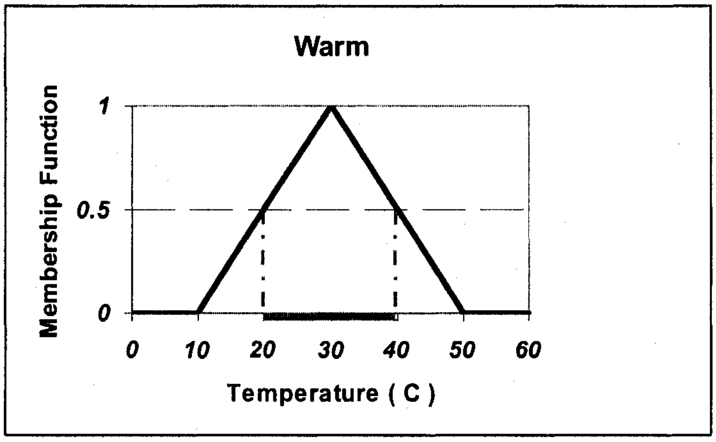

Figure 4.3 Alpha-cut demonstration for α= 0.5

For the arithmetic operations in fuzzy sets, the alpha-cut plays the role of a bridge between the intervals and crisp numbers, enabling us to apply arithmetic operations on the numbers. A short summary of these operations is offered here, but for a better understanding of the process the reader is referred to Klir and Yuan (1995) and Pedrycz and Gomide (1998). Considering two properties of fuzzy sets enables us to define arithmetic operations on fuzzy numbers in terms of arithmetic operations on their α-cuts (Klir 1995).

1) Each fuzzy set, and therefore each fuzzy number, can fully and uniquely be presented by its α-cuts.
2) The α-cuts of each fuzzy number are closed intervals of real numbers for all α Є [0, 1].

The calculation in this step is based on the diagrams from the first step (Figures 4.1 and 4.2). First of all, the variables should be converted from graphical format to a numerical equation, then find the alpha-cut of each diagram in order to proceed to the next step.

Step 3: Multiplication

As has been mentioned, the severity is a result of likelihood multiplied by impact. The multiplication in fuzzy numbers will be explained here simply. After finding the alpha-cuts (α-cuts) of both likelihood and impact, the multiplication will be performed on them. The complete process is shown in the example below. The general process of fuzzy variable multiplication is:

$[a, b] * [c, d] = \{ f*g \mid a \leq f \leq b,\ c \leq g \leq d \}$	**Equation 4.2**

Step 4: Defuzzification

This step is used to convert the fuzzy set obtained from the multiplication into a single crisp number output. The important point in this step is to choose a defuzzification method which makes the output number a good representative for the fuzzy set. The most common methods are center of gravity/area method, centre of maxima, mean of maxima, largest of maxima, and smallest of maxima. Among these methods, the centre of gravity is the most common and meaningful one. All methods are briefly reviewed here, but for more understanding the recommended references are Klir and Yuan (1995) and Pedrycz and Gomide (1998). These methods are also described in many papers such as the study by El-Cheikh (2007) on the COG (Centre of Gravity) method.

✓ ***Centre of Gravity (COG)***

This method, the most common one, determines the center of gravity of the area under the membership function. The equation takes the membership value, multiplied by each variable (X),then divided by the sum of the membership values:

$\text{Centroid} = \sum x \cdot \mu(x) / \sum \mu(x)$	**Equation 4.3**

Where μ(x) is the fuzzy output value; in other words, it is the membership value of the element X.

✓ ***Mean, Middle, Largest, and Smallest of Maxima***

This method takes all points whose membership value is equivalent to the largest membership values, and then, based on different methodologies, it considers different applications. For the middle, largest, and smallest of maxima it applies the middle value, the largest value, and the smallest value. These points are demonstrated in Figure 4.4.

The mean of maxima is slightly different, as it takes the average value of points with maximum values. These methods are acceptable and might make more sense in some cases, but since only maximum membership values are used and all other points are excluded, it is not considered as a good fit for this research.

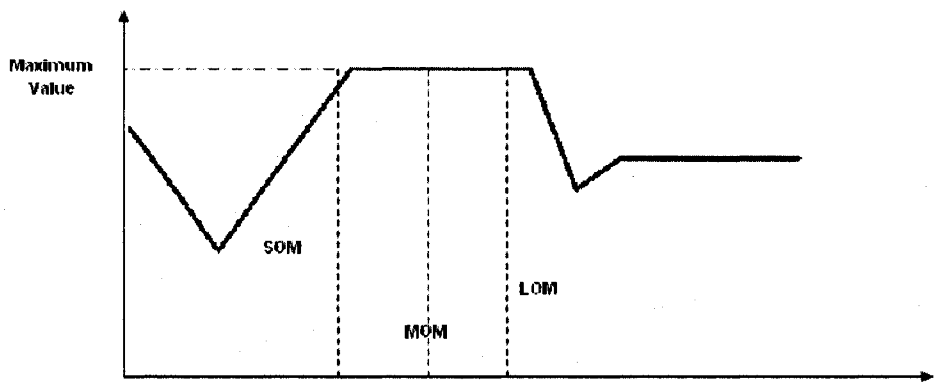

Figure 4.4 Representations of SOM, MOM, and LOM

<u>Step 5: Adopt weighted method</u>

As has been discussed earlier, risk factors affect a project in a number of different perspectives, such as time, cost, safety, etc. In this research, a weighted method is applied so as to combine all risk severities under a risk factor resulting in one number as the index for that risk factor. Considering the weights for each area, it is a direct result of the nature of the work, the involved parties' opinions, the project running phase, etc. For instance, conducting such analysis in the early stages of a project, from the contractor's point of view, may result in considering cost as the main goal, and therefore the weights would be chosen to magnify the cost effect. On the other hand, another analysis on the last phases of the project from the client's perspective might lead to an increase in the weight of time scheduling. In the example below a simple equal weight is assumed in each area.

Total Severity = $\sum W_i * COG_i$	**Equation 4.4**

Where:

i is the index for each area of risk, i.e. cost, time, technical issues, safety, etc.

W shows the assigned weight for the area.

COG is the centre of gravity for each area.

Step 6: Prioritize the risk factors and convert the result to a verbal format

The last step of the risk analysis is about interpreting and converting the numerical result of five previous steps to a meaningful verbal form. Meanwhile we can prioritize and rank all risk factors based on their order of importance. Using the "Risk Categories" chart, it will not be difficult to rank and prioritize all projects' risk factors. In the following chart, the severity is assumed to be an area where each risk factor falls in a given zone depending on the magnitude of its probability multiplied by the magnitude of its impact. The initial criteria for choosing the zones are fully dependent on company tolerance or the opinions of involved parties.

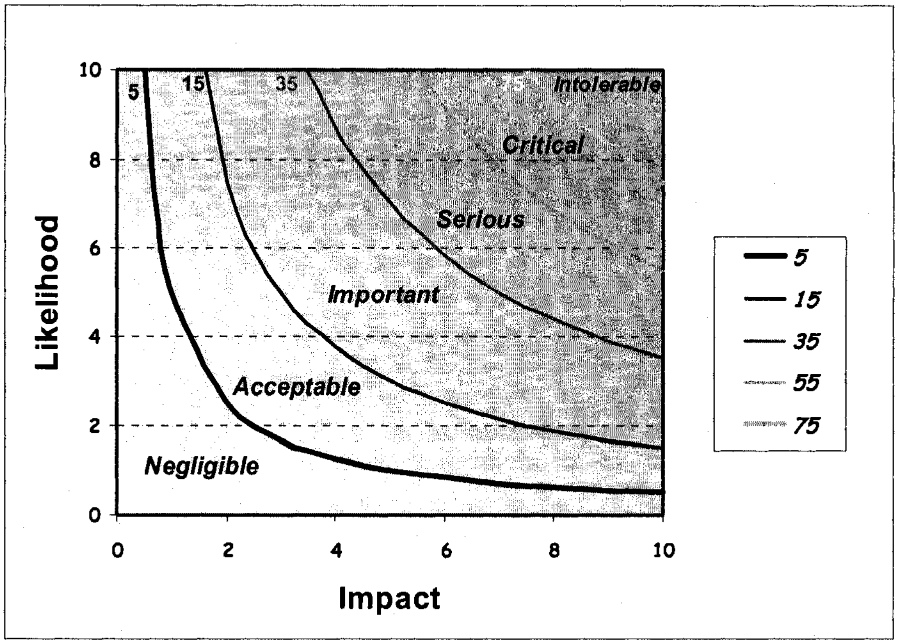

Figure 4.5 Risk categories curves

A simple problem is solved here using this method to clarify all steps while giving a better understanding of analysis.

4.3 Solving an Example

Assuming that the risk factor A is one of the registered risks of the project to be analyzed, this risk factor carries the following probability and impact. The areas to be considered for this example are time, cost, and safety. The following ideas have been collected from expert(s) regarding the probability of risk factor A to take place, as well as the consequences with respect to time, cost, and safety of the project individually.

Table 4.1: Example's probability and impacts

Probability of Risk Factor A	Impact on		
	Cost	Time	Safety
Likely	Substantial	Marginal	Negligible

Solution:

In order to conduct this analysis, the six steps explained in section 4.2 should be followed.

Step 1: Conversion of verbal judgments to a numerical scale

Using the charts provided in section 4.2, we first find the proper diagram for probability and impact mentioned in the example.

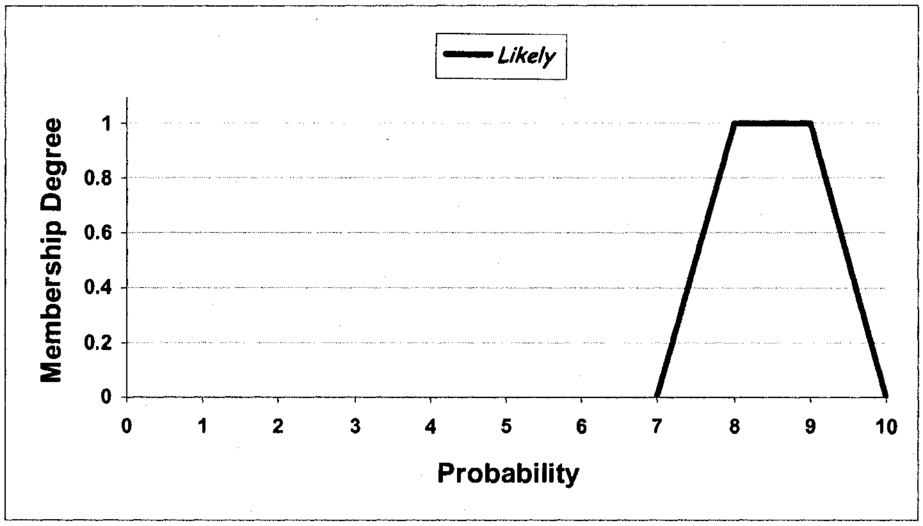

Figure 4.6 "Likely" probability membership function for risk factor A

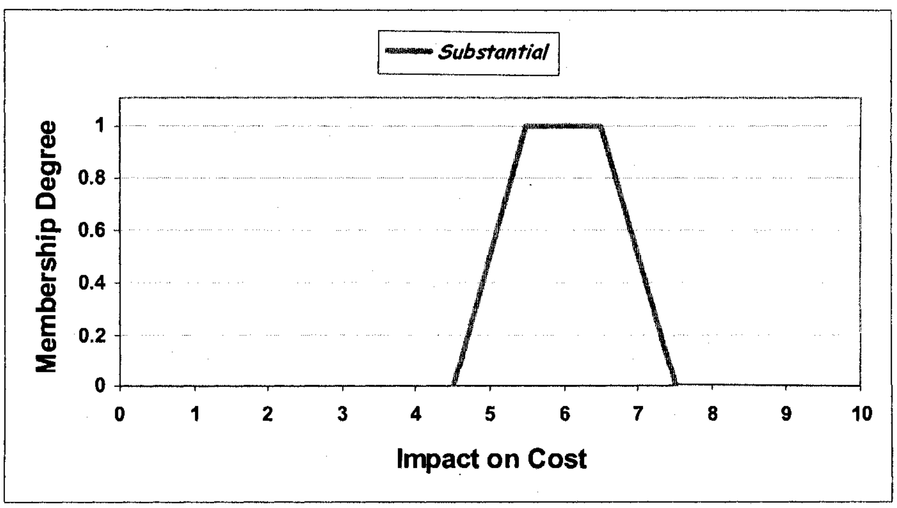

Figure 4.7 "Substantial" impact membership function for cost

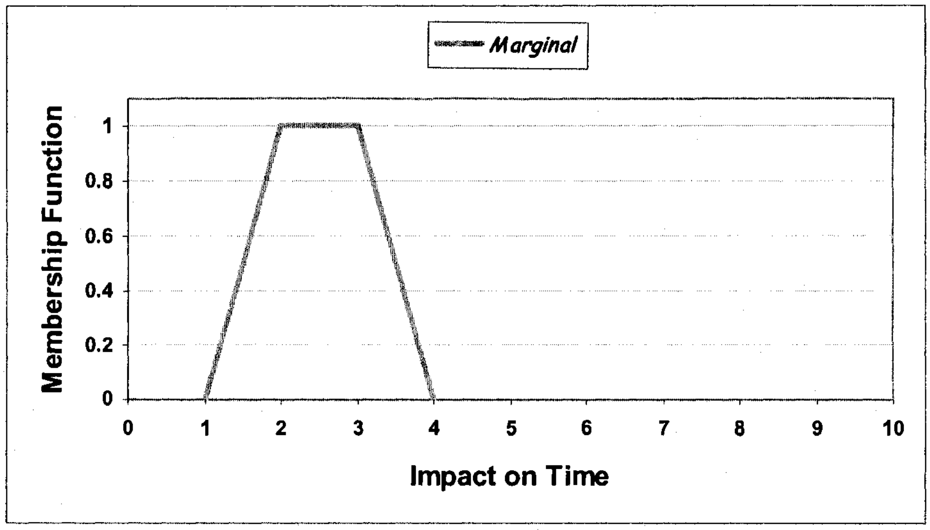

Figure 4.8 "Marginal" impact membership function for time

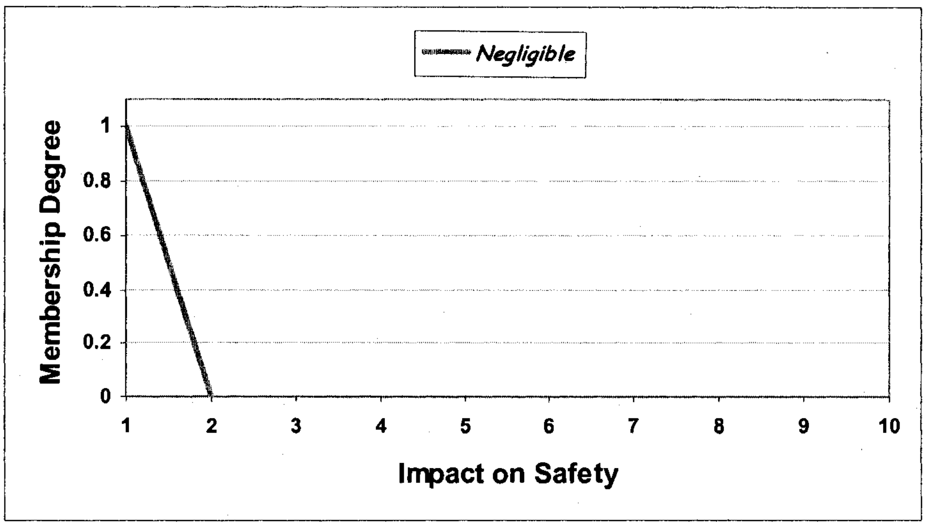

Figure 4.9 "Negligible" impact membership function for safety

Step 2: Finding α-cuts equations

Here we convert the diagrams to equations and then find their α-cuts in order to conduct the fuzzy logic calculation.

Probability:
(Likely)

$$\begin{cases} X-7 & 7<x<8 \\ 1 & 8=< x =<9 \\ 10-X & 9< x <10 \\ 0 & \text{Otherwise} \end{cases}$$

Imp. On Time:
(Marginal)

$$\begin{cases} X & 0<x<1 \\ 1 & 1=< x =<2 \\ 3-X & 2< x <3 \\ 0 & \text{Otherwise} \end{cases}$$

Imp. On Cost:
(Substantial)

$$\begin{cases} X-4 & 4<x<5 \\ 1 & 5 =< x =<6 \\ 7-X & 6<x<7 \\ 0 & \text{Otherwise} \end{cases}$$

Imp. On Safety:
(Negligible)

$$\begin{cases} 1-X & 0<x<1 \\ 0 & \text{Otherwise} \end{cases}$$

The calculations for α-cuts of Probability and Impact on Time are demonstrated here.

$$\begin{cases} P(^{\alpha}P_1) = (^{\alpha}P_1 - 7) = \alpha & \Longrightarrow \quad ^{\alpha}P_1 = 7 + \alpha \\ P(^{\alpha}P_2) = 1 = \alpha & \\ P(^{\alpha}P_3) = (10 - {}^{\alpha}P_3) = \alpha & \Longrightarrow \quad ^{\alpha}P_3 = 10 - \alpha \end{cases}$$

$$\begin{cases} I(^{\alpha}I_1) = {}^{\alpha}I_1 = \alpha & \Longrightarrow \quad ^{\alpha}I_1 = \alpha \\ I(^{\alpha}I_2) = 1 = \alpha & \\ I(^{\alpha}I_3) = (3 - {}^{\alpha}I_3) = \alpha & \Longrightarrow \quad ^{\alpha}I_3 = 3 - \alpha \end{cases}$$

$$\alpha\,(P.I) = [\,(7+\alpha),\,(10-\alpha)\,]\,.\,[\alpha,\,(3-\alpha)\,]$$

$$\alpha\,(P.I) = [\,(7\,\alpha+\alpha^{2}),\;(\alpha^{2}-13\alpha+30)\,]$$

Left endpoint (0, 8] :

$$7\,\alpha+\alpha^{2}=x \Longrightarrow (\alpha+3.5)^{2}=x+12.25$$

$$\Longrightarrow \alpha=\sqrt{(x+12.25)}-3.5$$

Right endpoint [18, 30):

$$\alpha^{2}-13\alpha+30=x \Longrightarrow (\alpha-6.5)^{2}=x+12.25$$

$$\Longrightarrow \alpha=6.5-\sqrt{(x+12.25)}$$

Step 3: Multiplication

Severity calculation for Time: First we should determine the alpha cuts for each equation and then apply the multiplication on probability and impact factors.

Severity = (Probability) * (Impact)

Multiplying two intervals to each other leads us to the following equation, which is mapped in Figure 4.7 accordingly.

$$\textbf{(P. I) (x) =}\;\textbf{(Time)}\quad \begin{cases} \mathbf{0} & \mathbf{x > 30} \\ \mathbf{\sqrt{(x+12.25)}-3.5} & \mathbf{0 < x < 8} \\ \mathbf{6.5-\sqrt{(x+12.25)}} & \mathbf{18 \leq x < 30} \\ \mathbf{1} & \mathbf{8 < x < 18} \end{cases}$$

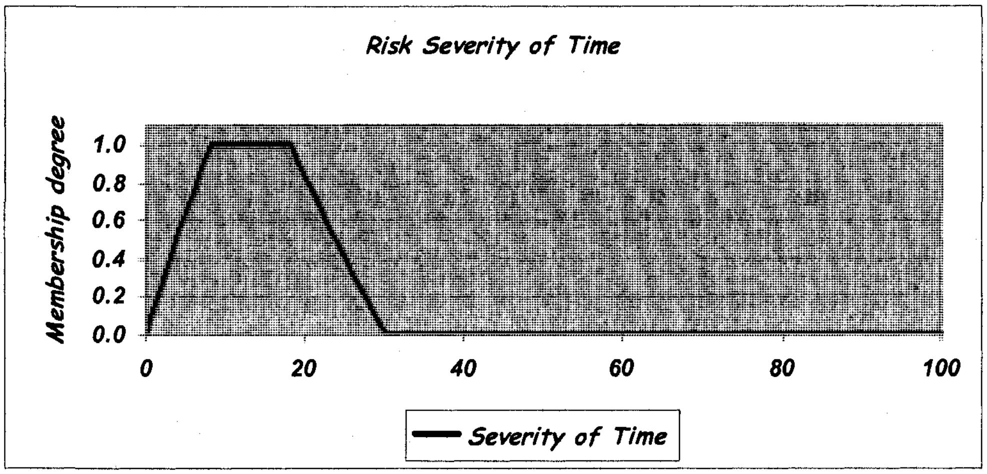

Figure 4.10 Risk severity of risk factor A on time

The same process has been conducted for cost and safety and the results are presented in the same diagrams as the time factor.

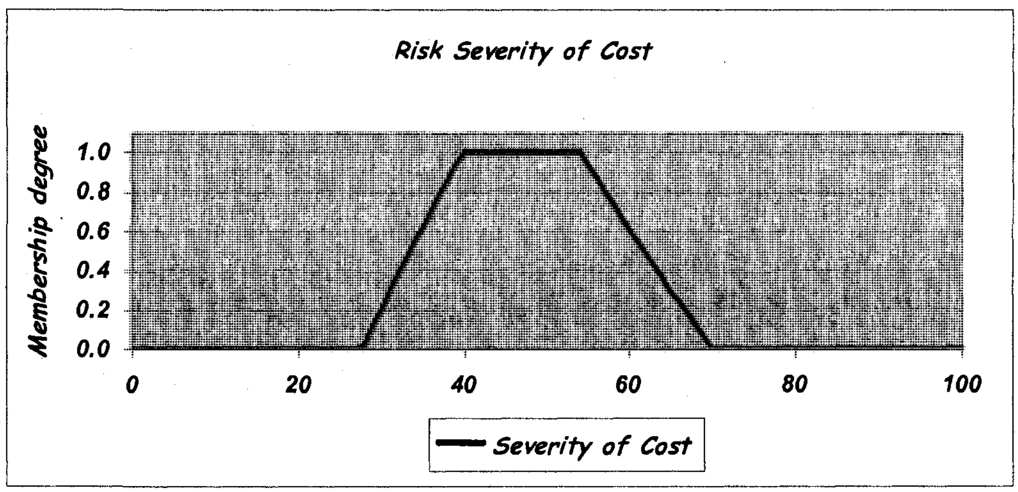

Figure 4.11 Risk severity of risk factor A on cost

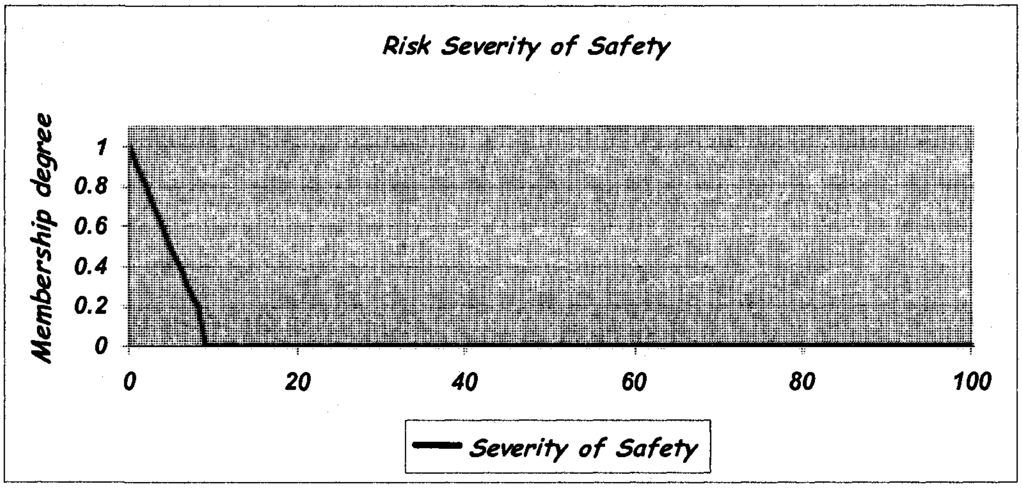

Figure 4.12 Risk severity of risk factor A on safety

Step 4: Defuzzification

At this stage the centre of gravity method is applied to find an index number for each diagram, and then a simple weighted summation is applied in order to get the result.

Time Diagram's GC = 14.2

Cost Diagram's GC = 48.1

Safety Diagram's GC = 3.3

Step 5: Adopting weighted method

For simplification, all three weights are assumed to be equal to 1/3 of the entire equation for this example.

$$\text{Total Severity} = W_T * 14.2 + W_C * 48.1 + W_S * 3.3$$
$$= 1/3\ (14.2 + 48.1 + 3.3) = 21.9$$

Assuming equal weights for all three criteria (time, cost and safety), we end up with a value of 21.9 on a scale of zero to 100.

Step 6: Prioritizing the risk factors and convert the result to a verbal format

The last step is to prioritize and analyze the risk factor based on the average we have determined for it. A risk categorized chart is presented here which can be used as the final step of our risk analysis. Each area shows a severity level of risks starting with low risk on the bottom left to the highest risk in the upper right position. It is also colored in such a way as to show higher risk in the darker portion of the chart. As can be seen in the figure, each zone is separated by the same value lines in different amounts. In this diagram the points from our example are shown as well, located in the "Important" zone.

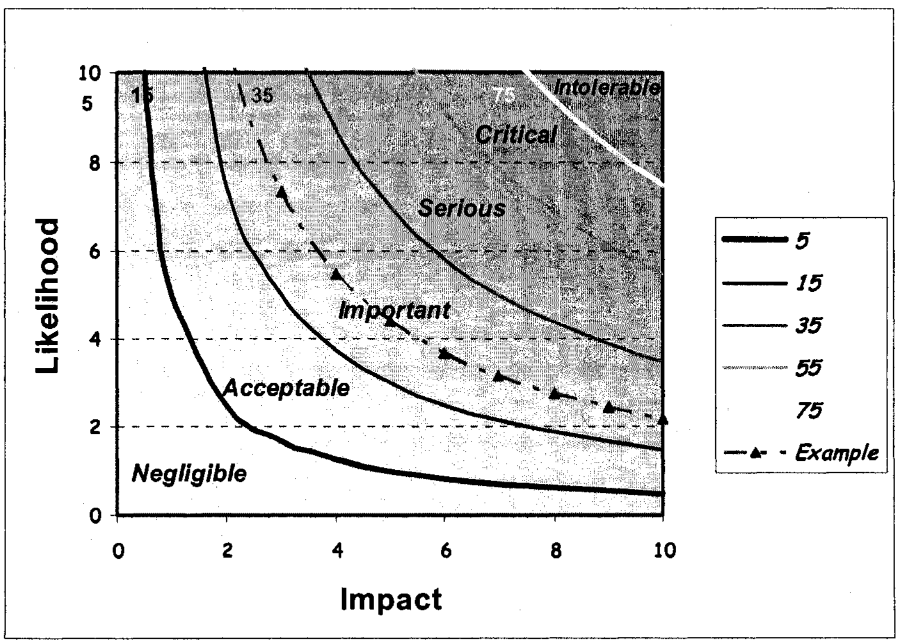

Figure 4.13 Risk Factor evaluation by using risk categories curve

Using this method we can calculate and rank all the risks register in a project and step forward to mitigate and manage them in the most appropriate way.

Chapter 5 Case Verification

5.1 Introduction

In this chapter an actual existing risk analysis case is examined and the fuzzy approach which is developed in this thesis will be used to reproduce the results. By this work we will be able to find how meaningful the results are and see current advantages and disadvantages of this approach to conducting a complete risk analysis.

5.2 23rd Avenue Interchange

5.2.1 Project Overview

The project selected to be reviewed as a case verification for application of fuzzy logic in risk management for construction is the 23rd Avenue Interchange in Edmonton, Alberta, Canada. This chapter will demonstrate a complete ROM application on this specific project using the developed guideline and quantification method by using the existing data and information from the project. Some parts of risk management and analysis are done by the consultant of the project which will be used only to clarify the method and/or to validate the final results.

Based on Chapter 3 there are five steps to be followed in a ROM analysis. These steps are:

1. Risk management planning
2. Risk review
3. Risk management and response
4. Risk monitoring and control
5. Closure

Each of these steps is described for the 23^{rd} Avenue Interchange project in the following sections. Some details are skipped because of confidential information regarding the project or irrelevance to the application of this specific method of risk analysis.

5.2.2 ROM Planning

The City of Edmonton Transportation Master Plan recommends that Gateway Boulevard/Calgary Trail be developed to full-free flow standard from the south city limits to north of 23 Avenue. A split-diamond interchange was proposed and a preliminary design was undertaken. The design has 23rd Avenue being elevated and passing over Gateway Boulevard/Calgary Trail. The location of the interchange is fairly constrained and surrounded by a residential area, a large shopping complex, a railway, and other business and industry. The project has a budget of approximately $107 million, and it is considered to be a fairly expensive interchange. The location is considered to be one of the highest traffic areas in the city.

The project has many constraints including:

- No construction on Gateway Boulevard/Calgary Trail during the World Masters Games (July 22 to July 30, 2005).
- Six lanes of traffic will be open at all times on Gateway Boulevard/Calgary Trail.
- Work on the southwest quadrant of the interchange cannot commence until the trailer park is acquired (likely by July 2006)
- Earthmoving operations and certain cast in place concrete operations are not generally feasible in the winter (November to April)
- City noise bylaw to be observed
- Extensive pipeline relocations are required to be completed prior to other major work commencing.
- High traffic and collision prone area

The City planned a two-year construction period if possible, by starting construction in early 2005 and completion by end of 2007. A construction staging and traffic accommodation has been developed for the construction period, this staging plan is not valid any more and a new strategy is needed to be addressed which might facilitate the achievement of project objectives. (Consultant Review Report)

5.2.3. ROM Review and Analysis for 23rd Avenue Project

Risk Identification

The first step in risk review includes risk identification and allocation. The risk register takes place in early stage of the project for instance the constructability analysis or feasibility studies. This part has been conducted by the consultant and they state that:
"Because this project has special characteristics in terms of site layout, and multiple construction methods a brainstorming session was held and risk factors identified"(Consulting Company's Report). The updated list of risk factors shows 43 risk factors to be analyzed. Details about risk factors can be found in the Appendix B, but are not necessary for the objective of this chapter as only the expert opinion about the likelihoods and impacts will be analyzed by the author not the source of risks.

Risk Analysis & Assessment

In this case verification, we assume a crisp number for each risk factor's probability and impact, and then find the severity of the risk factor by multiplying them. As discussed in the literature, the nature of construction projects and human beings' mindset makes assuming a crisp number for such uncertain areas unrealistic; Thus in current research it is tried to maintain all subjective ideas and situation while getting the most accurate answers by using the fuzzy intervals as input of the analysis. The modified probability membership function is presented in Figure 5.1 and the one showing the impact can be found in Figure 5.2. There is a reasoning behind the changes made to these two charts. As discussed before, the distribution and shapes of the fuzzy variables are assigned based on the experts' opinion, type of the project and other involved factors and restrictions for each specific job. In this case verification, the approach of risk quantification is set in a way that puts more weight on the higher magnitudes and probabilities; therefore as the base for expert opinion, the charts have been modified here in a way to better suit the original report.

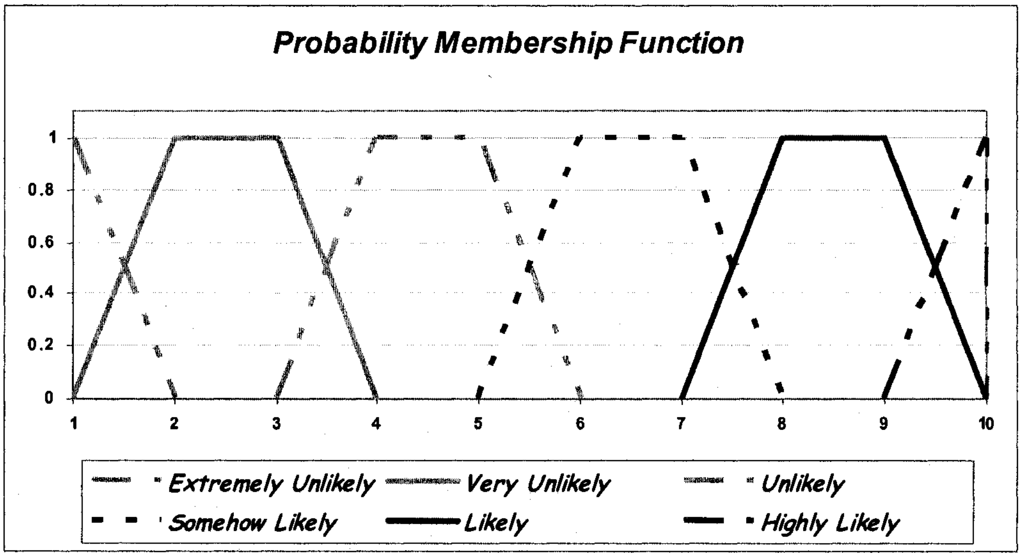

Figure 5.1 Probabilities fuzzy variable

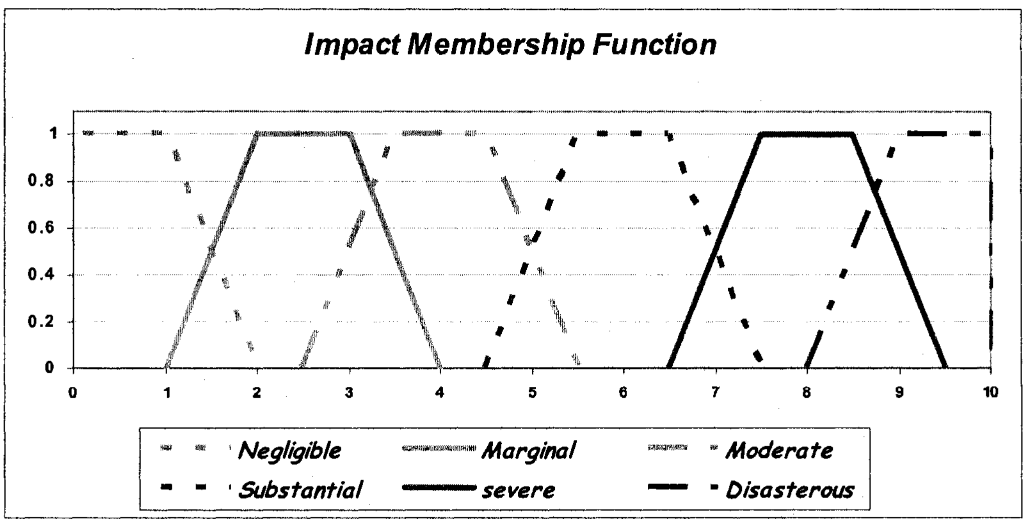

Figure 5.2 Modified impacts fuzzy variable

In this research apart from any qualitative risk analysis that could be conducted we selected the project to be quantitatively analyzed. The fuzzy quantification method explained in chapter 4 will be used in this part. A list of 43 registered risks provided by the risk committee is presented here with their relevant fuzzy intervals showing the probability of factors to take place and the magnitude of their impact. For fuzzy calculation an algorithm in Excel with Macro has been developed to find the severity of each factor by fuzzy multiplication of probabilities and impacts. The results are represented in Table 5.4. By using this algorithm it is possible to assign as much as selected intervals for probability and likelihood and apply the fuzzy calculation to them.

The following Tables show the comparison between the results we found using the fuzzy method versus the answers based on traditional crisp method. The answers with high competency signed with a happy face icon. There are few cells which show different results that are left empty. Comparing non-equal results shows that the fuzzy method considers the risks one step more serious which absolutely depends on initial assumptions and can be calibrated. Tables 5.1 to 5.3 show the indexes which has been used for different terms of Likelihood, Impact and Severity.

Table 5.1 Likelihood/Probability index

Likelihood/Probability			
HL	Highly Likely	**U**	Unlikely
L	Likely	**VU**	Very Unlikely
SL	Somewhat Likely	**EU**	Extremely Unlikely

Table 5.2 Magnitude/Impact index

Magnitude/Impact			
D	Disastrous	**Mod**	Moderate
Sev	Severe	**Mar**	Marginal
Sub	Substantial	**Neg**	Negligible

Table 5.3 Severity index

Severity			
Intolerable	In	**Important**	I
Critical	C	**Acceptable**	A
Serious	S	**Negligible**	N

Table 5.4 Comparison of the test set's results and fuzzy proposed method results

	Traditional Crisp Method						Fuzzy Method				
ID	**Likelihood**		**Magnitude**		**Severity**		**Probability**	**Impact**	**Severity**		☻
1.	50	L	50	Sub	2500	**C**	L	Sub	431	**C**	☻
2.a	20	SL	15	Mod	300	**I-S**	SL	Mod	232	**S**	☻
2.	10	U	50	Sub	500	**S**	U	Sub	232	**S**	☻
3.	50	L	50	Sub	2500	**C**	L	Sub	431	**C**	☻
4.	10	U	50	Sub	500	**S**	U	Sub	232	**S**	☻
5.	20	SL	5	Mar	100	**I**	SL	Mar	156	**I-S**	☻
6.	10	U	50	Sub	500	**S**	U	Sub	232	**S**	☻
7.	3	VU	200	Sev	600	**S**	VU	Sev	201	**S**	☻
8.	3	VU	50	Sub	150	**I**	VU	Sub	156	**I-S**	☻
9.	20	SL	50	Sub	1000	**S-C**	SL	Sub	332	**C**	☻
10.	10	U	100		1000	**S-C**	U			**S-C**	☻
11.	50	L	15	Mod	750	**S**	L	Mod	300	**C**	
12.	3	VU	5	Mar	15	**N**	VU	Mar	75	**A**	
13.	10	U	5	Mar	50	**A**	U	Mar	110	**A-I**	☻
14.	10	U	15	Mod	150	**I**	U	Mod	162	**S**	
15.	3	VU	1	Neg	3	**N**	VU	Neg	34	**N-A**	☻
16.	50	L	15	Mod	750	**S**	L	Mod	300	**S-C**	☻
17.	20	SL	50	Sub	1000	**S-C**	SL	Sub	332	**S-C**	☻
18.	20	SL	5	Mar	100	**I**	SL	Mar	156	**I-S**	☻
19.	1	EU	15	Mod	15	**N**	EU	Mod	55	**A**	
21.	3	VU	50	Sub	150	**I**	VU	Sub	156	**I-S**	☻
22.	3	VU	15	Mod	45	**A**	VU	Mod	110	**A-I**	☻
24.	10	U	5	Mar	50	**A-I**	U	Mar	110	**A-I**	☻
25.	3	VU	15	Mod	45	**A**	VU	Mod	110	**A-I**	☻
26.	50	L	5	Mar	250	**I**	L	Mar	201	**S**	
27.	3	VU	5	Mar	15	**N**	VU	Mar	75	**A**	

	Traditional Crisp Method						**Fuzzy Method**				
ID	**Likelihood**		**Magnitude**		**Severity**		**Probability**	**Impact**	**Severity**		☻
28.	50	L	1	Neg	50	**A-I**	L	Neg	90	**A-I**	☻
31.	10	U	100		1000	**S-C**	U			**S-C**	☻
32.	3	VU	15	Mod	45	**A**	VU	Mod	110	**A-I**	☻
33.	10	U	50	Sub	500	**S**	U	Sub	232	**S**	☻
34.	10	U	15	Mod	150	**I**	U	Mod	162	**I-S**	☻
35.	10	U	15	Mod	150	**I**	U	Mod	162	**I-S**	☻
36.	3	VU	15	Mod	45	**A**	VU	Mod	110	**A-I**	☻
36b.	50	L	5	Mar	250	**I**	L	Mar	201	**S**	
38.	1	EU	15	Mod	15	**N**	EU	Mod	55	**A**	
39.	3	VU	50	Sub	150	**I**	VU	Sub	156	**I-S**	☻
40.	3	VU	50	Sub	150	**I**	VU	Sub	156	**I-S**	☻
41.	20	SL	15	Mod	300	**I-S**	SL	Mod	232	**S**	☻
42.	20	SL	15	Mod	300	**I-S**	SL	Mod	232	**S**	☻
43.	20	SL	50	Sub	1000	**S-C**	SL	Sub	332	**C**	☻

The sign ☻ shows complete or very close results comparing to the results of consultant. The results show over than 80% matching between the fuzzy results and test sets' result. In general, the fuzzy analysis shows higher severity and in few cases it assigns a severity zone which is one level higher than conventional method which seems more accurate as this project cost estimates proceed to a larger number which means that some factors were not included in risk management procedure or have been under estimated. With applying this method the estimation should show a higher predicted budget which is more realistic.

Risk Prioritizing

Now that we have the severity fuzzy distributions, we can prioritize risks by choosing a proper method. As we discussed before, most organizations have limited resources to manage all risks equally in a project. Therefore, a proper assessment and prioritization will show the level of each risk factor, so that an appropriate level of effort can be applied to the management of the most significant ones. The defuzzification method which has been proposed in section 4.2 is the centre of gravity method. Using this method, we will be able to assign a number to each severity and then easily prioritize them: the higher the COG, the more severe the risk.

As it was mentioned earlier for more competency the final prioritizing chart is modified in an exponential format and Table 5.4 is set based on this curves. The interval 0-1000 is divided to 6 exponential zones and the rest is the same as figure 4.5.

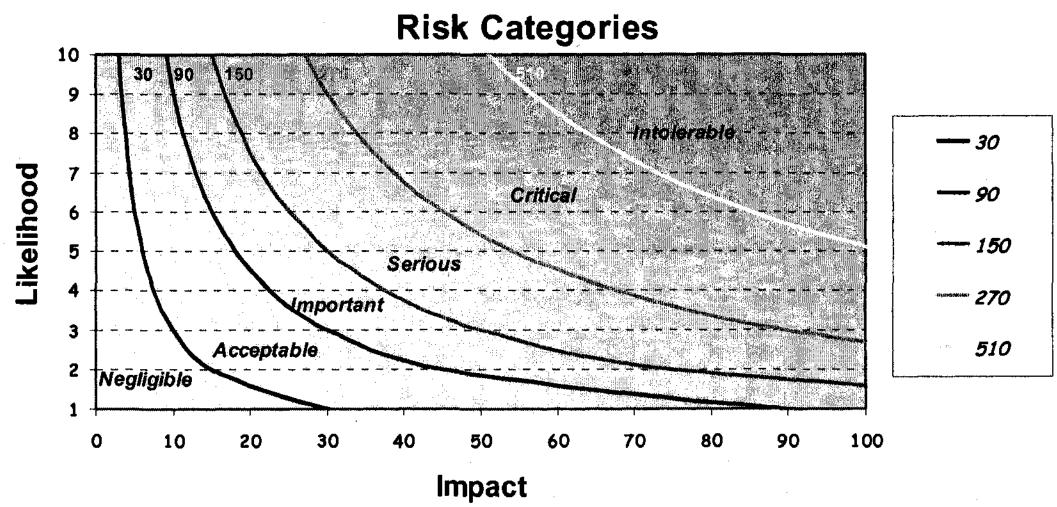

Figure 5.3 Exponential risk categories curves

Chapter 6 Conclusions

6.1 Research Summary

The present research endeavors to analyze the application of risk management to construction industry while considering a new quantitative approach by using the fuzzy logic concepts and fuzzy arithmetic functions.

Risk management has been applied in many fields before, but recently it has been getting more popular in construction industry as practitioners have found it to be beneficial, not only from economic perspective, but also from a technical and safety point of view.

The application of fuzzy logic and its functions

The current research followed a complete guideline for performing a generic risk and opportunity analysis regarding a specific quantitative fuzzy method to calculate and prioritize the risks in a real project which is taking place in Edmonton at the time of completing this research.

Chapter one explained the objectives and problem statement with a description about the methodology and organization of the research. It uncovered the origin of applying risk management in construction projects and the facts that construction environments are one of the most highlighted fields in risk management as the nature of the industry bears lots of uncertainty. Recent increasing complexity of the processes in construction has urged companies and all involved parties to consider a complete guideline and approach to fulfill their expectation considering budget and time frames while maintaining quality and safety on the job. These factors have lead researchers and managers to try different methods in achieving these goals, which resulted in deriving many new applications and guidelines in risk analysis and management over the last decade.

The second part of the research, presented in Chapter two of the thesis, focuses on introducing the ideas and concepts regarding risk management in construction. The definition of the concepts, terminologies, and research areas contributed to the application of risk management in construction, and different research fields within the area under this topic are reviewed in this phase. Moreover, this review tried to cover the works which has been done in the area of fuzzy logic, fuzzy sets and their applications in risk analysis and management.

Chapter three demonstrates a complete procedure to be taken to develop a risk management plan for a generic construction project. This chapter has been developed as a policy for a company considering some of the specific criteria of that company based on the available best practices. The contribution made in this part is developing a Hierarchical chart of possible risks and opportunities which is presented as a result. This chart includes different risk factors and their origin in a categorized organization. This chapter is an outcome of interviewing with experts within the industry and using historical surveys.

The fourth chapter focuses on the developing of a quantifying system for calculating the risk severity of different risk factors affecting a project. All of the functions are based on the fuzzy set theory, and the variables are defined in fuzzy environment and the fuzzy arithmetic has been applied for calculations. At the end, in order to report the results to managers or other parties involved in the project that need to know the results of risk analysis, a defuzzification method is addressed to compute a final score for rating and prioritizing the risk factors. In this method, a number on the scale of zero to 100 is assigned for each risk factor which shows the severity of that risk starting from zero for no risk to 100 for an intolerable risk. Afterwards, mitigation and management acts should be performed based on the risk management plan, but this is beyond the scope of this research.

In Chapter five, a case study was conducted using the introduced fuzzy logic approach. Here, the data was adopted from an existing project risk analysis from a project running in Edmonton, the 23^{rd} Avenue Interchange, which is a complex project due to its type, constraints, and limitations of time and budget. The case study demonstrates the efficiency of the introduced fuzzy application while validating and comparing the results with the existing risk analysis report being conducted with a different method. The new method was applied to identified risk factors and an analysis was run, producing two results. First, the severity of each risk factor should be addressed by a proper mitigation plan or fit into existing mitigation plans, and secondly risk factors should be prioritized in a categorical way.

6.2 Conclusions and Contributions

The use of fuzzy logic in risk analysis makes the process more realistic for the construction context. This research enables project characteristics and risk events to be assessed subjectively, as is usually the case in practice. The output of the calculations can be presented both numerically and linguistically, providing the decision maker with a wide, useful, and realistic guide to the most severe risks in the projects.

Using this method to consider monetary values or timelines can provide more information for decision makers to set appropriate contingency plans as well. One of the strong points of this method is that the decision maker can modify the basic impact and/or magnitude charts to better suit reality at any time in project and getting updated results to make better decisions at the time of mitigating and managing the risks and opportunities.

The integrated ROM plan intends to provide guidance to adopt a more holistic approach to managing risk. It enables managers and employees to better understand the nature of risk, and to manage it more systematically. It is necessary to develop a deeper understanding of risk so as to convert potential pitfalls into opportunities. In the stage of risk management, the process involves the formulation of management responses to the main risks/opportunities. Risk management may start during the review and analysis phase as the need to respond to risks may be urgent and the solution fairly obvious. Repetition between the risk review and risk management stages is likely.

Two points which are insisted on in this research are including the opportunities in the process to get best advantages out of a project and mastering the techniques and injecting them into the integrated project plan to shape the company culture. It is very important to distinguish between an efficient ROM plan and a bureaucratic process which adds no value to a project.

6.3 Recommendations for future research

Considering the risk management in Canadian construction companies a fundamental effort seems to be essential to benefit from this procedure practically. As it was discussed in chapter three the risk management procedure should be integrated into the company culture to be truly effective.

The application of fuzzy logic and fuzzy set theory attracting researchers increasingly as it found to be very effective and realistic in sense of data gathering, analyzing and reporting. The fuzzy logic made a bridge to connect the great scientific ideas and real work environment to enhance the results.
Different stages of risk management procedure which use fuzzy logic as a concept or tool can be a potential area for more work and research. The verbal interpretations in building the basic probabilities and Impacts charts in a company needs deep psychological and technical study and finding more meaningful and practical scales for quantification step and defuzzification can be another important area to research in.

References

AbouRizk, Simaan M.(2008). Risk Analysis for Construction Projects: A practical guide for engineers and project managers, Draft version, University of Alberta, Edmonton, Alberta, Canada.

Al-Bahar JF, Crandall KC. (1990). "Risk management in construction projects: a systematic approach for contractors", Counseil International du Batiment W55/W65 Joint Symposium. Sydney, 14-21 March.

Artto, K., Kähkönen, K., Pitkänen P.J.(2000). Unknown Soldier Revisited: A Story of risk Management, Project Management Association Finland, Helsinki.

Ayyub, Bilal M. and Haldar, A. (1984). "Project scheduling using fuzzy set concepts", Journal of Construction Engineering and Management, 110(2), 189-204.

Baccarini, D., Archer, R. (2001). "The risk ranking of projects: a methodology", International Journal of Project Management, Vol. 19, 139-145.

Baker, Scott , Ponniah, David, Smith, Simon, (1999). "Survey of Risk Management in Major U.K. Companies", Journal of Professional Issues in Engineering Education and Practice

CAMS (Department of Contract and Management Systems), (1998). Managing risks in contracting. Perth: Government of Western Australia.

Chao,L. and Skibniewski, M. (1998). "Fuzzy Logic for Evaluating Alternative Construction Technology", Journal of Construction Engineering and Management. 124(4), 297-304.

Chen Guanrong, Pham Trung Tat (2001). Introduction to Fuzzy Sets, Fuzzy Logic, and Fuzzy Control Systems, CRC press, 316.

Cheng, E. W. L., Li, H., Love, P.E.D., Irani, Z. (2001). Network communication in the construction industry, Corporate Communications: An International Journal, 2001, Vol. 6, No. 2, pp. 61-70.

Construction Industry Institute (1989)

Cooper, D. F. and Chapman, C. B. (1987). Risk Analysis for Large Projects. Wiley, Chichester.

El-Cheikh, M., Chan, A.H.C. and Lamb, J. (2007). "Fuzzy Applications in Cost Estimating and Construction Planning". Proceeding of the Eleventh International Conference on Civil, Structural and Environmental Engineering Computing. Civil-Comp Press.

Eldukair, Z.A., and Ayyub, Bilal M., (1990). "Uncertainty Assessment in Correlation of Construction Projects ", IEEE Xplore, December isssu, pp. 372-377.

Eschenbach T. G. (1992). "Quick sensitivity analysis for small projects and feasibility studies", AACE Transactions. L-6,1-8.

Faber, M. H. and Stewart, M. G. (2003). "Risk assessment for Civil Engineering Facilities: critical overview and discussion", Reliability Engineering and System Safety, 80, 173-184.

Fayek, Aminah, (1998). "Competitive bidding strategy model and software system for bid preparation", Journal of Construction Engineering and Management. 124(1), 1-10.

Fischoff, B., Slovik, P. and Lichtenstein, S. (1977). "Knowing with certainty: The appropriateness of extreme confidence", Journal of Esp. Psychology: Human Perception and Performance, 3 (4), 558-564.

Flanagan, R. and Norman, G. (1993). Risk management and construction, Blackwell Science, Oxford.

Grey S., (1995). Practical risk assessment for project management. Chichester: Wiley.

Guyonnet , D., Come, B.,Perrochet,P.,and Parriaux, A. (1999). "Comparing two methods for addressing uncertainty in risk assessment", Journal of Environmental Engineering, 125 (7).PP 660-666.

Hajek, Petr, (2006). "Fuzzy Logic", the Stanford Encyclopedia of Philosophy (Fall 2006 Edition), Edward N. Zalta (ed.)
URL = <http://plato.stanford.edu/archives/fall2006/entries/logic-fuzzy/>.

Hanna, A.S.,and Lotfallah, W.B. (1999). "A fuzzy logic approach to the selection of cranes, Automation in Construction", 8, pp 597-608.

Hillson, David, (2002). "Extending the risk process to manage opportunities", International Journal of Project Management 20, 235–240.

Hung T. Nguyen, Elbert A. Walker, (2006). A First Course in Fuzzy Logic, CRC press.

Jamison, Kenneth David, (1998). "Modeling Uncertainty Using Probabilistic Based Possibility Theory with Applications to Optimization", CiteSeer.IST, Scientific Literature Digital Library.

Kangari,Roozbeh, and Boyer, L.T. (1987). "Knowledge-based systems and fuzzy set in Risk Management". Microcomputers in Civil Enginerring, 2,273-283.

Kangari,Roozbeh,and Riggs,Leland S. (1989). " Construction Risk Assessment by Linguistics", IEEE Transactions on Engineering Management, 36(2), 126-131.

Kirchsteiger, C. (2005). "Review of industrial safety management by international agreements and institutions ", Journal of Risk Research, 8(1), 31-51.

Klir, George J.,and Yuon, B.(1995). "Fuzzy Sets and Fuzzy Logics: Theory and Applications", Prentice-Hall, New Jersey, USA.

Kosko, Bart, and Isaka, Satoru (1993). "Fuzzy logic", Scientific American, Vol 269, New York , 76-81.

Kosko, Bart (1997). Fuzzy Engineering, Prentice Hall, 550p

Kosko, Bart (1999). The fuzzy future: from society and science to heaven in a chip, Harmony books

Krinitzsky, Ellis L. (2002). "Epistematic and aleatory uncertainty: a new shtick for probabilistic seismic hazard analysis", Opinion paper, Engineering Geology 66, 157–159

Lindley, Dennis V. (1987). "The Probability Approach to the Treatment of Uncertainty in Artificial Intelligence and Expert Systems", Statistical Science, 2 (1), 17-24.

Lindley, Dennis V. (2006). Understanding Uncertainty, John Wiley & Sons publisher

Miller, R., Lessard, D. (2001). "Understanding and managing risks in large engineering projects", International Journal of Project Management, Vol. 19, pp. 437-443.

Morgenstern, N.R. (1995). "Managing risk in geotechnical engineering". The 3rd rd Casagrande Lecture, Proceedings of the 10th Pan-American Conference on Soil Mechanics and Foundation Engineering, Guadalajara, Vol. 4,102-126.

Nguyen, V. (1985). Tender Evaluation by Fuzzy Sets, Journal of Construction Engineering and Management. 11(3), pp. 231-243.

Novak, V. (1989). Fuzzy sets and their applications, Bristol: Adam Hilger.

Novak, V., Perfilieva, I., and Mockor, J. (2000). Mathematical principles of fuzzy logic, Dordrecht: Kluwer.

Paek, J.H., Lee, Y.W., Ock, J.H. (1993). "Pricing construction risk: fuzzy set application", Journal of Construction Engineering and Management, 119 (4), pp.743-56.

Pedrycz,W. and Gomide, F.,(1998), " An introduction to Fuzzy sets:Analysis and Design", MIT Press, Cambridge, Mass.

Perry, J. G. and Hayes, R. W. (1985). "Risk and its management in construction projects", Proceedings of the Institution of Civil Engineers, Part 1, 78, 499–521.

PRAM, (1997). Project Risk Analysis and Management Guide, Association for Project Management, High Wycombe, U.K.

Raftery, J. (1994). Risk analysis in project management. E and F N Spon, London, 143 p.

RAMP, (1998). Risk Analysis and Management for Projects, Institution of Civil Engineers (ICE), faculty of Actuaries, Institute of Actuaries, London.

Ross, Timothy J. (2004). Fuzzy Logic with Engineering Applications, John Wiley and Sons.

Ross, Timothy J., Bookers Jane M., and Parkinson, E. (2002). Fuzzy Logic and Probability Applications: Bridging the Gap, Wiley Press, Philadelphia, PA.

Ross, T. and Donald, S. (1995). "A fuzzy multi-objective approach to risk management, in Computing in Civil Engineering", Vol. 2, Mohsen, J.P. (ed.) ASCE, New York, pp. 1400–403.

Russell, Alan D. and Fayek, Aminah, (1994). "Automated Corrective Action Selection Assistant", Journal of Construction Engineering and Management, 120(1), 11-33.

Singhvi S. S. (1980). ''A practical approach to risk and sensitivity analyses'', Long Range Plng.,

Slovic, P. (1999). Trust, emotion, sex, politics and science: surveying the risk-assessment battlefield. Risk Analysis, Vol. 19, No. 4, pp 689-701.

Smith, Gary R. and Hancher, D. E. (1989). "Estimating precipitation impacts for scheduling." Journal of Construction Engineering and Management, 115(4), 552-566.

Stern, P.C. & Fineberg, H.V. eds (1996). Understanding Risk - Informing Decisions in a Democratic Society. National Academy Press, Washington D.C., 249 p.

Sun, H.W., Evans N.C. (2002). "Comparative Risk Indicators & Possible Climate Change Trends In Hong Kong And Implications For The Slope Safety System " , Geo Report No. 128 , The Government of the Hong Kong Special Administrative Region publisher.

Tah, J. H. M. and Carr, V. (2000). "A proposal for construction project risk assessment using fuzzy logic", Construction Management and Economics, 18:4, 491 - 500

Tah, J.H.M, and Carr, V. (2001), "Knowledge-Based Approach to Construction Project Risk Management", Journal of Computing in Civil Engineering

Teres Flores, J.R. (2006). "Risk Management in Canadian Tunneling Projects", Department of Civil and Environmental Engineering, University of Alberta.

Thompson P., Perry J. (1992). "Engineering construction risks: A guide to project risk analysis and risk management", London.

Tim Bedford, Roger M. Cooke (2001). Probabilistic Risk Analysis, foundations and methods , Cambridge University Press

Toakley, A.R. (1989). Risk, uncertainty and subjectivity in the building Procurement processed critical review, School of Building, University of New South Wales, 144 pp.

Vick, S. G. (2002). Degrees of Belief: Subjective Probability and Engineering Judgment, ASCE Press, 455 pp.

Voetsch, R.J., Cioffi, D.F., Anbari, F.T. (2004). "Project Risk Management Practices and their Association with Reported Project Success", Proceedings from IRNOP.

Wang, S. Q., Dulaimi, M.F., and Agurai, M.Y. (2004). "Risk management framework for construction projects in developing countries", Construction Management and Economics, 22, 237–252

Whitman, R. (1996). "Organizing and Evaluating Uncertainty in Geotechnical Engineering". ASCE 126(7), 583–593.

Wideman RM. (1992). Project and program risk management: a guide to managing risks and opportunities, Project Management Institute,Upper Darby, Pennsylvania, PA.

Wirba E.N., Tah J.H.M. and Howes, R. (1996). "Risk interdependencies and natural language computations", Journal of Engineering Construction and Architectural Management, 3(4), 251–69.

Zadeh, L.A. (1965). Fuzzy sets. Information and Control, 8, 338–53.

Zimmermann, H.-J. (1991). Fuzzy set theory and its applications, Dordrecht: Kluwer, second edition.

Appendix A Risk categories and evaluation table

Based on the Hierarchal risk breakdown structure chart in Figure 3.1, following table is produced in order to be used as a checklist or a prompt list.

	Risk Categories	**Possible Concerns**	**Low**	**Medium**	**High**
	Internal Risks				
	Local				
100	Labor	Productivity			
101	Labor	Availability			
102	Labor	Cost			
110	Material	Quality			
111	Material	Availability			
112	Material	Cost			
120	Subcontractor	Availability			
121	Subcontractor	Reliability			
122	Subcontractor	Financial Stability			
123	Subcontractor	Cost			
130	Equipment	Availability			
131	Equipment	Productivity			
140	Site	Weather Conditions			
141	Site	Ground Conditions			
142	Site	Existing Services			
143	Site	Adjacent/Existing Structures			
	Global				
200	Client	Selection Criteria			
201	Client	Financial Stability			
202	Client	Past Experience			

210	Pre-contract	Type of Project			
211	Pre-contract	$ Opportunities			
220	Contractual	Contract Type			
221	Contractual	Content(Manuscripted/ Standard)			
222	Contractual	Balance(Risk Allocation)			
230	Design	Designer			
232	Design	Constructability			
231	Design	Time schedule			
232	Design	Cost(in DB contracts)			
240	Location	Distance			
241	Location	Field Access			
242	Location	Area Restrictions			
250	Environmental	Considerations & Regulations			
260	Construction	Complexity			
261	Construction	Method			
270	Time Frame	constraints			
280	Management	Availability			
281	Management	Compatibility (Project Team)			
282	Management	Experience			
290	Financial(Project)	Cash Management			
291	Financial(Project)	Equity Retention			
292	Financial(Company)	Cash Flow			
293	Financial(Company)	Collection Risk			

ID #	Risk Categories	Possible Concerns	Low	Medium	High
	External Risks				
400	Economical	Inflation			
401	Economical	Local Market Climate			
402	Economical	International Market Climate			
403	Economical	Strikes			
410	Physical	Bylaws & Regulations			
411	Physical	Apposing Parties			
412	Physical	Natural hazards			
420	Political	Change of Government			
421	Political	War			
422	Political	Political Agenda			
430	Technological	New Construction Device			
431	Technological	Innovative Methods			
432	Technological	New IT			

Appendix B Risk factors' description for 23rd Ave Project

This chart is based on the consultant work of S.M.A. Consulting, which conducted the risk management and analysis for 23rd avenue interchange project.

ID	L	M	S	Risk Factor
1.	50	50	2500	The amount of fill required for the interchange (estimated to be 500,000 m^3) may delay the completion of the project by one year from its currently estimated delivery date.
2. a	20	15	300	If decisions regarding design are not completed by the time indicated, the project will be delayed by one season.
2.	10	50	500	If decisions regarding design are not completed by the time indicated, the project will be delayed by 3 month.
3.	50	50	2500	If all land is not acquired by December 31 2004, then tenders will be delayed or significant risk of increased project cost ($3M)
4.	10	50	500	If the geotechnical conditions were significantly worse (not suitable for MSE walls, or settlement at pipeline crossings etc.) than those assumed then the project will be delayed by 1 year and costs will escalate by $6 million.
5.	20	5	100	Lack of coordination with A.H.D. contractor for fill source/placement and detours will create traffic problems, and add to project costs and schedule.
6.	10	50	500	If constructability (especially site logistics) issues are not addressed then the project will be delayed by one season and its costs increased by more than 10%, would also create: disruption to businesses, disruption to motoring public, political interventions, delays to construction, emergency access affected, and affect airport access.
7.	3	200	600	If the design does not account for operational requirements, permanent traffic safety concerns and impaired functionality of the interchange will result.
8.	3	50	150	If maintenance issues are not addressed during the design, it will result in increased maintenance costs and safety concerns.
9.	20	50	1000	If poorer weather (less than ideal since the schedule is compressed) than normal is encountered during construction, the schedule may be delayed by up to 1 year.
10.	10	100	1000	If pipeline relocations are required then coordination will be necessary with "shutdowns". Integration and coordination with the interchange design will delay the planned preliminary design completion date of July 1, 2004 by one year and add to cost $6 million.

ID	L	M	S	Risk Factor
11.	50	15	750	Delay to utility (power, water, gas, telephone) relocations will delay subsequent relocations and detours.
12.	3	5	15	If construction of SEC drainage connections to the storm tunnel is delayed beyond May 1, 2005 then construction of NE ramp and retaining walls cannot proceed resulting in additional costs of $200,000.
13.	10	5	50	If retaining walls are required for 101 street over the existing pipelines then protection measure are needed which will impact construction costs.
14.	10	15	150	If ATCO regulating station cannot be relocated then the interchange design will have to accommodate it which could mean more construction dollars (higher retaining walls).
15.	3	1	3	If 1:25 storm event happens during construction, before the secondary system is connected to the tunnel, then the construction will be delayed and costs could be impacted (site flooding).
16.	50	15	750	Large project/ large contractors combined with short design period and short construction period could result in contractor claims.
17.	20	50	1000	If there is insufficient contractor or material supply capacity then costs increases (up to 20%), schedule delays and quality of workmanship will suffer.
18.	20	5	100	Installation of wick drains for ground improvement could intercept contaminated ground water and cause discharge to ground surface. (Increased costs for collection and treatment up to ~ $205K)
19.	1	15	15	If a train derails and crashes into retaining wall facing, panels will be destroyed and fill material may sluff locally. Costly repairs will be required.
21.	3	50	150	If there is inadequate management of the large design team then there will be delays to tender, collapse of partnership, or additional engineering or construction costs.
22.	3	15	45	If external communications programs are inadequate then project credibility fails during design or construction resulting in political intervention.
24.	10	5	50	If aesthetics don't meet public/politicians expectations then costly changes may be required or permanent "eye-sore" may be the result.
25.	3	15	45	If a girder or formwork falls on tracks (or road) during bridge construction then risk of accident/injury/claims
26.	50	5	250	Construction of retaining walls for ramps down to tunnel will likely require temporary shoring with tie-backs. Easement with adjacent property owners will likely be needed.
27.	3	5	15	Conflict between bridge piles and drainage tunnel may take place as a result of completing tunnel first which may add to costs $150,000 and delay schedule by up to a month.
28.	50	1	50	If road bridge is shortened with vertical walls tight to the roadway the aesthetics will be compromised

ID	L	M	S	Risk Factor
31.	10	100	1000	If existing conceptual plan in found to be not functional (budget, traffic capacity, safety, schedules, staging) then: • Project looses credibility • Schedule delays occur • Cost overruns • City gets less value on its investment.
32.	3	15	45	If there is significant public opposition during construction (i.e. traffic congestion during construction or large expense for perceived single benefactors) then the City will be pressured to expedite completion with additional investment (> $5 million).
33.	10	50	500	If contractors perceive project to be undesirable due to high risk then project costs will increase (~ 10million)
34.	10	15	150	If the identified budget of $75 million is inadequate by more than $10 million then project may be deferred.
35.	10	15	150	If budget approval for 2005/2006 does not occur then project may be deferred, lost investment in sewer infrastructure ($10 million).
36.	3	15	45	If CPR funding negotiations for 15% are unsuccessful then City contributes more towards project ($600,000).
36b.	50	5	250	If high speed rail (third rail) has to be allowed for then there will be an increase in cost of $500K assuming the Province and CP do not contribute to its costs
38.	1	15	15	If there is public opposition to the ongoing conceptual planning study to the North (including access closure at Gateway Theater) then there could be a design change which could affect schedule cost.
39.	3	50	150	If tree clearing is not completed by April 15, 2005, then project is delayed by one year.
40.	3	50	150	If emergency planning (for pipelines, ethane plant, airport, railway, flooding) is not adequately addressed in contract then emergency response is compromised resulting in public claims, loss of life and property, and contractor claims. (plus negligence –personal and professional).
41.	20	15	300	If facilitated sessions (VE, safety, constructability) result in significant design changes then design completion will be delayed.
42.	20	15	300	If City departments and utilities are not responding then delay to design completion will occur and will impact schedule.
43.	20	50	1000	If there are poor contractor relationships then there will be cost overruns, lost opportunities for project improvements, and added value, and delays to schedule.
44.				Opportunity: look at shortening the bridge and use one span to save on cost.

Appendix C Excel-Macro program for calculating severity

```
Sub GenerateFields()

' Macro recorded 27/06/2008 by aferguso
'
'

  Dim NSize As Integer
  Dim MSize As Integer
  Dim I As Integer
  Dim J As Integer

  Range("B2").Select
  NSize = ActiveCell.FormulaR1C1
  Range("I2").Select
  MSize = ActiveCell.FormulaR1C1

  For I = 1 To NSize
    Range("A" & (I + 2)).Select
    ActiveCell.FormulaR1C1 = "A" & I
  Next

  For I = 1 To MSize
    Range("H" & (I + 2)).Select
    ActiveCell.FormulaR1C1 = "B" & I
  Next

  Dim Max As Integer
  If NSize > MSize Then
    Max = NSize + 4
  Else
    Max = MSize + 4
  End If

  Range("B" & Max).Select
  ActiveCell.FormulaR1C1 = "A"
  Range("C" & Max).Select
  ActiveCell.FormulaR1C1 = "B"
  Range("D" & Max).Select
  ActiveCell.FormulaR1C1 = "C"
  Range("E" & Max).Select
  ActiveCell.FormulaR1C1 = "D"
  Range("F" & Max).Select
  ActiveCell.FormulaR1C1 = "CoG"

  Dim Row As Integer

  For I = 1 To NSize
    For J = 1 To MSize

      Row = Max + MSize * (I - 1) + J
      Range("A" & Row).Select
      ActiveCell.FormulaR1C1 = "C" & I & J
```

```
        Range("B" & Row).Select
        ActiveCell.Formula = "=B" & (2 + I) & "*I" & (2 + J)

        Range("C" & Row).Select
        ActiveCell.Formula = "=C" & (2 + I) & "*J" & (2 + J)

        Range("D" & Row).Select
        ActiveCell.Formula = "=D" & (2 + I) & "*K" & (2 + J)

        Range("E" & Row).Select
        ActiveCell.Formula = "=E" & (2 + I) & "*L" & (2 + J)

        Range("F" & Row).Select
        ActiveCell.Formula = _
        "=(((C" & Row & "-B" & Row & ")/2*(B" & Row & "3+2*(C" & Row & _
        "-B" & Row & ")/3)) + ((D" & Row & "-C" & Row & ")*(C" & Row & _
        "+(D" & Row & "-C" & Row & ")/2))+((E" & Row & "-D" & Row & _
        ")/2*(D" & Row & "+(E" & Row & "-D" & Row & ")/3)))/((C" & Row & _
        "-B" & Row & ")/2+(D" & Row & "-C" & Row & ")+(E" & Row & "-D" & Row & ")/2)"
      Next
    Next

End Sub
```