Department of Civil Engineering

Risk Management of Civil Projects by Using Fuzzy Logic

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DECLARATION

This thesis contains no material, which has been accepted for the award of any other degree in any institution.

This thesis contains no material previously published by any other person except where due acknowledgement has been made.

All of data are original from the participants.

Signature: …Amin Amini………

Date: ………13/12/2017……….

To:

Maryam, ***my love, my wife & joy of my life, who made this possible with her inspiration and support***

My dear father & mother and my beloved grandma (R.I.P)

&

All who risk their lives to help make the world a better place to live

ABSTRACT

Risk management is one the most important challenges of all modern management systems and is considered one of the key responsibilities of every civil project management system from feasibility stage, investment, design, construction to operation and usage stages.

The complexity and magnitude of oil & gas projects expose them to a huge range of risks and uncertainties. Risks can impact the anticipated scope, cost, quality and accomplishment time of oil & gas projects in different stages of exploration, excavation and production, transportation, refining and marketing.

Risk management models which apply certain mathematics and divalent logic that need accurate data, are less compatible with the uncertainty space of oil & gas civil projects which may lead to models with low precision and lack of flexibility. Unlike the classic logic, fuzzy logic assigns more than a simple binary truth value of 1 (truth) or 0 (false) to the veracity of an element. With fuzzy logic, propositions can be represented with degrees of truthfulness and falsehood so it is more compatible with the uncertainty atmosphere of risks.

The main purpose of this study was to introduce and develop an appropriate model for risk management, which takes advantage of experts' knowledge in various fields by involving vague and imprecise data in risk management to reduce time and error rate in identifying, analysing, monitoring and responding to risks.

In this study after identifying and classifying the risks which affect oil & gas projects, a model based on fuzzy inference system is developed for evaluating and analysing the most effective risk parameters during the construction of oil & gas projects (extraction platforms, refineries, transport pipelines, etc.). This study investigates 16 risks of the constructional risk category, out of 17 categories of risks containing 249 identified risks and determines the most serious risks of this category.

By applying the above studies, we can consequently find answers to some management challenges arising from uncertainty and ambiguity in the expression of probability of occurrence and impact magnitude of potential risks.

The approach taken in this study will show the risk managers in companies that how by using fuzzy logic in modelling qualitative and experimental judgements, they can make quick and accurate strategic decisions in an uncertain environment with minimal risk and maximum profitability.

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ABBREVIATIONS

Actual Cost	AC
Agency Construction Managers	ACM
American Society of Civil Engineers	ASCE
Analytical Hierarchy Process	AHP
Basic Risk Item	BRI
Bidding Price	BP
Binder Dijker Otte	BDO
British Petroleum	BP
Build-Operate-Transfer	BOT
Catastrophic	CA
Centre of Area	COA
Centre of Largest Area	COLA
Centre of Gravity	COG
Certain	C
Chief Risk Officer	CRO
Construction Managers	CM
Critical	CR
Department of Energy	DOE
Electronic Commerce	EC
Engineering, Procurement and Construction	EPC
Enterprise Risk Management	ERM
Event Tree Analysis	ETA
Evidential Reasoning	ER
Extra High	EH
Failure Mode and Effect Analysis	FMEA
Failure Mode Effect and Criticality Analysis	FMECA
Fault Tree Analysis	FTA
Fuzzy Mean	FM
First of Maxima	FOM
Fuzzy Analytical Hierarchy Process	FAHP
Fuzzy C-Means	FCM
Fuzzy Decision Support System	FDSS

Fuzzy Decision Support System	FDSS
Fuzzy Group Decision Making	FGDM
Fuzzy Group Method of Data Handling	GMDH
Fuzzy Inference System	FIS
Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference	FLINMAP
Fuzzy Multi Attribute Decision Making	FMADM
Fuzzy Multi Attribute Direct Rating	FMADR
Fuzzy Quality Control	FQC
Fuzzy Risk Assessment	FRA
Fuzzy Techniques for Order Preference by Similarity to Ideal Solution	FTOPSIS
Hazard and Operability Studies	HAZOP
Hazard Identification	HAZID
High	H
Institute of Internal Auditors	IIA
Integrated Operation	IO
Intelligent Decision System	IDS
International Energy Agency	IEA
International Oil Companies	IOC
K-Nearest Neighbours	K-NN
Laboratory for International Fuzzy Engineering	LIFE
Largest or Last of Maxima	LOM
Liquefied Natural Gas	LNG
Limited Liability Partnership	LLP
Low	L
Lower Limit	LL
Mean of Maximum	MOM
Medium or Moderate	M
Medium Low	ML
Membership Function	MF
Minor	MI
Monte Carlo Simulation	MCS
Multiple Criteria Group Decision Making	MCGDM
Overall Risk Factor	ORF
Precedence Diagramming Method	PDM

Preliminary Hazard Analysis	PHA
Probability Density Function	PDF
Probability-Impact	P-I
Program-Evaluation and Review Technique	PERT
Project Management Body of Knowledge	PMBOK
Project Management Institute	PMI
Quality Method	QM
Crisp Value of Total Net Loss	RC
Risk Breakdown Structure	RBS
Risk Discrimination	RD
Risk Discrimination Comparison	RDC
Risk Impact	RI
Risk Influencing Factors	RIF
Risk Likelihood	RL
Risk Magnitude	RM
Risk Probability	RP
Risk Severity	RS
Robust Agglomerative Gaussian Mixture Decomposition	RAGMD
Security Risk Factor Table	SRFT
Self-Organizing Feature Map	SOFM
Slightly High	SH
Slightly Low	SL
Smallest of Maximum	SOM
Statistical Package for the Social Sciences	SPSS
Three-Dimensional	3D
Trapezoidal Fuzzy Number	TPFN
Triangular Fuzzy Number	TFN
Upper Limit	UL
Very Low	VL
Weighted Average Method	WAM
Weighted Fuzzy Mean	WFM
Work Breakdown Structure	WBS

1. INTRODUCTION

1.1. Project Overview

The oil & gas industry plays a very important role as the world's main source of energy supply. The complex and sensitive global conditions, politically and economically, have faced oil & gas industry and dependent companies with many modern challenges. Risk management policies are considered one of the highly regarded of these modern challenges. With regard to the uncertain and the ambiguous atmosphere of oil and gas projects, various risk management systems try to apply models, which can involve uncertainties in identifying and analysing the risks more.

Whereas models based on divalent logic don't consider the uncertainties arising from vague data, the fuzzy management knowledge by using fuzzy systems theory can be a new approach to solve the problem and an answer to questions posed in management systems. Fuzzy systems by applying fuzzy logic theory and fuzzy measures can model parameters such as human knowledge, experience and judgments. In this way, classic management techniques expand to the fuzzy environment, and regards to its flexibility, it can be used for multiple management systems, including risk management, decision making and planning.

In this study a fuzzy model based on fuzzy inference system was developed to evaluate the risks during the construction of oil & gas projects according to the principles and standards defined in risk measurement. The flexibility of this model makes it adaptable to different conditions where the classification or evaluation of risk factors and risk components change.

1.2. Background

Civil projects in oil and gas are very complex and time-consuming process from the initial stages of feasibility assessment and investment appraisal to design, completion and utilization. During an oil & gas project a large group of people with different expertise and skills in different, but related activities must be coordinated. This complex procedure is influenced by a wide range of risk factors with various nature and origins that can be categorized under various types of grouping. The focus of this study is on one of the risk categories that appears in many risk grouping types and contains the risk factors that affect an oil and gas project during its construction.

Project risk management has been practiced since the mid-1980s and is one of the main knowledge areas of the Project Management Institute's PMBOK (Project Management Body Of Knowledge) (Tüysüz & Kahraman, 2006).

Improving performance of the construction projects and increasing the contractual obligations, requires an efficient and coordinated risk management approach.

Risk comes from uncertainty and inadequacy of information, but it is distinguished from uncertainty. Risk is a measurable uncertainty where the uncertainty is an immeasurable risk. (Hillson, 2003; Kangari, 1988; Olsson, 2007) In multifactor and non-linear systems where human reasoning, expert knowledge and imprecise information are valuable inputs, risk management faces many challenges in providing practical solutions. One of the provided solutions by mathematic and logic is fuzzy logic.

The sentence "*All things are partially true or false*" is considered a principle among fuzzy theory thinkers against the "*rejection the third position*" principle of divalent theory thinkers (Faraji, Faraji, & Faraji, 2002). Sentences like "*air temperature is 30 ° C*", "*the first even number is 2*" and like this, are true or not and they are not out of these two conditions.

Since the beginning of mathematics, expressing the truthfulness of mathematical propositions in the form of true or false was assumed certain, clear and definite, and there wasn't any other statement out of these two. Divalent system has been the basis of logic and math and therefore the world of science has been founded on this basis (Kosco, 1993).

Bart Kosco in '*Fuzzy Thinking'* calls this approach as the black and white attitude and knows it as a misconception of science and claims that science has considered the grey or fuzzy realities with black and white mathematics tools so it seems that realities are only black and white (Kosco, 1993). What is the value of fuzzy theorists? Are issues that are not so crisp and clear and there are streaks of uncertainty and ambiguity in them? Doubt the being limited the truth of an expression only to two values of true or false showed itself since the beginning of the 19th century in Lukasiewicz works and followed him logicians and mathematicians like Kleene, Bochovar and Post however the used word was '*vague*' not '*fuzzy'*.

Another effective approach of this thinking took place by Dr. Lotfi Zadeh the professor of electrical and computer engineering at Berkeley University by using the word "*Fuzzy*" instead of '*ambiguity*' (L. A. Zadeh, 1965). Many fundamental concepts of fuzzy set theory were introduced by Zadeh in the late 1960s and early 1970s. After the introduction of fuzzy sets in 1965, he presented the algorithm concepts of fuzzy systems in 1968 and fuzzy decision making in 1970 in his works.

Using the '*IF-THEN'* rules was the great event of 1970s for fuzzy theory and birth of fuzzy controllers for real systems. In 1975, Mamdani and Assilian determined a primary framework for fuzzy controlling and applied it to a steam engine.

The next achievement belonged to Holenblad and Ostergard. In 1978 they used the first fuzzy controller completely for an industrial procedure which was fuzzy control of cement producing in cement furnace (L. X. Wang, 1997).

The primary usage of fuzzy logic in risk assessment appears in the late 1980s. (Kangari, 1988) described the application of fuzzy set theory and knowledge-based system for construction risk management by proposing a model which combined various information for decision making under uncertainty.

The use of fuzzy logic in different fields of engineering and management has been increased significantly. Nowadays there are many fuzzy risk management models that would be reviewed in the next sections of this script.

1.3. Objectives

The proposed research program targets the construction risk management of oil & gas projects by applying fuzzy logic. Motivation for the research is provided by the increased complicated risk factors resulting from increasing uncertainty space of civil projects for making accurate and timely decisions. The objectives of the research are as follows:

- To perform a preliminary study into the risk management standards and methods and usage of fuzzy logic concepts in this area.
- Identifying the risk factors which affect the oil & gas projects which are considered kind of civil infrastructure projects.
- Classifying the identified risks in an effective way which is more compatible with nature and sources of the risks.
- Providing a flexible, adaptable and user friendly questionnaire that can collect the experts' qualitative judgments and knowledge in the best way and is compatible with uncertainty space and linguistic variables.
- Developing a model using a fuzzy inference system to investigate the risks under the construction risk category.

In this survey, probability of occurrence and magnitude impact of each risk and also the understanding of experts from linguistic variables used for expressing the probability and consequence of risks, are investigated trough the detailed questionnaire. The functions and rules used in the fuzzy inference system of the proposed model are formed based on the most reputable risk management standards and codes. The flexibility of this model is essential for an effective risk management, which requires a reporting and review structure to ensure that risks are effectively identified and assessed and that appropriate controls and responses are in place.

1.4. Significance

The capability of fuzzy logic in the conveying of concepts raised from uncertainty and the relation that exists between risk and uncertainty inspired this research to utilize a fuzzy logic-based model for correction the insufficiencies of simple and classic mathematical models in risk management.

Contrasting from traditional approaches, the proposed model allows convenient use of qualitative and vague inputs, which play an important role in risk management of complex and large sized projects like oil & gas projects. By using this flexible and dynamic fuzzy model which is compatible with different stages of risk management procedure, we can model and analyse the verbal judgments to reduce the uncertainties come from the human mind and the environment as well as the degree of human judgment inaccuracy and find answers for some management challenges arising from uncertainty and ambiguity to overcome the complexity of risk management in a tangible way.

A more accurate evaluation of risks helps managers in a better project planning by giving them the ability of prediction the unwanted events. The outcomes of this study can be used in multi attribute decision making models for a better comparison of different projects regards to threatening risks. This helps the managers in companies to make quick and accurate strategic decisions for offering bids on projects with minimal risk and maximum profitability.

1.5. Thesis Outline

Within the thesis outline, the stages of the study, which is a breakdown of this research and also the limitations and benefits of this study are explained.

1.5.1. Stages of the study

This thesis includes the following chapters:

- Chapter 1: The introduction chapter explains the project overview, background, objectives, significance and outline of the study.
- Chapter 2: The chapter of background and literature review, first presents the definitions of basic concepts and theoretical foundations of this study like risk, project risk management, fuzzy logic and fuzzy systems, then reviews previous conducted

researches and studies related to risk management of oil & gas projects and background of fuzzy risk management in engineering and construction.

- Chapter 3: Presents the project methodology, the proposed model and taken methods and techniques for collecting and obtaining the required data.
- Chapter 4: Data analysis chapter presents results of data analysis and the discussion of the findings.
- Chapter 5: Provides summary of results and conclusions and recommendations for further research.

1.5.2. Limitations of the study

Limitations are certain constraints that the objects of the study are defined in that framework. The limitations of this study are as follows:

- This research identifies and classifies the risks of oil & gas projects, but investigates the risk factors occur during the construction operations of an oil & gas project such as construction of extraction platforms, refineries and transport pipelines which are categorized under *Construction Risk* group. Thus the risk factors under *Operational Risks* group, *Managerial Risks* group, *Supply and Logistic Risks* group or *Legal Risks* group are not investigated in this research. In this study 249 risk factors were identified and categorized under 17 risk groups and the *Construction Risks* group that contains sixteen (16) risk factors is the Group 5 of this classification.
- This project determines numerical values of construction risks of oil & gas projects that affect project objectives. Four components have been determined as *Project Objectives* in this study as follows:
    1. Time
    2. Cost
    3. Quality
    4. Scope
- Regarding to the global aspects of oil & gas projects, identifying and assessing the risk factors and risk groups includes reviewing the researches and questioning the experts involved in civil oil and gas industry from inside and outside of the Australia.
- This study is not a project oriented one, but it is a risk oriented project. It means that this study does not compare different projects to each other according to existing risks, but it evaluates the risk factors exist in the construction of an oil and gas project. Nevertheless, the proposed model in this study can be customized for a particular project, location or a specific condition.

1.5.3. Benefits of the study

The results of this study can benefit the managers in oil & gas companies or government or researchers in the following ways:

- The numerical values of risks help managers to perform a better project planning to accomplish a project in a specific time, with predefined allocated funds that provide expected quality and scope.
- Flexibility of the model allows managers to customize it for a particular project, location or condition.
- The results of this study can be used in multi attribute decision making models which are project oriented like models based on simple additive weighting methods, Analytical Hierarchy Process (AHP) or Fuzzy Multi Attribute Decision Making (FMADM).

2. BACKGROUND AND LITERATURE REVIEW

2.1. Risk History

The history of risk concept and risk assessment as potential of losing something valuable is quite protracted. This valuable thing can be physical health, movable and immovable wealth, social status and reputation or even emotional feelings. Terje Aven points to Athenians risk assessing before decision making in 2400 years ago (Aven, 2012). He quoted a paragraph from the Pericles' Funeral Oration in Thucydides', 'History of the Peloponnesian War' in 431 BC:

> *"We Athenians in our persons take our decisions on policy and submit them to proper discussion. The worst thing is to rush into action before the consequences have been properly debated. And this is another point where we differ from other people. We are capable at the same time of taking risks and assessing them beforehand. Others are brave out of ignorance; and when they stop to think, they begin to fear. But the man who can most truly be accounted brave is he who best knows the meaning of what is sweet in life, and what is terrible, and he then goes out undeterred to meet what is to come."*

Peter Bernstein in '*Against the Gods'* tells the remarkable story of risk during the centuries and explains how understanding and interpretation of risk over the times has developed. However, there were many extraordinary scientists, astronomers, engineers, inventors, mathematicians, chemists and philosophers in mankind's history whose achievements were remarkable, he separates the past and modern ages where the mastery of risk ends; the notion that the future does not follow the gods' whim and people are not obedient to nature. He believes that what formed the modern western society, where risk understanding, measuring and its consequence weighting (Bernstein, 1998).

Aswath Damodaran describes a very short history of risk. He mentions this fact that how searching for food and shelter exposed the prehistoric humans to danger from wild animals and bad weather conditions and led to a short and brutal life for them. Even the more established civilizations in Babylon, Persia, Sumer and Greece faced with risks such as war, drought and disease. He knows the advent of shipping as a new milestone for taking the risk in human history. When the Vikings began their voyages in search of new lands to pillage from Scandinavia toward Britain and even across the Atlantic to the America a new historic period for shipping trades was begun that defined new equations for risk and return. On one side of this equation was the risk of ships sinking and being attacked and robbed by pirates and on the other side there was the rewards from returning back the ships with cargo. Development in trade through the sea separated the physical and economical risk while rich traders bet their stock and money; the poor sailors risked their lives on the ships. With the development of trading ship lines, lucrative trade of spice from India to the Middle East and from there to Europe, which had flourished for centuries, took a new form. In the middle of the second millennium, at the golden age of sea voyages of the Spanish and the Portuguese followed by the British and the Dutch, took the risk of death, disease and war explore new sea routes to reduce the risk of losing cargo, this risk taking adventure built the foundation of the new empires and caused a new turning point in the history of the world (Damodaran, 2008).

2.2. Risk Definition

Regarding the presence of risk in every activity, there are several and varying definitions of this word. The Oxford English dictionary defines risk as: '*a chance or possibility of danger, loss, injury or other adverse consequences*' and defines '*at risk*' as exposed to harm or danger. This dictionary refers the origin of '*risk*' to mid-17th century from the French word 'risque' (noun), 'risquer' (verb) and from Italian words '*risco*' and '*rischiare*', which means '*danger*' and '*run into danger*' respectively (Dictionary, 2004). In this context risk has been used to signify negative outcomes and consequences while in many other ones taking a risk can also result in a positive outcome as a third possibility risk is related to the uncertainty of outcome.

One of the practical and applicable definitions of risk has been presented by the Institute of Risk Management (Hopkin & IRM). This Institute defines risk as the combination of the probability of an event and its consequence. Consequences can range from positive to negative (Hopkin & IRM, 2014). Institute of Risk Management (Hopkin & IRM) defines three types of risks:

1. Hazard risks or pure risks: The insurable events that prevent an organization from achieving its goals and can only have negative impacts.
2. Control risks: Risks that create uncertainty about the ability to achieve the goals of the organization. The potential losses due to fraud are kind of control risks.
3. Opportunity risks or speculative risks: Risks that an organization takes to enhance the achievement of its mission. These risks are the most important type of risks for the future long-term success of any organization.

Paul Hopkin brings the example of owning a motorcar. While owning a motorcar for most of people is an opportunity to become more mobile and get the related benefits, on the other hand, there are some uncertainties in having a motorcar related to its maintenance and repair costs. In a case that the motorcar is involved in an accident the obvious negative outcomes occur. Finally, he defines risk as 'event with the ability to impact (inhibit, enhance or cause doubt about) the mission, strategy, projects, routine operations, objectives, core processes, key dependencies and / or the delivery of stakeholder expectations (Hopkin & IRM, 2014).

One of the earliest discussions about risk was presented by Frank Knight in 1921. He summarized the differences between '*risk*' and '*uncertainty'* and believed that only a quantified uncertainty should be considered as a risk. He clarifies this through an example of two individuals drawing red and black balls from an urn. While the first individual is ignorant about the number of each colour, the second person is aware that the numbers of red balls are three times the number of black balls. The second individual knows that the probability of drawing a red ball is 75%, whereas the first one considers a 50% chance for the same situation that is a misperception. Knight argues that the first individual is not exposed to risk, but he suffers from ignorance, whereas the second one is exposed to risk (Knight, 2006).

In the paper '*Defining Risk*' by Holton, he considers two required ingredients for a risk to exist. The first factor is uncertainty about the potential consequence from an experiment and the other one is that the outcome should have significance in providing utility. For example, a person who does skydiving without a parachute is not exposed to any risk because with no uncertainty he will face the death. Also the activity of drawing balls out of an urn is not a risky activity if one's health or wealth remains unaffected if a black or red ball is drawn (Holton, 2004).

Aswath Damodaran discussed the different ways that risk is defined by different disciplines from engineering to insurance and finance and notes to some of the distinctions (Damodaran, 2008):

- Risk versus Probability: Some definitions of risk only consider the probability of an event, whereas some more comprehensive ones focus on both probability and consequences of the event. For example, the probability of a severe earthquake may be very small but its consequences are very calamitous thus this earthquake categorized as a high risk event.
- Risk versus Threat: In some definitions a threat is a low probability event with very large negative consequences that the likelihood cannot be assessed by the analysts, like a catastrophic earthquake with a low probability of happening while a risk is defined as an event with a higher probability that there is enough information to assess its likelihood and consequences.

- All outcomes versus Negative outcomes: While some definitions of risk focus only on negative or harmful outcomes of an event, other ones consider every variation from the expected objectives as risk whether positive or negative. He notes that while most of the engineering disciplines define risk as production of the probability of an undesirable event and its negative consequences, disciplines related to finance define it as variation of actual returns on an investment from the expected return.

Figure 2-1 shows the Chinese symbol for risk that best indicates the last distinction mentioned above. This symbol combines two aspects simultaneously to produce the concept of risk. The first aspect is the downside of danger (crisis) and the second face is the upside of opportunity. This definition reflects both positive and negative sides of taking risks at the same time, which means any taken approach for minimizing the risk will reduce the potential opportunity.

Figure 2-1: The Chinese symbol for risk

Organizations, institutes, sources and authorities have different definitions of '*risk*'. One of the definitions which is compatible with three types of events outlined in the motor car ownership has been presented by ISO Guide 73. The definition of risk in this international guide to risk-related definition is: '*effect of uncertainty on objectives*'. Based on Guide 73 an effect may be positive, negative, or a deviation from the expected. This definition does not seem to be easily applicable to everyday life and reflects three situation of opportunity, a hazard or an uncertainty for an event (ISO 73:2009). This guide adds that risk is often described by an event, a change in circumstances, a consequence, or a combination of these and how they may affect the achievement of objectives.

Australian and New Zealand risk management standard: AS/NZS ISO 31000: 2009 which is supported by the International Standard ISO/IEC 31010:2009–Risk Management; IEC/FDIS 31010 Risk Management–Risk Assessment Techniques; and ISO Guide 73:2009–Risk Management Vocabulary defines risk as the '*effect of uncertainty on objectives*'(AS/NZS ISO 31000:2009). For this definition this guideline considers following notes:

- Note 1: An effect is a deviation from the expected positive and/or negative.

- Note 2: Objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process).
- Note 3: Risk is often characterized by reference to potential events and consequences, or a combination of these.
- Note 4: Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence.
- Note 5: Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood.

An alternative definition of risk is what presented by the Institute of Internal Auditors (IIA). This institute defines risk as ‘the uncertainty of an event occurring that could have an impact on the achievement of objectives’ (IIA 2120, 2010). It notes that risk is measurable in terms of consequences and likelihood.

Charles Yoe knows risk as the ‘chance’ of an undesirable outcome that is usually created due to lack of information about events that have not yet happened and defines it as a measure of the probability and consequence of uncertain future events (Yoe, 2011). That consequence could be a loss like flood, illness, fire, financial setback, death or any sort of hazard or an unrealized potential failure, such as unexpected produced benefits of the investment, unrestored ecosystem or any sort of a missed opportunity. He considers two important components to describe a risk, first, chance, likelihood or probability of occurrence and second, an undesirable outcome or consequence and describes it by the following simple equation (Equation 2-1).

$$Risk = Probability \times Consequence \qquad \text{Equation 2-1}$$

Since the focus of this research is on the risk factors that occur during the construction of an oil & gas project and are more related to engineering disciplines, the basis of risk assessment in this study is the Equation 2-1. The both elements of probability and consequences must be present for calculating a real risk, thus if an event of any consequence has no likelihood of occurrence, there is no risk. In the same way, if there is no consequence or undesirable outcome, then there is no risk.

2.3. Project Risk

As this study’s focus is on risks occurring during the construction of oil & gas projects, we need a more specific definition of project risk. It is very important that we note every risk has a main cause and if it happens, it has an impact. For example, the cause may be a required permit for starting a construction project requires or having adequate particular professional personnel assigned to a task. In this case risk event is that the permit may take longer than what planned or the personnel may be inadequate for the task.

Project risk in BS 31100 has been defined as '*Risk relating to delivery of a product or service, especially with the constraints of time, cost and quality*' (BS 31100:2008, 2009).

Project Management Institute (PMI) in the 5th edition of Project Management Body of Knowledge (PMBOK) guide, defines project risk as *'an uncertain event that, if it occurs, has a positive or negative effect on the prospects of achieving project objectives*' (PMI, 2013).

This definition has four fundamental points:

1. Uncertain event: something may or may not occur, e.g. sickness of a project personnel or an unpredicted weather condition makes a process impossible.
2. If it occurs: If a forecasted risk actually occurs, it is no longer a risk, but it is an issue or matter that had been predicted before.
3. Positive or negative effect: project risk necessarily does not have negative aspects like increased completion time or decreased quality; it can also have positive aspects, in PMBOK guide there are a lot of instances that the expression "reduce risk and enhance opportunities" is used. For example, the risk of using new technology leads to new enhanced and valuable product features or some project modifications leads to opening up a new market segment.
4. Project objectives: risk occur can affect the project goals. Severe negative risks can lead to the cancellation of a project, whereas minor risks may slightly increase the completion time or total cost of a project.

2.4. Project Objectives

In this research the impacts of risk on project' objectives are evaluated within a recognized framework by Project Management Institute (PMI).

PMBOK guide specifies four general objectives of any project as:

1. Time
2. Cost
3. Quality
4. Scope

2.4.1. Time of project

The PMBOK guide defines project time with its function that is listing planned dates for performing activities and meeting identified milestones in the project plan. Schedule of project is created through analysing activity sequences, activity durations with planned start and expected finish dates and resource requirements. It usually remains preliminary before the completion of project plan development when the resource assignments are confirmed. Additional details such as documentation of all identified assumptions and constraints, support the project schedule. The extent of details depends on application area. For example, when it comes to construction projects, it will probably include such items as resource histograms, cash-flow projections, and order and delivery schedules. The project schedule is controlled and developed by '*Project time management*' procedure. Project time management is considered as a subset of project management that includes required procedures to guarantee a well-timed completion of the project and consists of defining the activities, sequencing the activities, estimating the duration of activities, schedule development and controlling changes to the project schedule (PMI, 2013).

2.4.2. Cost of project

Total project cost is defined by the U.S. Department of Energy (DOE) as all costs specific to a project incurred through the start-up of a facility, but prior to the operation of the facility (DOE, 1997). So total project cost includes total estimated cost and other project costs or:

$$\textit{Total project cost} = \textit{Total estimated cost} + \textit{other project costs} \qquad \text{Equation 2-2}$$

The cost of the project needs to be managed under a subset of project management called '*Project cost management'*. This procedure applies following processes to ensure that the project is completed within the approved budget (PMI, 2013):

- Resource planning: determining the resources (personnel, equipment, and materials) and the quantities of each required to perform the project activities
- Cost estimating: developing an estimate of the cost of required resources
- Cost budgeting: assigning the total estimated cost to each project activity
- Cost control: controlling changes that affect the project budget

2.4.3. Quality of project

The PMBOK guide defines quality as: "*the totality of characteristics of an entity that bear on its ability to satisfy stated or implied needs*" (PMI, 2013). Stated and implied needs are the inputs to developing project requirements. The quality of a project should satisfy the needs for which it was taken and is managed under '*Project quality management'* through the following processes:

- Quality planning: identifying the relevant standard qualities to the project and the way to satisfy them
- Quality assurance: evaluating total project performance on a regular basis to guarantee that the project will satisfy the relevant quality standards
- Quality control: through this process the specific project outcomes and the compliance of relevant standards are monitored and the methods to eliminate the sources of unacceptable performance are identified.

2.4.4. Scope of project

Specific project goals, deliverables, tasks, costs and deadlines are determined and documented as a part of project planning called project scope. In other word the project scope defines the project boundaries (Donaldson & Siegel, 2001). PMBOK defines scope as "*the sum of products and services to be provided as a project*" (PMI, 2013). Defining the project scope is one of the most essential and critical steps of the project planning that determines what is supposed to be delivered at the end of the project to the client. During the completion of large and long term projects like oil and gas projects, some risk factors may cause some changes to the project scope that need to be controlled by project team members. The better a project has been '*scoped'* at the beginning the better the project team members are able to manage the project scope changes due to risks. The project scope is managed under 'Project cost management' procedure which is a subset of project management that includes the processes to make sure the project includes all of the work required, and only the work required, to complete the project successfully. It consists of initiation, scope planning, scope definition, scope verification, and scope change control.

2.5. Risk Management

2.5.1. History and origins of risk management

Risk management has various origins, but one of the earliest origins of risk management goes back to insurance management function in the United States. In the 1950s increasing the cost of insurance and limitation of coverage extension caused the risk management became better coordinated and more widespread. Purchasing an expensive insurance with insufficient coverage without taking other protection policies wasn't justifiable for organizations anymore, so they realized that paying adequate attention to the quality of protection of property and people by developing health and safety standards, concerning about the product liability and other risk control issues is inevitable. This was a combined method of risk financing and risk controlling that was developed during the 1970s in Europe and caused the concept of total risk cost became important. After establishing this approach, it was realized that there are many insurable risks that facing the organizations which led to applying risk management methods and techniques to other disciplines like project management, market and credit risk more seriously during the 1980s (Hopkin & IRM, 2014). In this decade financial departments realized that they need to a more coordinated insurance risk management and financial risk management policies. In 1990s, many financial institutions creativity included a structured consideration of operational risks in their risk management.

At that time corporate governance and listing requirements persuaded directors in creating the first Chief Risk Officer (CRO) role by putting more emphasis on Enterprise Risk Management (ERM). During the 2000s CRO positions grew rapidly in companies related to energy, banking and insurance due to the development of investment models and internal risk management systems by financial services companies.

In 2008 the global financial crisis occurrence and risk management methods couldn’t prevent the crisis. This encountered the risk management contribution role in success of financial companies with many questions; however, it seems that this failure was because of incorrect applying the risk management procedures rather than an inherent deficiency in taking the risk management approaches.

2.5.2. Risk management frameworks and definitions

Such as definitions of risk there are a variety different definitions and frameworks for risk management taken by different organizations, companies and authorities. It is obvious that describing all the risk management strategies and approaches is beyond the scope of this manuscript so in this context, we review some of the most famous risk management frameworks and standards. Institute of Risk Management standard (Hopkin & IRM), the British Standard (BS 31100) published in 2008, entitled ‘Risk Management – Code of Practice’, the American COSO ERM framework and the international standard ISO 31000 published in 2009 which is the latest risk management standard are different creditable approaches to risk management that are the best established ones. It is notable that ISO guide 73 as a standardized language and the common language of risk has been developed to be used in all ISO standards (Hopkin & IRM, 2014).

Every risk management process is supported by a structure which is called a risk management framework. This supportive structure assists the progress of communication and access to the risk information. The Figure 2-2 shows the risk management framework so that the risk management process has been surrounded by its supporting components (Hopkin & IRM, 2014).

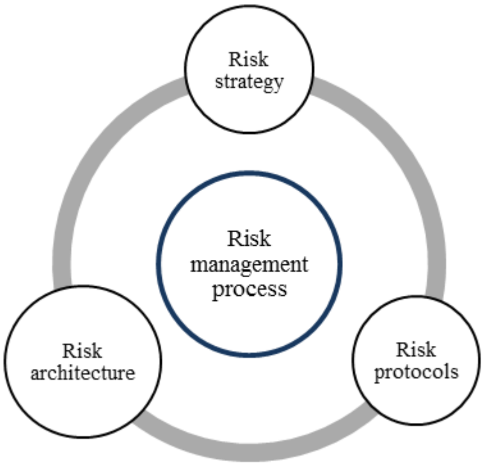


Figure 2-2: Components of a risk management framework

The descriptions of risk management framework components are as follows:

- Risk architecture: it defines roles, responsibilities, communications and risk reporting structure.
- Risk strategy: along with risk appetite, attitudes and philosophy are defined in the risk management policy.
- Risk protocols: regulations defined in the risk guidelines for the organization and include the rules and procedures as well as the risk management methodologies, tools and techniques that should be used.

Following a risk management standard by an organization is involved in setting up the structure, administration, responsibilities, communication and reporting components of risk management, which will be recorded in a risk management policy.

Based on British Standard BS 31100, risk management framework is a set of elements that provide foundations and organizational arrangements for designing, implementing, monitoring, reviewing and continuously improving risk management processes throughout the organization (BS 31100:2008, 2009). Figure 2-3 illustrates the risk management framework presented by BS 31100.

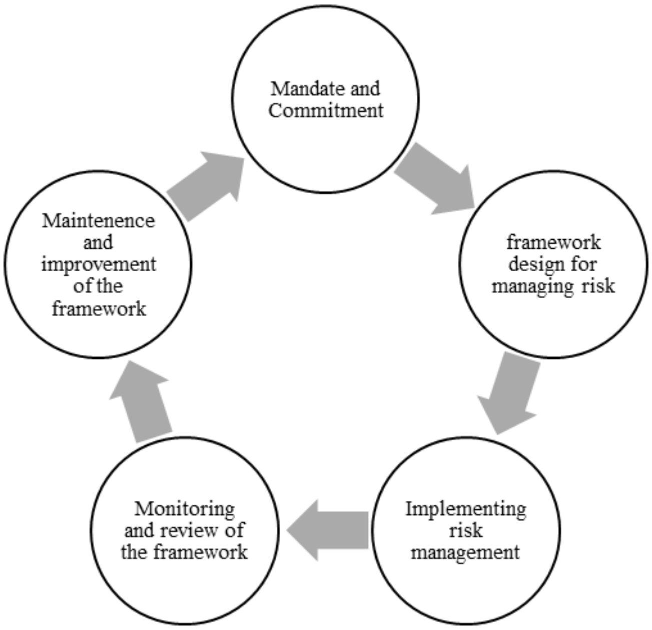


Figure 2-3: Risk management framework from BS 31100

Institute of Risk Management (Hopkin & IRM) knows modern risk management as an integrated, systematic and comprehensive approach that provides a framework for organizations to deal with and to react to uncertainty through evaluation, control and monitoring of three types of risks. These three types of defined risk by this institute mentioned in the previous section are hazard risks, control risks and opportunity risks that can affect the results of their operations IRM defines risk management as: '*Process which aims to help organizations understand, evaluate and take action on all their risks with a view to increasing the probability of success and reducing the likelihood of failure*'. This guide determines three factors for a successful risk management (Hopkin & IRM, 2014):

1. The communications and reporting structure (architecture)
2. The overall strategy that is taken by the organization for risk management (strategy)
3. The established set of procedures and guidelines (protocol)

The outcome of a risk management procedure is very beneficial for organizations and helps them to achieve:

- Successful and effective strategy: Through analysing the risks related to different strategic choices, better strategic decisions will be made that are capable to deliver the required results.
- Effective processes and projects: By considering the selection of alternative processes and risks involved in the other available options and also delivering the process changes more reliably by way of projects that would lead to more effective processes and projects.

- Efficient operations: By predicting the events that may cause disruption and taking actions to reduce the occurrence probability of these events, the potential future damages will be decreased.

For example, in a theatre performance some events like the absence of a key role actor or sickness of a significant staff like director, power cut off, delay in audience arrival because of transportation failure or road closure can cause disruption in the performance. As an example of practical risk management, the management of the theatre can take some decisions to reduce the chance of cancellation of the show because of the occurrence of one these events.

Figure 2-4 illustrates the proposed risk management process by IRM (Hopkin & IRM, 2014).

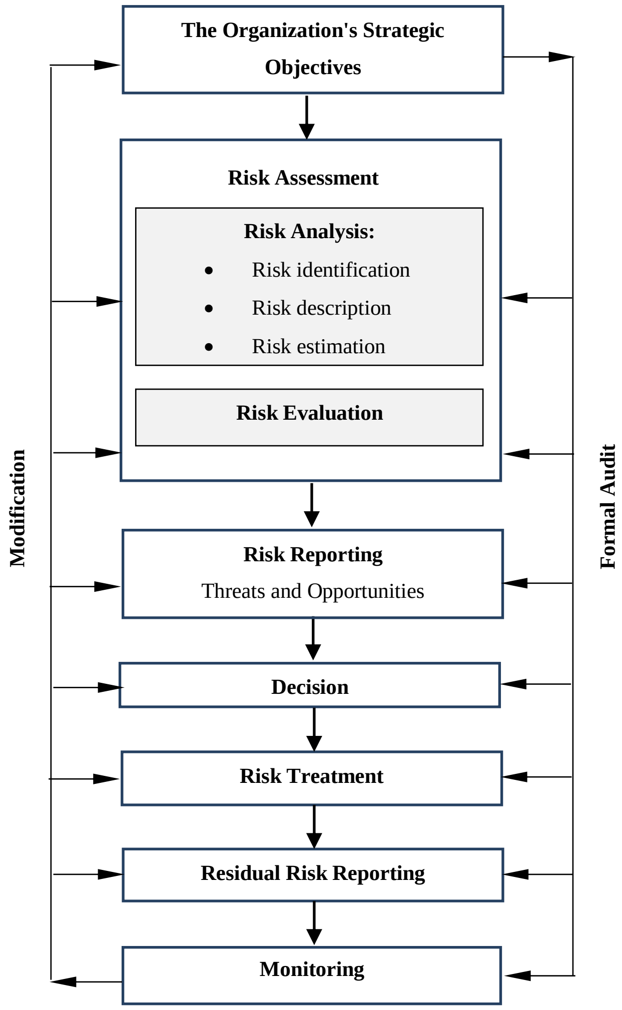


Figure 2-4: IRM risk management process

ISO Guide 73 and BS 31100 define risk management as:' Coordinated activities to direct and control an organization with regard to risk' (BS 31100:2008, 2009; ISO 73:2009). Table 2-1 shows some other definitions of risk management presented by HM Treasury, London School of economics and the Business Continuity Institute, which are the most authentic business and economic departments and organizations in the world.

Table 2-1: Definitions of risk management (Hopkin & IRM, 2014)

Organization	**Definition of risk management**
ISO Guide 73 BS 31100	Coordinated activities to direct and control an organization with regard to risk
Institute of Risk Management (Hopkin & IRM)	Process which aims to help organizations understand, evaluate and take action on all their risks with a view to increasing the probability of success and reducing the likelihood of failure
HM Treasury	All the processes involved in identifying, assessing and judging risks, assigning ownership, taking actions to mitigate or anticipate them, and monitoring and reviewing progress
London School of Economics	Selection of those risks a business should take and those which should be avoided or mitigated, followed by action to avoid or reduce risk
Business Continuity Institute	Culture, processes and structures that are put in place to effectively manage potential opportunities and adverse effects

ISO 31000, the new international risk management standard, considers two levels of risk assessment (ISO 31000:2009):

1. The inherent level: at this level the likelihood and magnitude of risk are shown using a risk matrix. This level is often referred to entire or gross risk which has not been managed yet.
2. The current level: this level usually reflects the managed level of risk.

With an example, these levels of risk are explained. Imagine crossing a busy road which is inherently very dangerous without the existence of adequate traffic control tools because of the high probability of accident occurrence which may have very significant consequences. In this case there is a high perception of risk so the paid attention by pedestrians and drivers for the existing traffic control devices in the place would be greater. Installing other control devices will manage the existing inherent risk by decreasing the speed of passing vehicles and increasing the risk awareness of both drivers and pedestrians. Figure 2-5 shows risk management process defined by ISO 31000.

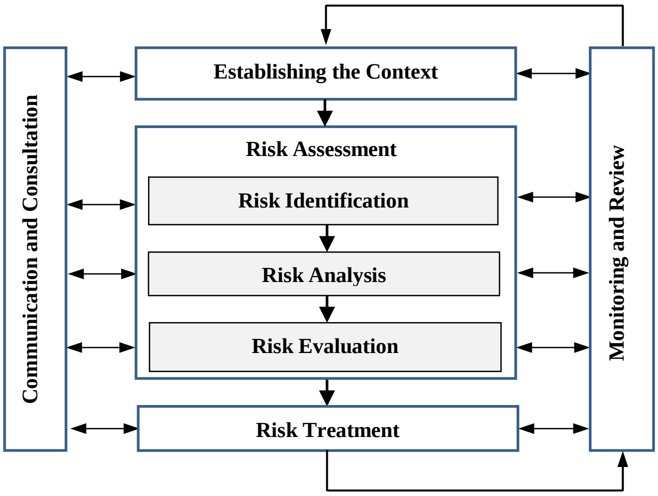


Figure 2-5: ISO 31000 risk management process

2.5.3. Principles of risk management

Several attempts have been made to define risk management principles. ISO 31000 introduced a detailed list of 11 risk management principles as follows (AS/NZS ISO 31000:2009):

1. Creates and protects value: through the continuous review of agency's processes and systems, contributes to the achievements of its objectives.
2. Be an integral part of organisational processes: at both operational and strategic levels, risk management needs to be integrated with an agency's governance framework and become a part of its planning process.
3. Be part of decision making: risk management helps decision makers in making informed choices, identifying the priorities and selecting the most proper action.
4. Explicitly address uncertainty: identifying the potential risks assist agencies in implementing control and treatment policies to maximize the gain opportunity while minimizing the loss chance.
5. Be systematic, structured and timely: risk management needs to be consistent across an agency to ensure efficient, consistent and reliable results.
6. Based on the best available information: For an effective risk management, understanding and considering all available relevant information to an activity is necessary. Also being aware of the limitations of information and how it can inform the entire risk management process is very important.
7. Be tailored: the risk profile, internal and external operating environment of an agency should be included in its risk management framework.
8. Take into account human and cultural factors: the contribution of people and culture in achieving the agency's objectives should be recognized by risk management process.

9. Be transparent and inclusive: engaging internal and external stakeholders throughout the risk management process, acknowledges that communication and consultation are two important keys for identifying, analysing and monitoring the risk.
10. Be dynamic, iterative and responsive to change: a risk management process should be flexible. To deal with challenging environment, a continuous risk management procedure is essential to identify new emerged risks and make allowances for those no longer exist.
11. Facilitate the continual improvement of organisations: investing resources over time and being able to demonstrate the continual achievement of objectives, are circumstances of existence a mature risk management in organizations.

BS 31100 has also set out 11 principles for risk management. As a consolidated version of BS 31100 and ISO 31000, we can separate these principles in two groups as shown in Table 2-2. The first group the first group is what risk management should be and the second group is what risk management should deliver.

Table 2-2: Principles of risk management (Hopkin & IRM, 2014)

What risk management should be	What risk management should deliver
Proportionate to the level of risk within the organization	Compliance with laws and regulations
Aligned with other business activities	Assurance regarding the management of significant risks
Comprehensive, systematic and structured	Decisions that pay full regard to risk considerations
Embedded within business processes	Efficiency, Effectiveness and Efficacy in operations, projects and strategy
Dynamic, iterative and responsive to change	

Different styles of risk managements can offer different answers to risk problems. Applying a complementary approach of various risk management styles can be a good solution to deal with risks within an organization. Through controlling the negative risks and investing on opportunities a successful risk management is expected to achieve the following objectives:

- Making results less negative by managing the hazard risks
- Reducing the extent of possible outcomes by applying control management
- Making outcomes more positive by managing the opportunities

2.6. Project Risk Management

Risk management is not an idle or inactive procedure, however it is a progressive and developing discipline. However, origins of risk management go back to the insurance industry and hazard management, during the past decade, various areas of expertise contributed to its evolution. Some of the most developed specialist areas are included:

- Project risk management
- Energy risk management

- Medical and clinical risk management
- Operational risk management

Project risk management is one of the areas that the application and development of risk management techniques and tools is very clear. It has had a widespread use in delivering projects related to construction, technology, market, business enhancement, IT systems or any producing project and considered as one the most powerful tool in every project management practice.

Among the three types of hazard risks, control risks and opportunity risks, as mentioned earlier, the emphasis of project risk management is on the management of control or uncertainty risks, which has made it a separate practice with separate guidelines within the risk management. Some resources like IRM know project risk management as a type of control management. So as an extension of regular project a planning, project risk management deal with risks and uncertainties that cause deviations from expected objectives and tries to reduce and control the undesirable variability of outcomes.

During a project, there may be several situations that the obtained developments are more fortunate than expected. As well as controlling the negative uncertainties a proper project risk management should have a sufficiently flexible structure to take account of these opportunities and benefits the total project. For example, consider a road project, which is included, building of several bridges and tunnels. If by any chance because of the unexpected good soil condition one of these bridges can be completed earlier than scheduled plan, the total completed project timescale can benefit from this early completion.

The guide of project management institute (PMBOK) defines project risk management as: “A systematic process of identifying, analysing, and responding to project risk”. Based on this guide it is expected from project risk management to maximize the likelihood and consequences of positive events and minimize the probability and outcomes of adverse events that can affect project objectives.

PMBOK considers six major processes for project risk management. Each of these processes consists of three sections: inputs, tools and techniques and outputs. Figure 2-7 shows an overview of the following major processes (PMI, 2013):

1. Risk management planning: this is the process of deciding how to approach and plan the risk management activities for a project.
2. Risk identification: risks that might affect the project are determined in this phase and their characteristics are documented.

3. Qualitative risk analysis: performing this process on risks and conditions, helps to prioritize the effects of risks on project objectives. Some characteristics of project environment that may contribute to project risk are considered as risk conditions such as poor project management approaches or project management practices that are dependent on some uncontrollable external contributors.
4. Quantitative risk analysis: The likelihood and consequences of the risks are measured in this process and their implications for project objectives are estimated.
5. Risk response planning: both enhancing opportunities and reducing negative events to the project's objectives are planned by developing techniques and procedures at this stage.
6. Risk monitoring and control: in this phase monitoring the residual risks, determining the new risks, carrying out risk reduction plans and evaluating their effectiveness throughout the project life cycle are performed. The project life cycle has been illustrated in Figure 2-6.

There are some salient points relating to these major processes:

- These processes have interactions with each other and also with the processes of other knowledge area.
- Generally, each of these processes occurs at least once throughout every project.
- However, these processes have been presented as discrete elements with well described interfaces, in practice, may overlap each other.

If the negative consequences of a risk are balanced with rewards and opportunities that may be gained by taking the risk, that risk may be accepted by the organization. Commitment of organizations to provide high quality information for risk management throughout the project life cycle is a key factor for the success of every project.

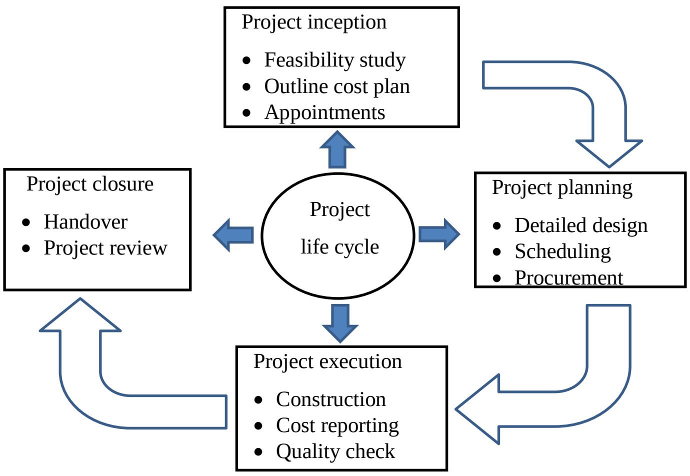


Figure 2-6: Project lifecycle

PROJECT RISK MANAGEMENT

Risk Management Planning

1. Inputs
- Project charter
- Organization's risk management policies
- Defined roles and responsibilities
- Stakeholder risk tolerances
- Template for the organization's risk management plan
- Work breakdown structure (WBS)

2. Tools and Techniques
- Planning meetings

3. Outputs
- Risk management plan

Risk Identification

1. Inputs
- Risk management plan
- Project planning outputs
- Risk categories
- Historical information

2. Tools and Techniques
- Documentation reviews
- Information-gathering techniques
- Checklists
- Assumptions analysis
- Diagramming techniques

3. Outputs
- Risks
- Triggers
- Inputs to other processes

Qualitative Risk Analysis

1. Inputs
- Risk management plan
- Identified risks
- Project status
- Project type
- Data precision
- Scales of probability and impact
- Assumptions

2. Tools and Techniques
- Risk probability and impact
- Probability/impact risk rating matrix
- Project assumptions testing
- Data precision ranking

3. Outputs
- Overall risk ranking for the project
- List of prioritized risks
- List of risks for additional analysis and management
- Trends in qualitative risk analysis results

Quantitative Risk Analysis

1. Inputs
- Risk management plan
- Identified risks
- List of prioritized risks
- List of risks for additional analysis and management
- Historical information
- Expert judgment
- Other planning outputs

2. Tools and Techniques
- Interviewing
- Sensitivity analysis
- Decision tree analysis
- Simulation

3. Outputs
- Prioritized list of quantified risks
- Probabilistic analysis of the project
- Probability of achieving the cost and time objectives
- Trends in quantitative risk analysis results

Risk Response Planning

1. Inputs
- Risk management plan
- List of prioritized risks
- Risk ranking of the project
- Prioritized list of quantified risks
- Probabilistic analysis of the project
- Probability of achieving the cost and time objectives
- List of potential responses
- Risk thresholds
- Risk owners
- Common risk causes
- Trends in qualitative and quantitative risk analysis results

2. Tools and Techniques
- Avoidance
- Transference
- Mitigation
- Acceptance

3. Outputs
- Risk response plan
- Residual risks
- Secondary risks
- Contractual agreements
- Contingency reserve amounts needed
- Inputs to other processes
- Inputs to a revised project plan

Risk Monitoring and Control

1. Inputs
- Risk management plan
- Risk response plan
- Project communication
- Additional risk identification and analysis
- Scope changes

2. Tools and Techniques
- Project risk response audits
- Periodic project risk reviews
- Earned value analysis
- Technical performance measurement
- Additional risk response planning

3. Outputs
- Workaround plans
- Corrective action
- Project change requests
- Updates to the risk response plan
- Risk database
- Updates to risk identification checklists

Figure 2-7: Risk management overview (PMI standard)

2.7. Qualitative and quantitative risk analysis

Figure 2-7 is a very concise and comprehensive illustration of the six major project risk management processes. Detailed description of each process stages is beyond the scope of this context. The most significant distinction of the fuzzy risk management approach taken in this study with the classical approach is related to 'Risk Analysis' discussion. So in the next section and before commencing the 'Fuzzy' concepts, classical qualitative and quantitative risk analysis are discussed.

2.7.1. Qualitative risk analysis

Probability and consequence of each identified risk should be assessed through qualitative risk analysis. This process provides a prioritized list of risks that can affect the project objectives potentially and guides the risk response planning by addressing the most serious risks. To adjust to the project risk changes, qualitative risk analysis should be revised during the project's life cycle.
Qualitative risk analysis uses followings as its input materials:

- Risk management plan
- Identified risks
- Project status: project progress level can determine the uncertainty of the risks.
- Project type: simplicity or complexity, using simple and common technologies or applying innovative and more advanced technologies can affect the uncertainty of occurrence the risks and their consequences
- Data precision: measuring the reliability and the extent of data that used to determine the risks.
- Scales of probability and impact: these are the key factors of Equation **2-1** that are used for assessing every single risk.
- Assumptions analysis: risks due to inconsistency, inaccuracy or incompleteness of assumptions are identified using this analysis.

Based on PMBOK guide qualitative risk analysis uses some tools and techniques as follows:

- Risk probability and impact: using lingual or verbal words for describing the probability and consequence of risks such as very high, high, moderate, low and very low. The probability of risk is the likelihood that a risk may happen and the consequence of risk is the effect or impact of risk on project objectives. As mentioned earlier, these two factors are applied to score every single identified risk not the overall project.

- Probability/impact risk rating matrix: scaling risk probability on a horizontal axis and risk consequence on a vertical axis and combing these two scales can construct a matrix to rate the risks. A risk probability varies from 0.0 (no probability of occurrence) to 1.0 (certain occurrence). A relative probability scale (ordinal scale) from very unlikely to almost certain or specific probabilities by using a general scale (e.g., 0.1, 0.3, 0.5, 0.7, 0.9) can be assigned to each risk probability.
- The risk's impact scale indicates the magnitude or severity of its effect on the project's objectives. Each risk consequence can be scaled using an ordinal or a cardinal scale. The cardinal scale uses linear (e.g., 0.1, 0.3, 0.5, 0.7, 0.9) or nonlinear values (e.g., 0.05, 0.1, 0.2, 0.4, 0.8) and indicates how an organization tends to prevent high impact risks. Using well defined scales is very important as they can be developed using agreed definitions within the organization.
- The risk rating matrix assigns linguistic terms (very low, low, moderate, high and very high) or their equivalent numerical value obtained by multiplying the probability in consequence of each risk. Using expert judgments that don't use historical data makes this kind of assessment very difficult and inaccurate. In this research, we try to enhance this process by applying fuzzy logic. Table 2-3 illustrates risk impacts on four project objectives: cost, schedule, scope and quality using both cardinal and ordinal scales. Agreement on preparing these relative scales should be done within the organization and before the project begins.

Table 2-3: Risk impact on project objectives (Hopkin & IRM, 2014)

Evaluating impact of a Risk on Major Project Objectives (ordinal scale or cardinal, non-linear scale)					
Project Objective	**Very Low 0.05**	**Low 0.1**	**Moderate 0.2**	**High 0.4**	**Very High 0.8**
Cost	Insignificant cost increase	<5% cost increase	5–10% cost increase	10–20% cost increase	>20% cost increase
Schedule	Insignificant schedule increase	Schedule slippage <5%	Overall project slippage 5–10%	Overall project slippage 10–20%	Overall project slippage >20%
Scope	Scope decrease barely noticeable	Minor areas of scope are affected	major areas of scope are affected	Scope reduction unacceptable to the client	Project end item is effectively useless
Quality	Quality degradation Barely Noticeable	Only very demanding applications are affected	Quality reduction requires client approval	Quality reduction unacceptable to the client	Project end item is effectively unusable

Table 2-4 shows Probability-Impact (P-I) risk rating matrix. Every array of this matrix is calculated by simple multiplication of values assigned to probability and impact of risk. In this matrix the severity of risk varies by colour from green for the low risks, yellow for the moderate risk to red for the high risk condition. Scoring the risk helps in categorizing the risk for response actions.

- Project assumption testing: assumption stability and the consequences of a probable false assumption on the project, are two factors that recognized assumptions must be tested against them.
- Data precision ranking: to have a useful qualitative risk analysis, we need to provide accurate and honest data. Using data precision ranking method helps to evaluate the degree to that data about risks will benefit the risk management process. This technique examines the knowledge extent of the risk, available data, data quality, data reliability and data integrity.

Table 2-4: Probability-Impact risk rating matrix (PMI Standard)

Risk Score for a Specific Risk						
Probability		Risk Score = P × I				
VH	0.9	0.05	0.09	0.18	0.36	0.72
H	0.7	0.04	0.07	0.14	0.28	0.56
M	0.5	0.03	0.05	0.10	0.20	0.40
L	0.3	0.02	0.03	0.06	0.12	0.24
VL	0.1	0.01	0.01	0.02	0.04	0.08
		0.05	0.10	0.20	0.40	0.80
		Very low (VL)	Low (L)	Moderate (M)	High (H)	Very High (VH)
		Impact on an Objective (cost, time, or scope)				

Qualitative risk analysis leads to following outcomes (PMI, 2013):

- Overall risk ranking for the projects: through providing a ranking list of project risks, comparison between different projects based on each risk score becomes possible. It can affect the procedure of beginning, resumption and cancellation of a project as well as assigning budget, personnel and resource to projects with different risk positions.
- Providing a list of prioritized risks: risk rating or WBS level are two criteria that risks can be prioritized according to them. Grouping the risks based on the need for response, helps risk managers to take immediate and quick responses to top ranked risks. Risks also can be prioritized according to a particular project objective (e.g., quality, cost, time, scope) that is affected by them.
- Providing a list of risks for additional analysis and management: quantitative and risk analysis and more management action and more analysis are performed for risks grouped as high or moderate rank.

- Trends in qualitative risk analysis results: repeating the qualitative analysis may lead to a prevailing tendency that can increase or decrease the importance of further analysis or risk response.

2.7.2. Quantitative risk analysis:

Analysing the probability and consequence of each risk on project objectives numerically is performed using quantitative risk analysis. It generally follows qualitative risk analysis. Monte Carlo simulation and decision analysis are two methods that are used in this process to fulfil the following objectives:

- Determining the likelihood of achieving a particular project objective.
- Quantifying the project risk and determining the amount of cost and schedule contingency reserves that may be required.
- Quantifying risks relative contribution to project risk to identify risks that need the most attention.
- Identifying practical and accessible time scale, cost, scope and quality.

It is noticeable that qualitative and quantitative risk analysis procedures can be used independently or together that depends on available funds, time, or special need for a particular kind of statement about risk and effect. Quantitative risk analysis uses followings as its inputs:

- Risk management plan
- Identified risks
- List of prioritized risks
- List of risks for additional analysis and management
- Historical information: it can be afforded through gathering information and performing studies on previous or similar accomplished projects by risk specialists. Risk databases that may be accessible from industry or other private sources are other ways to reach historical information.
- Expert judgements: the professional opinions of project team members or specialists and experts from inside or outside the organization can be used as input.
- Other planning outputs: it includes project logic, estimates of project length, WBS listing of all cost elements with cost estimate and technical objective models of the project.

Quantitative risk analysis uses some tools and techniques to evaluate the data including as follows:

- Interviewing: one of the methods for quantifying the risk probability and its consequence on project' objectives is interviewing the subject matter experts and project stakeholders. Gathering the required information depends on the specific type of probability distribution diagrams that will be used. Quantitative risk analysis usually uses continuous distributions presenting both probability and consequence of risks. Triangular, uniform, normal and beta distributions are some of the most used ones. Figure2-8 illustrate normal distribution and Figure 2-9 represents a triangular distribution. In these figures, vertical axis is the probability and the horizontal axis is impact of risk.

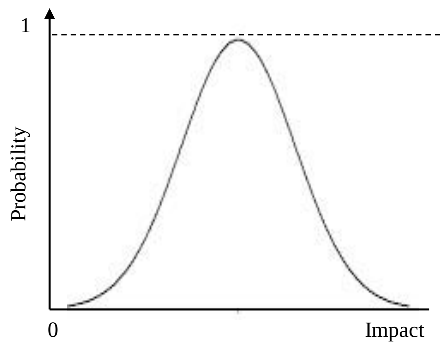


Figure2-8: Normal distribution

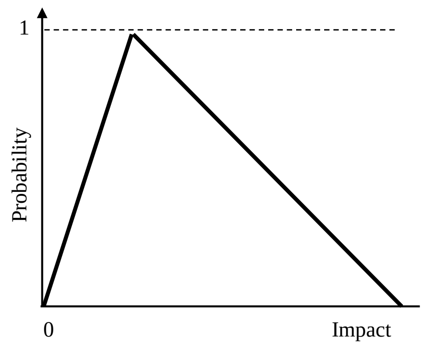


Figure 2-9: Triangular distribution

For example, in case of using distribution diagrams, information can be gathered through asking three values: optimistic (the lowest possible), the pessimistic (the highest possible) and the most possible estimation for project' elements. This three-point estimation has been illustrated in Table 2-5. Figure 2-10 shows the related cumulative likelihood distribution diagram. For other kinds of distributions such as the normal distribution, mean value and standard deviation may be used. The cumulative probability distribution in Figure 2-10 indicates the risk of exceeding the budget estimate assuming triangular distribution with the range shown in Table 2-5. The diagram that has been formed by using Monte Carlo simulation shows that the probability of completing the project by 41 million dollars is 12 percent in other words there is an 88 percent risk that the budget overruns this amount. Based on this diagram a conservative organization needs to allocate 50 million dollars if it wants a 75 percent probability of success.

Table 2-5: An example of three-point estimations for WBS components

	Project Cost Estimates (Million $)		
WBS Element	Lowest possible	Most possible	Highest possible
Design	4	6	10
Build	16	20	35
Test	11	15	23
Total Project	31	41	68

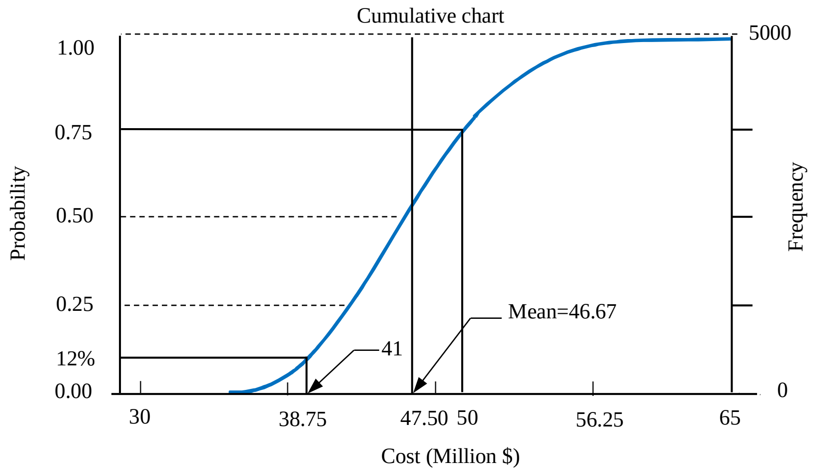


Figure 2-10: Cost risk simulation

- Sensitivity analysis: through this analysis the risks that have the most potential effect on the project are identified. By choosing each project element uncertainty and holding the other uncertain elements at their baseline values and examining its impact on project objective the effect extent of selected uncertainty is determined.
- Decision tree analysis: this analysis usually is structured like a tree. Each branch of this tree diagram is formed by choosing an available alternative and calculating the risk probability, the costs or opportunities that taking that decision may have. Through quantifying all the uncertain implications, costs, rewards and pursuant decisions the decision tree is solved that finally leads to choose the highest expected value option among all available choices.
- Simulation: a project simulation is a procedure that uses a model to translate the specified uncertainties at a detailed level into their potential effect on project objectives that are expressed at the total project level. Monte Carlo technique is one of the most popular methods to perform the project simulation. For example, it can use a usual project Work Breakdown Structure (WBS) as a model for a cost risk analysis. This simulation has been shown in Figure 2-10. Another example, can be using the Precedence Diagramming Method (PDM) schedule for schedule risk analysis.

The outputs of quantitative risk analysis are as the following:

- Prioritized list of quantified risks: it includes a list that the threats and opportunities to the project have been ranked with their impact values.
- Probabilistic analysis of the project: predicting the potential timescale and cost of the project through listing the probable completion dates and costs with their associated reliance levels.

- The probability of achieving the cost and time objectives: this probability can be estimated by quantitative risk analysis considering the current plan and the current knowledge of the risks.
- Trends in quantitative risk analysis results: repeating the analysis may result in a trend of results.

2.8. Fuzzy logic

2.8.1. Fuzzy logic vs classic logic

In the classical logic, a simple proposition '*P*' that is a linguistic or declarative statement is strictly true or strictly false (T.J. Ross, Booker, & Parkinson, 2002). Propositions like 'the first day of January 2016 is Sunday', 'the weather temperature is 30°C' and 'the only even prime number is 2' are true or false and not out of these two situations. There are other propositions which are not very clear and there are traces of ambiguity and uncertainty in them. If a group of people is asked that the married ones raise their hands, there would be a certain group of married and single people, but if you ask the same group that the people who are satisfied with their marriage raise their hands, there would be a group of people who are not sure and have raised their hands somewhat but not quite. Such a reaction may reflect the relative satisfaction or low satisfaction. Unlike the theme like dead or alive, male or female, married or single and so on that are clear, crisp and precise sets and there is no doubt in belonging a particular member to those sets there are sets of happy, satisfied, tall, pretty and smart people who have a collection of qualitative characteristics for which there is no clear boundaries. These linguistic concepts are ambiguous. People in their daily life deal with lots of these kinds of concepts and use them in their arguments and reasoning. Propositions like 'today is hot', 'weather is cloudy', 'I am hungry', 'this colour is bright', 'I will come early tomorrow' and so on express qualitative states and these qualitative states in different situations and conditions have different performance.

In classical logic, a binary truth value is assigned to the veracity of an element in the proposition '*P'*, which is a value of 1 (True) or 0 (False). For example, consider the '*P'* statement as: 'today is hot'. This proposition in the different seasons can convey different quantitative conditions. The person who is present at the place and hears this sentence can have a true understanding of that situation without any additional explanation but if the receiver of this sentence is a computer with 0 and 1 evaluation system that is not given any other information except the weather temperature, would evaluate this sentence as 0 or 1 because of the crisp boundary that must be defined for recognizing the hot weather so it must be expressed as: '*Weather with the temperature over 35 centigrade degree is hot'*, based on classical logic weather to 34.99 degrees is not considered as hot weather at all. So there is a crisp boundary between true and false in classical logic, which causes making decisions about processes that contain nonrandom uncertainty, such as the uncertainty in natural language, be less than perfect.

An intelligent fuzzy system acts in a different way. In Fuzzy logic, a statement can be either true or false and also can be neither true nor false. Fuzzy logic is non-monotonic logic. It is a superset of conventional logic that has been extended to handle the concept of partial truth, the truth values between ‘completely true’ and ‘completely false’. It is a type of logic that recognizes more than simple true and false values. With fuzzy logic, propositions can be represented with degrees of truthfulness and falsehood. For example, if the today’s weather temperature is 35 C°, the statement “today is hot” might be 90% true if today is a winter day, 70% true if it is a spring day, and 50% true if it is expressed in a summer day. Figure 2-11 shows the fuzzy interpretation of hotness of weather with 35°C in different seasons. The horizontal axis shows the weather temperature and the vertical axis shows the degree of truth in percentage. The blue, green and orange curves indicate the understanding of weather hotness in winter, spring and summer respectively.

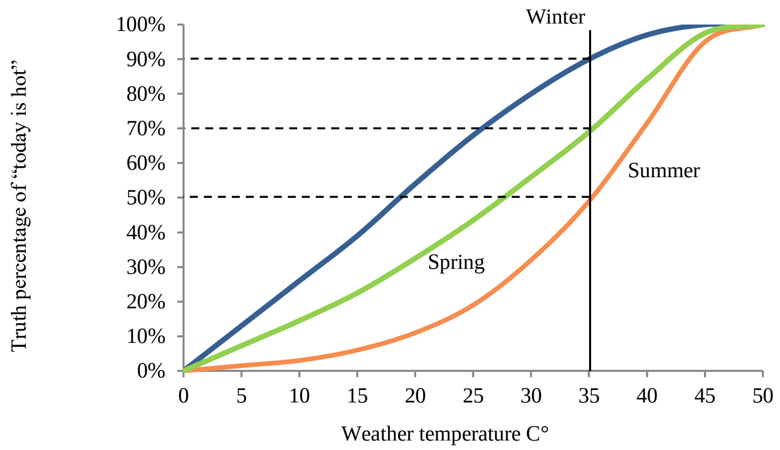


Figure 2-11: Fuzzy interpretation of hotness of weather with 35°C in different seasons

In another form if the horizontal axis indicates the qualitative conditions and the vertical axis represents the temperature degree, different qualitative conditions result in different quantitative values regarding to different seasons curves. As it is shown in Figure 2-12 the ‘*Hot*’ weather conditions may interpret to 35°C in the winter, 40°C in the spring or 50°C in the summer.

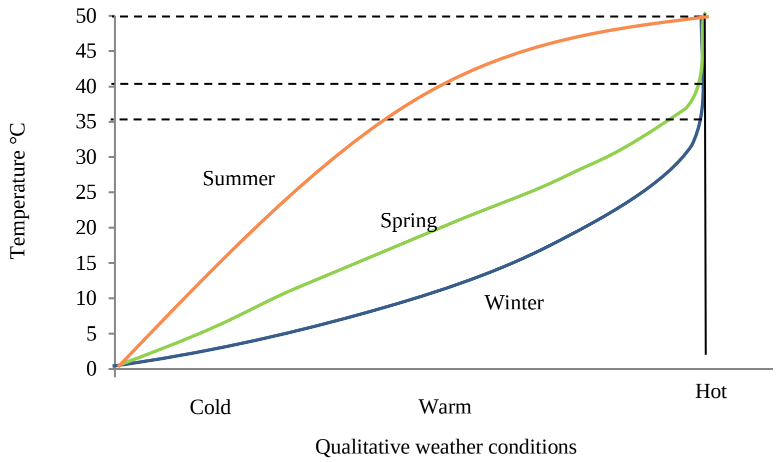


Figure 2-12: Fuzzy interpretation of a hot weather in different seasons

2.8.2. A short history of fuzzy logic

Treating truth as a linguistic variable leads to a fuzzy linguistic logic, or simply fuzzy logic (L. A. Zadeh, 1975a). The Oxford English dictionary defines "Fuzzy" as difficult to perceive; indistinct or vague; confused and not expressed clearly (Simpson, Weiner, & Press, 1989).

While the famous German philosopher Immanuel Kant in 1780 insisted on the fact that logic basically is a complete knowledge due to the Aristotle work, during the 19th and 20th centuries Boole, Pierce, Frege and Russell created great changes in logic and presented stronger techniques (Haack, 1978). Then in the second half of the 20th century, the science society faced with the birth of a new logical theory called 'fuzzy logic' with foundations different from Aristotelian logic, however, with a scrutiny of science history the roots of this kind of attitude can be found in the years before the official presentation of fuzzy theory in 1965.

Doubt the being limited the truth of an expression only to two values of true or false showed itself since the beginning of the 19th century in Lukasiewicz works and followed him logicians and mathematicians like Kleene, Bochvar and Post. The starting point of this approach began by extending two values to three values and then n-valued and infinite-valued systems were introduced that were basis of various algebra. In 1937, the quantum philosopher Max Black published an article on logical analysis in philosophy of science journal that called it ambiguous. In this paper Black expanded the multivalued logic to the sets and noted that the fuzzy sets have made our imaginations and thoughts consistent with each other; however, the word he used was 'vague' not '*fuzzy*'. Black's theory was not welcomed and was forgotten and he didn't pursue it anymore (Kosco, 1993).

The original fuzzy logic founded by Lotfi Zadeh the Professor of Electrical and Computer Engineering at Berkeley University as a key to decision-making when faced with linguistic and non-random uncertainty. He used the word 'fuzzy' instead of ambiguity (L. A. Zadeh, 1965). Many fundamental concepts of fuzzy set theory were introduced by Zadeh in the late 60's and early 70's. After the introduction of fuzzy sets in 1965, he presented the concepts of the fuzzy systems' algorithm in 1968, fuzzy decision making in 1970 in his work. He notes that fuzzy logic is a precise logic of imprecision and approximate reasoning (L. A. Zadeh, 1975b). It may be viewed as an attempt at formalization/mechanization of two remarkable human capabilities; First, the capability to converse, reason and make rational decisions in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility – in short, in an environment of imperfect information- and second, the capability to perform a wide variety of physical and mental tasks without any measurements and any computation (Lotfi A. Zadeh, 2001).

New research areas usually should be supported by the scientific and academic centers, but unfortunately it didn't happen in the case of fuzzy theory and many researchers in fuzzy area had to change their field of study. Zadeh's theory was criticized by many university professors like Rudolf Kalman the professor of UCLA and the inventor of Kalman filter that enables the accurate targeting of moving objects. He said: "*No doubt professor Zadeh's enthusiasm for fuzziness has been reinforced by the prevailing political climate in the U.S. one unprecedented permissiveness. 'Fuzzification' is a kind of scientific permissiveness; it tends to result in socially appealing slogans unaccompanied by the discipline of hard scientific work and patient observation. I must confess that I cannot conceive of 'fuzzification' as a viable alternative for the scientific method*." (D. Mcneill & Freiberger, 1994). He didn't know any chance for Zadeh's theory to deal with the science fundamental problem that is proposing methods for system analysis.

Zadeh's colleague, William Kahan, who was a mathematician at Berkeley added three more contentions: "*I cannot think of any problem that could not be solved better by ordinary logic*." "*What Zadeh is saying is the same sort of thing as technology got us into this mess and now it can't get us out*." "*What we need is more logical thinking, not less. The danger of fuzzy theory is that it will encourage the sort of imprecise thinking that has brought us so much trouble*." (D. Mcneill & Freiberger, 1994).

Zadeh's reaction to these quotes was different. He called these viewpoints the '*hammer principle*' and said: "*the only tool you have is a hammer, everything begins to look like a nail*" (Von Altrock, 1995). He adds: "*I was fully cognizant that I was doing something that would spark controversy*" (D. Mcneill & Freiberger, 1994). Bart Kosco in the book 'fuzzy thinking' calls true or false approach as the black and white attitude and knows it a big mistake of science (Kosco, 1993). He says: "*what makes society turn is science, and the language of science is math, and the structure of science is logic and the bedrock of logic is Aristotle, and that's what goes out with fuzzy*" (D. Mcneill & Freiberger, 1994).

Zadeh's expertise was control systems. In 1973 he published a paper titled: "*Outline of a new approach to the analysis of complex systems and decision processes*". This paper founded the basis of fuzzy control by introducing the concept of linguistic variables for the human knowledge formulating (L. A. Zadeh, 1973). Using the If-Then rules was the great event of 70's for fuzzy theory and birth of fuzzy controllers for real systems. In 1975, Mamdani and Assilian determined a primary framework for fuzzy controlling and applied it to a steam engine (Mamdani & Assilian, 1975). The next achievement belonged to Holenblad and Ostergard. In 1978 they used the first fuzzy controller completely for an industrial procedure which was fuzzy control of cement producing in cement furnace (L. X. Wang, 1997).

Cognizer Almanac had predicted $150 million for the global market for fuzzy logic in 1991 that almost half of this amount was for training and custom applications. The prediction of Cognizer for 1995 was $ 3.5 billion. The success of Japanese in commercial application of fuzzy logic in producing several industrial and electrical goods was stunning. They used fuzzy logic in 100 different product areas from washing machines and video cameras to elevators and underground trains. In 1990 Japanese companies earned about $ 1.5 billion from the sale of fuzzy products. Using the, development costs fuzzy logic application in production reduced time to market, decreased development costs and enhanced product performance. The share of U.S was pretty less from the fuzzy products. It was very important to U.S competitiveness to incorporate fuzzy logic into their products. Many U.S firms like Ford Motor Co., Motorola and even NASA began to use fuzzy technology in their manufacturing process and products (*U. S. Industrial Outlook, 1994*, 1994).

In 1992, IEEE one of the most reputed organizations in engineering held the first international conference in the field of fuzzy systems and in 1993, launched its fuzzy system section (Niimura & Tanaka, 1996). Nowadays, significant activities are carried out in theoretical aspects of fuzzy logic and new fuzzy structures have been investigated highly detailed with less prejudice. Fuzzy logic made the elites of logic and mathematicians aware of some problems of classical logic and provided conditions to challenge these problems.

2.8.3. Fuzzy set vs crisp set

In contrast to classical set theory, each element, either fully belongs to the set or is completely excluded from the set. In other words, classical set theory represents a special case of the more general fuzzy set theory. In crisp set, membership of element *X*: $\mu_A(X)$ of set *A*, is defined as:

$$\mu_A(x) = \begin{cases} 1 & x \in A \\ 0 & x \notin A \end{cases} \qquad \text{Equation 2-3}$$

For example, Figure 2-13 shows a crisp set of height between 5 to 7 feet, thus every height in this range has the same value of truth equals to 1 which means it belongs to this set, and every height out of this range has a value of 0 that means this value does not belong to this set.

Dr. Zadeh developed the concept of ‘fuzzy sets’ to account for numerous concepts used in human reasoning which are vague and imprecise e.g. tall, old (L. A. Zadeh, 1965). In his paper of 1965 he stated: “*The notion of a fuzzy set provides a convenient point of departure for the construction of a conceptual framework which parallels in many respects the framework used in the case of ordinary sets, but is more general than the latter and, potentially, may prove to have a much wider scope of applicability, particularly in the fields of pattern classification and information processing. Essentially, such a framework provides a natural way of dealing with problems in which the source of imprecision is the absence of sharply defined criteria of class membership rather than the presence of random variables*.’’

A fuzzy set expresses the degree to which an element belongs to a set. If *X* is a collection of objects denoted generically by *x*, then a fuzzy set *A* in *X* is defined as a set of ordered pairs:

$$A = \left\{ x, \mu(x_A) \middle| x \in X,\ \mu(x_A) \in [0,1] \right\}$$ Equation 2-4

The characteristic function of a fuzzy set, $\mu_A(x)$ is allowed to have values between 0 and 1, which denotes the degree of membership of an element in a given set and is called as ‘membership function’ or MF for short If the If the values of the membership function is restricted to either 0 or 1, then *A* is reduced to a classical set (Castillo & Melin, 2008). In Figure 2-14, a fuzzy set of heights between 5 and 7 feet and around 6 has been illustrated. In this example the fuzzy set *A* may be described as follows: *A* = {(5, 0), (5.5, 0.5), (6, 1), (6.5, 0.5), (7, 0)}.

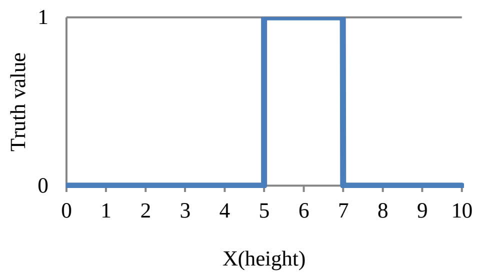


Figure 2-13: A crisp set of height between 5 to 7 feet

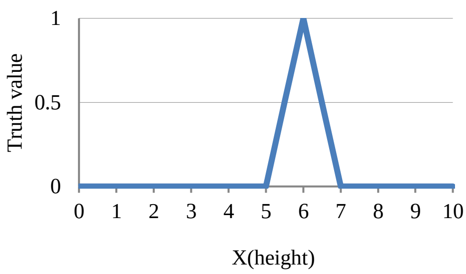


Figure 2-14: A fuzzy set of height around 6 feet

Fuzzy sets are often incorrectly assumed to indicate some form of probability. Even though they can take on similar values, it is important to realize that membership grades are not probabilities. The probabilities of a finite universal set must add to 1 while there is no such requirement for membership grades.

2.8.4. Fuzzy set vs fuzzy number

A fuzzy number is a fuzzy set on the real numbers. It represents information such as '*about m*'. A fuzzy number must have a unique modal value 'm', be convex, normal and piecewise continuous (D. Dubois & Prade, 2012). Fuzzy numbers generalize classical real numbers and roughly speaking a fuzzy number is a fuzzy subset of the real line that has some additional properties. They are capable of modelling epistemic uncertainty and its propagation through calculations. The fuzzy number concept is basic for fuzzy analysis and fuzzy differential equations, and a very useful tool in several applications of fuzzy sets and fuzzy logic(Bede, 2012).

A fuzzy set is not a fuzzy number since it is not fuzzy convex and normal. An alternative and more direct definition of convexity is the following (L. A. Zadeh, 1965):

A is convex if and only if for all x_1 and x_2 in *X* and all λ in [0, 1]:

$$f_A[\lambda x_1 + (1-\lambda)x_2] \geq Min[f_A(x_1), f_A(x_2)]$$ Equation 2-5

A fuzzy set *A* is normal if we can always find a point $x \in X$ such that $\mu_A(X) = 1$. The shape (a) represented in Figure 2-15, is a fuzzy set not a fuzzy number and shape (b) in that figure is a convex set but not a normal one.

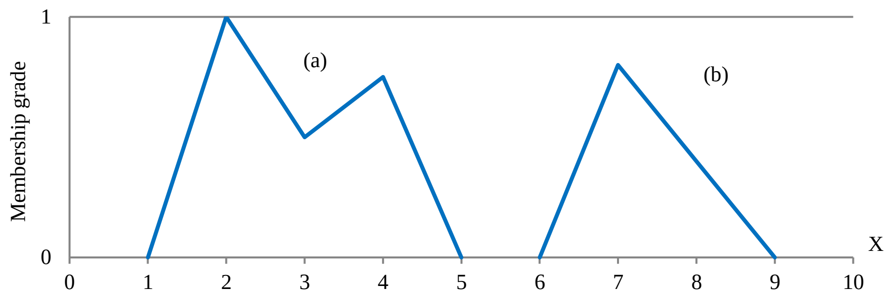


Figure 2-15: Normal but not convex fuzzy set (a) and convex, but not normal fuzzy set (b)

A fuzzy set is completely characterized by its membership function (MF). A membership function associated with a given fuzzy set, maps an input value to its appropriate membership value. The only condition a membership function must really satisfy to be considered as a fuzzy number is that it must vary between 0 and 1. The function itself can be an arbitrary curve whose shape we can define as a function that suits us from the point of view of simplicity, convenience, speed, and efficiency.

Figure 2-16 shows three membership functions of water in three qualitative conditions: cold, warm and hot. According to these MFs a sample of water with temperature between 0°C to 100°C may belong to two of these conditions, but with different membership grades it happens where the MFs overlap each other. For example, the water with 60°C temperature is considered as warm water with a membership grade (0.8) as it can be considered as hot water with a membership grade (0.2) while water between 0°C to 30°C just considered as cold water and water with more than 70°C considered only as hot water however the degree of belonging 20°C water to cold water is less than the degree of belonging 10°C water to this state.

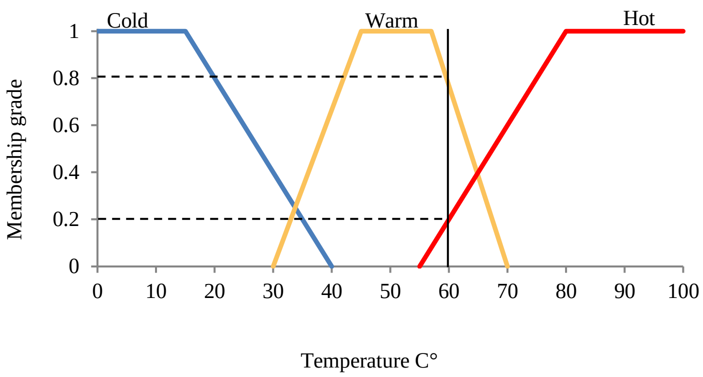


Figure 2-16: Membership functions of water in three qualitative conditions: cold, warm and hot

2.8.5. Membership value assignments

Introducing the possibility theory against the probability theory by Zadeh (L. A. Zadeh, 1978) opened a new vision for many authors to study the conversion problem of the probability distribution to the possibility distribution when membership functions are considered numerically equivalent to possibility distribution. Two famous transformation methods are: bijective transformation by Dubois and Prade (Didier Dubois & Prade, 1983) and the conservation of the uncertainty method by Klir (Klir, 1990).

Saaty proposed a pairwise comparison matrix for computing the membership values. The entries of this matrix were relative preference defined on a rational scale (Saaty, 1980).

Valliappan and Pham discussed a membership function construction method using subjective and objective information (Pham & Valliappan, 1993). The subjective part is experts' opinions and judgments and the objective part are statistical date and their known Probability Density Function (PDF). In the proposed framework assumptions of the 'Program-Evaluation and Review Technique' (PERT) was used to derive the normalized subjective measures through the beta distribution. Then by using the kernel of the fuzzification, the subjective part is transformed into a fuzzy set.

Witold Pedrycz has shown that the routinely used triangular membership functions provide an immediate solution to the optimization problems emerging in fuzzy modelling (Pedrycz, 1994).

Chen and Otto suggested a method using measurement theory and constrained interpolation for constructing the membership function in a way that they used a measurement scale construction for a given finite set of determined membership values and determined the remaining membership values using interpolation (J. E. Chen & Otto, 1995).

Civanlar and Trussell proposed a membership function generation method for statistically based data. They believed that the membership function has a relationship to some physical property of the set so they considered two properties for membership functions derived from statistics: making some allowance for deviation from the value obtained by the measurement and being naturally quantitative. The produced membership functions using their method are optimal with respect to a set of reasonable criteria and also adjustable to possibility-probability consistency principle (Civanlar & Trussell, 1986).

By summarizing subjective versus objective on one dimension and individual versus group on the other hand, Biligic and Turksen considered five categories of interpretations for production of membership functions (Bilgic & Turksen, 1997). They discussed these interpretations for the meaning of $\mu_T(x) = 0.7$, represented for the vague expression: "*John (x) is tall (T)*", where $\mu_T(x)$ is the membership degree of *x* defined on a fuzzy set tall (*T*), as:

- Likelihood view: 70% of a given population consider John as a tall person.
- Random set view: 70% of a given population described '*tall*' as an interval containing John's height.
- Similarity view (typicality view): to the degree 0.3 (a normalized distance), John's height is away from the prototypical object which is truly '*tall*'.
- Utility view: the utility of confidence that John is tall is 0.7.
- Measurement view: when compared to others, John is taller than some and this privilege is 0.7.

Biligic and Turksen introduced eight methods: polling, direct rating (point estimation), reverse rating, interval estimation (set valued statistics), membership function exemplification, clustering methods and neural-fuzzy methods for constructing the membership function (Bilgiç & Türkşen, 2000). They had discussed measurement theory as a framework which can find the appropriate method for each type of interpretation (Suppes, Krantz, Luce, & Tversky, 1989).

Where in direct rating (Bilgic & Turksen, 1997) the parameter or variable is being classified according to a fuzzy concept (like importance degree, tallness, darkness, etc.) and the question is: 'How *F* is *a*?', in polling technique we find the membership functions values, proportional to positive answers to a presented subject. The question in this method is: 'Do you consider *a* as *F?*' where '*a*' is the parameter and '*F*' is a fuzzy concept. In such kind of indirect way, we can define an interval scale and generate the membership value based on the frequencies that each interval gets when the scale is being questioned by a group of experts. In other words, each interval gets a weight equal to the number of agreements (Wierman, 2010).

Whereas describing all the methods and efforts done in constructing the membership functions is beyond the scope of this script, most famous methods and techniques have been summarized in Table 2-6. The major part of this table is based on studies done by Medasani et al. (Medasani, Kim, & Krishnapuram, 1998), Sancho-Royo and Verdegay (Sancho-Royo & Verdegay, 1999) and Sivanandam and Sumathi (Sivanandam, Sumathi, & Deepa, 2007) about different methods and techniques for membership functions generation.

Table 2-6: Different methods and techniques for membership functions construction

Membership Function Generating Methods	Applied Techniques
Subjective perception based methods	▪ Interval estimation ▪ Continues direct valuation ▪ Direct rating ▪ Reverse rating ▪ Polling ▪ Pairwise comparison (Relative preference) ▪ Parameterized MF (Based on distance from ideal state or deductive reasoning)
Heuristic methods	▪ Piecewise linear functions (linearly increasing, linearly decreasing or a combination of these) ▪ Piecewise monotonic functions(S-functions, Sin(x), π-Functions, exponential functions,…)
Histogram based methods	▪ Modeling multidimensional histogram using a combination of parameterized functions
Transformation of probability distributions to possibility distributions	▪ Bijective transformation method ▪ Conservation of uncertainty method
Fuzzy nearest neighbor method	▪ K-Nearest Neighbors(K-NN)
Neural network based methods	▪ Feed forward multilayer neural networks
Clustering based methods	▪ Fuzzy C-Means(FCM) ▪ Robust agglomerative Gaussian mixture decomposition (RAGMD) ▪ Self-Organizing Feature Map(SOFM)
Genetic Algorithm	▪ Fitness function evaluation
Inductive Reasoning	▪ Entropy minimization (Clustering the parameters corresponding to the output classes)

2.8.6. L-R Fuzzy Numbers

There are various types of membership functions, e.g. S-shaped function, Z-shaped function, triangular membership function, trapezoidal membership function, Gaussian distribution function, exponential function, *Pi* function and vicinity function (Bede, 2012). A more convenient and concise way to define a MF is to express it as a mathematical formula.

Dubois and Prade, introduced the concept of L-R approximations of fuzzy numbers and replaced the convolution type operations by interval based ones (Didier J Dubois, 1980). All of the mentioned membership functions are presentable in a form of L-R fuzzy numbers. Every L-R fuzzy number (or interval) 'u' has the membership function of the following form: (Stefanini & Sorini, 2009)

Equation 2-6

$$\mu_u(x) = \begin{cases} f_L(\frac{x-a}{b-a}) & if\ x \in [a,b] \\ 1 & if\ x \in [b,c] \\ f_R(\frac{d-x}{d-c}) & if\ x \in [c,d] \\ 0 & otherwise \end{cases}$$

Where $f_L, f_R : [0, 1] \to [0, 1]$ are two continuous, increasing functions, satisfying $f_L(0) = f_R(0) = 0,\ f_L(1) = f_R(1) = 1$. The compact interval [a, d] is the support and the core is [b, c]. The usual notation is $u = (a, b, c, d), f_L, f_R$ for an interval and u = (a, b, c) for a number.

L-R fuzzy numbers are considered important in the theory of fuzzy sets and their particular cases as triangular and trapezoidal fuzzy numbers, when the functions f_L and f_R are linear, are very useful in applications. These straight line membership functions have the advantage of simplicity. The simplest MF is the triangular membership function.

In this research we use triangular and trapezoid membership functions to define fuzzy membership functions of risk probabilities, risk consequences or impacts on project objectives: time, cost, quality and scope and finally membership functions of risk scores. They way that these functions are defined would be discussed later in this script. A triangular MF is specified by three parameters {a, b, c} as follows:

$$Triangular(x;a,b,c) = \begin{cases} 0 & x \le a \\ (\frac{x-a}{b-a}) & a \le x \le b \\ (\frac{c-x}{c-b}) & b \le x \le c \\ 0 & c \le x \end{cases}$$

Equation 2-7

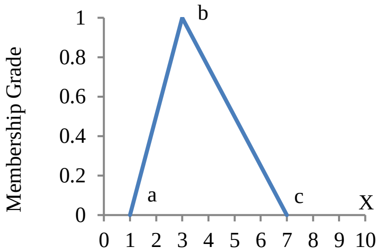


Figure 2-17 : A triangular MF

The parameters {a, b, c} (with a < b< c) determine the x coordinates of the three corners of the underlying triangular MF. Figure 4, illustrates a triangular MF defined by a triangle (x; 1, 3, 7) on a 10 grade scale which can be based on 10 fuzzy linguistic values or 10 pre-defined conditions such as effectiveness grade, importance degree, agreement level, etc.

A fuzzy uncertain quantity has a range of values between the lowest possible limit (below which there are no possible values) and highest possible limit (beyond which there are no possible values). The membership grades represent the degrees of belief in the truth levels of the values in the range of the fuzzy number. The three corners of a TFN present the lowest possible value (a), the most possible value (b), and the highest possible value (c). The values in the range between the lowest and highest possible values have a membership grade between 0 and 1, with the most possible value having a membership grade of 1. The lowest and highest possible values have membership grades of 0 because they represent the lower and upper limits of the fuzzy range outside which no values belong to the fuzzy number. The membership grade for a given value in the range between the lowest possible value and the highest possible value is evaluated using linear interpolation by finding the membership grade on the straight line corresponding to a given value in the fuzzy range.

The trapezoidal membership function has a flat top and really is just a truncated triangle curve. A 'trapezoidal MF' is specified by four parameters {a, b, c, d} as follows: (a ≤ b ≤ c ≤ d) (Melin & Castillo, 2001). Figure 3, illustrates a trapezoidal MF defined by trapezoid (x; 1, 3, 6, 9).

$$Trapezoid(x;a,b,c,d) = \begin{cases} 0 & x \le a \\ (\frac{x-a}{b-a}) & a \le x \le b \\ 1 & b \le x \le c \\ (\frac{d-x}{d-c}) & c \le x \le d \\ 0 & d \le x \end{cases}$$

Equation 2-8

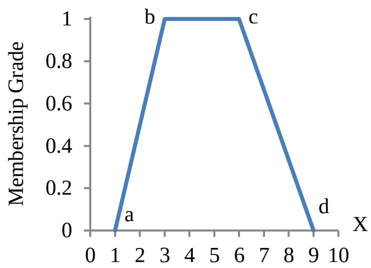


Figure 2-18 : A trapezoidal MF

2.9. Fuzzy management

The traditional approach of management was based on logic of zero (0) or one (1). Relying only on this kind of analysis in the age of information that digital computers control almost all circumstances is impossible. An effective management depends on taking proper decisions and accurate data analyzing so the use of classical logic will cause managerial deviations and managers need to investigate the distance between two options in the form of a continuum. Fuzzy logic is a new approach to address ambiguities in decisions on the basis of classical logic. Fuzzy management systems by using fuzzy logic can process the qualitative data like human memory and create models to provide required information for managers' decision making. Moreover, these systems combined with neural networks and learner functions can easily consider the experience of managers and update themselves automatically. General characteristics of fuzzy management can be stated as follows (Asai, 1995):

- Real coefficients and conditions of shortages which are set by the planners intuitively can be easily and flexibly illustrated by membership functions and find answers to these problems in a mathematical way.
- Obtaining knowledge and skills needed for management systems from experts in natural language and create models and computer programs easily by using fuzzy inference. Natural language often uses the attributes and constraints such as ‘very’, ‘little’, ‘some’ and ‘approximately’ that can be shown by membership functions and given as input to computer programs.
- Providing several possible answers by obtaining the upper and lower limits of responses considering experts, managers and specialists’ opinions that lead to more practical solutions than classic management techniques that offer a limited number of answers.

Fuzzy management science methods according to each operation of management have been shown in Table 2-7 (Asai, 1995).

Table 2-7: Fuzzy management science methods (Asai, 1995)

Operations		Methods
Data and experience acquisition		• Fuzzy database, Fuzzy knowledge base
Planning	Constructing the models	• Fuzzy models of large scale systems • Fuzzy structural models • Fuzzy regression models • Fuzzy Group Method of Data Handling (GMDH)
	Analysis and evaluation	• Fuzzy multivariate analysis (quantification theory) • Fuzzy integral • Fuzzy AHP • Fuzzy reliability analysis
	Optimization and decision	• Fuzzy mathematical programming • Fuzzy multi objective planning • Fuzzy multi attribute decision making • Fuzzy statistical decision making • Fuzzy Decision Support System(FDSS)
Administrative management		• Application of fuzzy theory to behavioural science • Application of fuzzy theory to securities investment • Fuzzy production management • Fuzzy Quality Control(FQC) • Fuzzy expert systems

2.9.1. Data and experience acquisition

2.9.1.1. Fuzzy database

It is obtained from fuzzification of a conventional database and extension of a relational model of a standard database to a fuzzy relational model. In this way the fuzzy data can be presented with fuzzy sets effectively. In terms of application fuzzy database fields can be used in fuzzy expert systems which are part of decision making support systems for management and administration.

2.9.1.2. Fuzzy knowledge base

To create a fuzzy knowledge base, experts' experience and experienced techniques in actual operations is received in natural language and then they are converted to IF-THEN rules. In fuzzy knowledge base, fuzzy propositions are used instead of crisp propositions by using a membership function to process values like 'very', 'low', 'some', 'almost' and so on. In fuzzy management science along with fuzzy database and various fuzzy models, fuzzy knowledge base is used to create decision making support systems.

2.9.2. Constructing the models

2.9.2.1. Fuzzy structural models

Classical structural models use graphs to represent the diverse and complex systems of management, but in these models membership functions are used instead of two-valued (0 or 1) logic to express the relation between different parts of the graph.

2.9.2.2. Fuzzy regression models

The regression models have been created and used to deal with management programming problems like prediction. While the classical models are created using the received data from experts in fuzzy regression models, fuzzy numbers are used.

2.9.2.3. Fuzzy GMDH:

It is a method to model nonlinear, large-scale and complex systems and is used in programming of management problems like prediction. In this method for modelling the systems, fuzzy numbers are substituted the model parameters.

2.9.3. Analysis and evaluation

2.9.3.1. Fuzzy quantification theory

In the classical quantification theory of an object characteristic, its properties are categorized and numerical values (*0*) or (*1*) are used for judgement about describing characteristics of that object. Humans describe objects' properties qualitatively and imprecisely. Fuzzy set theory includes fuzzy quantifiers and categorizes the object properties using fuzzy sets and qualitative judgements.

2.9.3.2. Fuzzy integral

In the classic method, the overall evaluation of a product is obtained using the linear combination: $\Sigma Q_i X_i$. In this combination X_i is the i^{th} property of product and Q_i is the weight of i^{th} property in the evaluation of that product. For example, in the assessment of a product some of its properties like performance (X_1), appearance (X_2) and being economical (X_3) are considered then the weight of each of these properties is determined using pair comparison or other methods. Regarding to the assigned weights and each property grading the overall evaluation of the product is obtained. Fuzzy integral claims the overall evaluating of approaches that formulate the subjective thoughts and human judgments flexibly. This method is not limited to the product evaluations and can be used for evaluation of ideas and various strategies.

2.9.3.3. Fuzzy AHP

In Analytic Hierarchy Process or AHP various products or options are evaluated through determining the weight and value of each option and applying pair comparison. Fuzzy AHP is the fuzzification of this procedure.

2.9.4. Optimization and decision making

2.9.4.1. Fuzzy mathematical programming

Classical mathematical programming is frequently used in various levels of decision making and programming in management by using objective functions and constrained conditions. Deviation, fluctuation and flexibility always exist in the real problems, so in these cases mathematical programming with fuzzy objective functions and constraints are used.

2.9.4.2. Fuzzy multi-objective programming

Making decisions and planning for real management problems involved in satisfying a large number of constraints and mutually opposed objectives. Using fuzzy multi objective programming is a useful tool for determining the fuzzy membership function of objective functions and constraints that are mostly fuzzy.

2.9.4.3. Fuzzy Multi attribute Decision Making (FMDM)

The type of decision making that various qualitative criteria of several options are needed to be evaluated is called multi-attribute decision making. Most of decision making problems in the real world are from this type of decision making. When the weights of factors and evaluation values are given by fuzzy numbers and linguistic expressions it is called fuzzy multi attribute decision making.

2.9.4.4. Fuzzy statistical decision making

In the conventional decision making the option with the highest expected effectiveness is selected as the best option. In actual decision making problems when conditions and activities are presented by fuzzy sets it is called fuzzy statistical decision making.

2.9.5. Administrative management

2.9.5.1. Application of fuzzy theory to behavioural science

There are several parameters in behavioural science that are expressed by qualitative and linguistic variables. For example, to determine leadership styles, the desire of employees can be expressed in terms of very low, low, medium, high and very high. Fuzzy behaviour models can be designed through converting the linguistic and qualitative variables into fuzzy numbers.

2.9.5.2. Application of fuzzy theory to securities investment

Nowadays applying fuzzy logic in financial management through using an interval between *0* and *1* for measuring the investment and capital budgeting factors like cash flow, cash outflow, internal rate of return and current value of investment is a suitable alternative for classical approach based on crisp values *0* and *1*.

2.9.5.3. Fuzzy production management

Parameters like goals, resource values, products efficiency coefficients and delay have imprecision and high degree of uncertainty. Using fuzzy logic to design the production management models, production and operations planning, comprehensive planning, production ideal planning and production continuity planning instead of applying classical logic that use crisp parameters can improve the results significantly.

2.9.5.4. Fuzzy quality control

There are several parameters and factors in the statistical quality control issue that have a high degree of imprecision and ambiguity. Parameters like number of sampling/observation, sampling gaps, confidence limits, manufacturer risk and consumer risk are the kind of factors that cannot be measured certainly. Fuzzy logic is one of the most efficient approaches for measuring the factors imprecision in statistical quality control so that more realistic information can be collected for making management decisions.

2.9.5.5. Fuzzy expert systems

An expert system consists of two main elements the knowledge base and the inference engine. Knowledge base contains (IF-THEN) rules. Inference engine executes the inference by using backward and forward searching techniques. Fuzzy expert system is created.by converting the knowledge base from crisp state to fuzzy.

Whereas the fuzzy management method that was used for risk management in this study was a fuzzy expert system, it would be discussed in detail in upcoming sections of this script.

2.10. Fuzzy systems

Fuzzy systems are universal approximators (Kosko, 1994). With universal approximators, systems are addressed which can approximate any mapping (function). The fuzzy system can be regarded as an interpolation between numbers of points, each defined by a fuzzy rule (Jager, 1995).

Different researchers consider the different categories of fuzzy systems. One of these classifications is dividing fuzzy systems to two broad categories: fuzzy expert systems and fuzzy decision-making systems (Saletic, Velasevic, & Mastorakis, 2002). Fuzzy decision making systems can use a decision- making block or decision-making matrix instead of rule base where fuzzy expert system develops a kind of qualitative reasoning system for a specified domain of expertise (Saletic et al., 2002).

2.10.1. Fuzzy proposition

There are two types of fuzzy proposition. Simple fuzzy proposition and compound fuzzy proposition (L. X. Wang, 1997). Simple fuzzy proposition would be like this: '*X is A.*' that *X* is linguistic variable and *A* is linguistic value. Compound propositions are combinations of simple fuzzy propositions using connectors '*and*', '*or*', '*not*' to indicate the fuzzy intersection fuzzy union and fuzzy complement, respectively. Considering $P: x \in A$, $\overline{P}: x \notin A$, $Q: x \in B$. There are five logical connectives for combining two simple propositions *P* and *Q* on the same universe of discourse (T.J. Ross et al., 2002):

1. Disjunction (∨): it is equal to fuzzy union. $P \vee Q \Rightarrow x \in A$ or B so:

$$T(P \vee Q) = max(T(P), T(Q))$$ Equation 2-9

2. Conjunction (∧): it is equal to fuzzy intersection. $P \wedge Q \Rightarrow x \in A$ and B so:

$$T(P \wedge Q) = \min(T(P), T(Q))$$ Equation 2-10

3. Negation (−): it is equal to fuzzy complement

$$\begin{aligned} &If\ \ T(P) = 1,\ then\ \ T(\overline{P}) = 0 \\ &If\ \ T(P) = 0,\ then\ \ T(\overline{P}) = 1 \end{aligned}$$ Equation 2-11

4. Implication (→): $P \rightarrow Q \Rightarrow x \in A$ hence:

$$T(P \rightarrow Q) = T(\overline{P} \cup Q)$$ Equation 2-12

5. Equivalence (↔or⇔): P ↔ Q ⇒ x ∈ A, B hence:

$$T(P \leftrightarrow Q) = \begin{cases} 1 & for\, T(P) = T(Q) \\ 0 & for\, T(P) \neq T(Q) \end{cases}$$ Equation 2-13

The important point about fuzzy disjunction connective, logical '*or'* known as '*inclusive or'* is that it is completely different from natural language '*or'* known as *'exclusive or'*. The *'exclusive or'* implies exclusion. For example, chips or salad on a restaurant menu implies selecting one of the options not both, but the *'inclusive or'* which is most used in logic implies that a compound proposition is true if either of its simple propositions is true or if both are true.

2.10.2. Fuzzy inference system and fuzzy controllers: a short history

Fuzzy inference systems are types of fuzzy expert systems that are known as fuzzy rule-based, fuzzy model, fuzzy associative memory or fuzzy knowledge-based systems (Sivanandam et al., 2007). In recent decades, usage of fuzzy controller has found a remarkable position in science and advanced engineering. Fuzzy controllers (or fuzzy control systems) were initially implemented in Japan. In 1974 Mamdani designed a fuzzy algorithm to apply for controlling of a simple dynamic plant (Mamdani, 1974). In 1985, Seiji Yasunobu and Soji Miyamoto of Japanese company, Hitachi, provided simulations that demonstrated the feasibility of fuzzy control systems for the Sendai railway. Developing their ideas resulted in using fuzzy systems to control accelerating, braking, and stopping the train when the line opened in 1987 (Eberhart & Shi, 2011). In early 1980's Dr. Takeshi Yamakava of the Kyushu institute of technology registered patents for integrated circuits embodying fuzzy logic. In 1987 He successfully used a set of simple chips using these circuits in an inverted pendulum experiment. In this classic control problem, a vehicle tries to keep a pole mounted on its top by a hinge upright by moving back and forth (Grant & Jordan, 2015). In 1988 the Laboratory for International Fuzzy Engineering (LIFE) was established in Japan, which was a cooperative arrangement between 48 companies to pursue fuzzy research. It increased the industrial and consumer applications of the fuzzy rule base or inference systems in the world significantly. Firms such as Sony, Nissan, Boeing, General Motors, Allen-Bradley, Chrysler, Eaton, Maytag, Mitsubishi and Whirlpool used fuzzy controllers in designing air conditioners, refrigerators, energy-efficient electric motors, dishwashers, character and handwriting recognition tools, voice-controlled robot helicopters, elevator systems, automotive transmissions and so on. For example, Matsushita Vacuum cleaners that interrogated dust sensors and adjust suction power accordingly, washing machines that automatically set the best wash cycle for the best use of water, energy, and detergent based on load-weight, fabric-mix, and dirt sensors (F. M. McNeill & Thro, 2014), and Cannon auto focusing cameras that applied a charge-coupled device to measure the clarity of the image in six regions of its field of view and use the information provided to determine if the image is in focus were designed based on fuzzy microcontrollers (Irwin, 1997).

2.10.3. Advantages and disadvantages of using fuzzy logic for system control

Advantages of using fuzzy logic for system control are as follows (F. M. McNeill & Thro, 2014):

- Fuzzy logic control simplifies knowledge acquisition and representation.
- Compared to conventional systems with fewer values and decision more observed variables can be evaluated.
- Working very similar to human mind makes it very suitable for processing the not numerical linguistic variables.
- There is no need to understand all the variables to relate output to input. This results in a more accurate and stable control system compared to conventional systems.
- Rapid prototyping is possible because the system designer does not need to know everything about the system before starting.
- Because of easier design they cost cheaper than conventional systems.
- They have enhanced robustness.
- A great complexity can be encompassed using a few rules.

Disadvantages of fuzzy logic control are as follows:

- Developing a model based on a fuzzy system is hard.
- However, they are easier to design and faster to prototype, fuzzy systems need more simulation and fine tuning before becoming operational.
- Sometimes collecting the experts' knowledge in order to optimize or enhance the accuracy of reference' membership functions is not as easy as it seems (Author opinion).

2.10.4. Stages of a fuzzy inference system

Figure 2-19 shows the different types of fuzzy inference methods. Fuzzy inference methods can be classified into direct methods and indirect methods. The most commonly used methods are direct methods like Mamdani's and Sugeno's (Lu, Jain, & Zhang, 2012). However, indirect methods are technically interesting, but these methods are relatively complex. In this study the Mamdani's method was used for fuzzy assessment of construction risk factors, which is the most popular fuzzy inference techniques. This method was introduced by Professor Ebrahim Mamdani of London University in 1975 by applying a set of fuzzy rules that had been supplied by some experienced operators. This inference system was used for controlling the steam engine and boiler combination (Mamdani & Assilian, 1975).

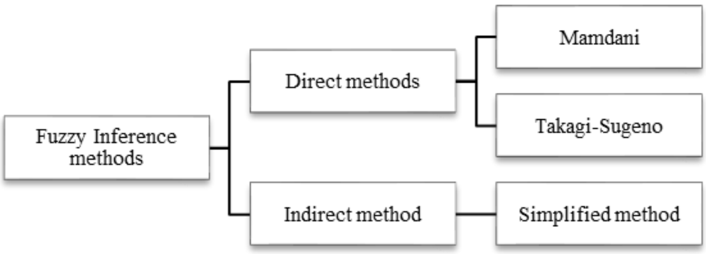


Figure 2-19: Fuzzy inference methods

The general structure of all fuzzy inference systems is almost the same, however there are some differences between some applied techniques in each step. The general structure of a fuzzy inference system has been illustrated in Figure 2-20.

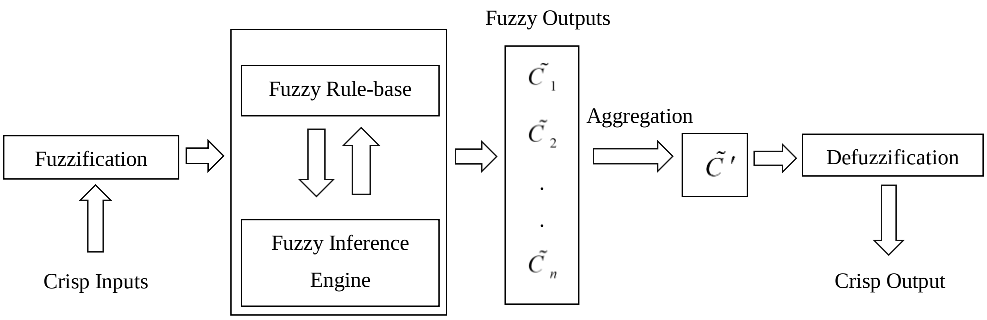


Figure 2-20:Structure of a fuzzy inference system (Castillo & Melin, 2008)

As a Mamdani fuzzy inference system used in this study, we try to explain stages of a fuzzy inference system by focusing on this method. The Mamdani fuzzy inference system consists of following general stages (Negnevitsky, 2011):

1. Fuzzification of inputs
2. Rule evaluation
3. Aggregation of outputs
4. Defuzzification

2.10.4.1. Fuzzification

Fuzzification is the operation of converting or transforming a crisp set or value to a fuzzy set or a fuzzy set to a fuzzier set. Through this step, crisp inputs or measured values are translated into linguistic concepts (Ibrahim, 2004). For example, refer to figure 1.11 translating the 60 °C into three linguistic concepts of cold, warm and hot and then come to a correct decision about taking a shower or not due to familiarity with the Celsius temperature scale is kind of fuzzifying. For every fuzzification two main steps are recognizable (Saade & Diab, 2004):

- **Step 1:** Defining or assigning fuzzy sets for each variable that overlap each other. Fuzzy sets are introduced by membership functions.
- **Step 2:** Mapping the input values into their membership grades in the input fuzzy sets.

2.10.4.2. Rule evaluation

Through this stage the connection between input and output fuzzy set is provided. Rule evaluation consists of two sections:

- **Section 1:** Fuzzy rule-base: in this section the inference rules in the form of (*IF-THEN)* rules are set. Fuzzy connectives (*AND & OR*) are used in *IF* part of the rules. The Mamdani fuzzy rules first presented in 1974 has the following general form (Mamdani, 1974):
  - $r_k : IF\ x_1 is\ \tilde{A}_1^k\ AND\ x_2\ is\ \tilde{A}_2^k\ and\ ...and\ x_{N_x}\ is\ \tilde{A}_{N_x}^k\ THEN\ y_1\ is\ \tilde{C}_1^k, ..., y_{N_y}\ is\ \tilde{C}_{N_y}^k$

- Where r_k is the kth rule, *x* are input variable, $\tilde{A}_K$ are the fuzzy sets representing the kth rule antecedents, y is the output variable, N_x is the number of controller inputs and $\tilde{C}_K$ are the fuzzy sets representing the k^{th} rule consequent.
- **Section 2:** Inference engine: inference engine applies the implication from *IF* parts toward *THEN* parts of the rules by using appropriate fuzzy operators. In this part the degree of fulfillment for the each rule is determined, where fuzzy sets $\tilde{C}_i$ are assigned to the universe of discourse of the output variable consequent. Figure 2-22 shows Mamdani method for fuzzy inference. The most well-known implications based on conjunctions (T-norms) are the implications used by Mamdani (1974) presented by Equation 2-14. Table 1.3 shows some of famous implication operators (Jager, 1995).

$$I\ (a,b) = min\ (a,b) \qquad \text{Equation 2-14}$$

Table 2-8: Fuzzy implications I(a, b) (Jager, 1995)

$\mathbf{I}(\mathbf{a},\mathbf{b})$	**References**
$Min(a,b)$	Mamdani (1974)
ab	Larsen (1980)
$Min(1-a+b,1)$	Łukasiewicz
b^a	Yager (1980)
$\begin{cases}1-a & if\ \ b=a\\ b & if\ \ a=1\\ 1 & otherwise\end{cases}$	Dubois and Prade
$Min(1-a,\ min(a,b))$	Zadeh (1975)
$1-a+ab$	Reichenbach
$Max(1-a,b)$	Kleene (1938)
$\begin{cases}b & if\ \ a>b\\ 1 & otherwise\end{cases}$	Godel
$\begin{cases}1 & if\ \ a\le b\\ 0 & otherwise\end{cases}$	Gaines (1976)

2.10.4.3. Aggregation

The process of obtaining the overall of *THEN* parts or consequences of the rules which are the results of individual rules into one output fuzzy set $\tilde{C}'$ is known as aggregation (T.J. Ross et al., 2002). There are two simple cases in determining an aggregation strategy:

1. Conjunctive system of rules: in this case the unification of rules consequents is done by '*and'* connectives. The aggregated output (consequent) *y* or its corresponding fuzzy set $\tilde{C}_i'$ is found by the fuzzy intersection of individual rule consequent y_k or its corresponding fuzzy set $\tilde{C}_i$ where:

   $y=y_1\, and\ y_2\, and ...and\ y_k \quad k=1,2,\ldots,N_r\,(Number\ of\ \ rules)$

   or

   $\tilde{C}':y_1\cap y_2\cap...\cap y_k$

   This is defined by the membership function:

   $$\mu_y(y)=min(\mu_{y1}(y),\mu_{y2}(y),...,\mu_{yk}(y)) \quad for\ y\in Y$$

2. Disjunctive system of rules: the case that the satisfaction of at least one rule is required is called a disjunction system of rules. In this case "or connects the rules and the unification or aggregation of all individual rules is found:

   $y=y_1\, or\ y_2\, or ...or\ y_k \quad k=1,2,\ldots,N_r\,(Number\ of\ \ rules)$

or

$\tilde{C}': y_1 \cup y_2 \cup ... \cup y_k$

This is defined by the membership function:

$$\mu_y(y) = max(\mu_{y1}(y), \mu_{y2}(y), ..., \mu_{yk}(y)) \quad for\ y \in Y$$

Mamdani inference engine uses a disjunctive system of rules for aggregation. It is known as the *max-min* method. This technique chooses a *min* operator for the conjunction in the premise of the rule as well as for the implication function and a *max* operator for the aggregation. It can be summarized as following general formula (Jager, 1995):

$$\mu_y(y) = max[min\{max[\mu_{(\tilde{A}_1^k)}(x) \wedge \mu(x_1)], max[\mu_{(\tilde{A}_2^k)}(x) \wedge \mu(x_2)]\}]$$

Where $\mu(x_1)$ and $\mu(x_2)$ are the membership functions for inputs $i(x_1)$ and $j(x_2)$, respectively. In this figure the fuzzy inputs are represented by a singleton which is a crisp input value, but if the input is a triangular membership functions the intersection of these inputs and the antecedent membership functions (*A11, A12* for the first rule and *A21, A22* for the second rule) results in triangles instead of a point.

2.10.4.4. Defuzzification

Defuzzification is a mathematical process used to convert a fuzzy set or fuzzy sets to a crisp point. It is a necessary step because fuzzy sets generated by fuzzy inference in fuzzy rules must be somehow mathematically combined to come up with one single number as the output of a fuzzy controller or model (Zhang & Liu, 2007).

Runkler mentioned that whereas a defuzzification operator selects significant crisp value it needs to have some basic properties. He considered two main categories of them: theoretical interest and application orientated ones and separated them into static, dynamic, statistical and implementation properties. Runkler describes some important properties of the defuzzification process as follows (Runkler, 1996):

1. Consistency: when a defuzzification maps convex crisp sets to their centroid, it is called consistency.
2. Section invariance: When a magnification of a regarded section, does not affect the results, the defuzzification is called section invariant.
3. Monotonicity: If the defuzzification result remains unchanged or moves toward a single element when its membership grade increases or if by decreasing the membership grade of a single element the defuzzification result moves to the opposite direction or remains constant it is called monotonous defuzzification.

4. Linearity: A linear defuzzification result is maintained after affine transformation such as rotation, reflection, translation and scaling.
5. Offset and scale invariance: if membership values offsets or scaling does not affect the defuzzification result, it is called offset invariant defuzzification and scale invariant defuzzification respectively.
6. Compatibility: the defuzzification method chosen must be compatible with the inference, composition, and other operators used in the fuzzy system.
7. Arithmetic compatibility: A defuzzication is arithmetically compatible, if it defuzzifies *'about a'* to '*a*' which equals to the mean value with a membership grade of 1.
8. Exclusion: in exclusive defuzzification methods negative information is recognized with a nonzero membership value.

In the following, some of the existing defuzzification methods that are the most widespread defuzzification methods are presented (Genther, Runkler, & Glesner, 1994; Van Leekwijck & Kerre, 1999). To have a better understanding of differences between several strategies for defuzzification of the output of a rule-base fuzzy system, some parameters and variables need to be defined, which are commonly used in defuzzification formulas as follows:

- $\tilde{C}_k$: fuzzy output set or the consequent fuzzy set after applying an implication operator.
- $\tilde{C}'$: the aggregated (overall) diagram of fuzzy output (as a result of the inference) sets using maximum operator.
- $\tilde{C}'_k$: the kth segment of $\tilde{C}'$
- $\mu_{c'_k}(x)$: the function of kth segment of $\tilde{C}'_k$
- a_k : the pre-calculated numerical value of the output set $\tilde{C}_k$
- α_k: the degree of each consequent fuzzy output set $\tilde{C}_k$
- w_k : weighted associated with each $\tilde{C}_k$
- X^*: defuzzification output of $\tilde{C}'$

- Centre of gravity (COG) or Centroid: X* is the point along the X axis about which the area would balance.

$$X^* = \frac{\int_{c'} x \, .\mu_{c'_k}(x)dx}{\int_{c'} \mu_{c'_k}(x)dx} \qquad \text{Equation 2-15}$$

- *Bisector or Center of Area (COA): X** is the point along the *X* that crossing line parallel to μ axis divides the total region of C' into two sub-region of equal area.

$$\int_{z^{inf}}^{z(COA)_{c'}} x.\mu_{c'}(x)dx = \int_{z(COA)_{c'}}^{z^{Sup}} x.\mu_{c'}(x)dx$$ Equation 2-16

- *Weighted average method (WAM):* this method is valid for symmetrical output membership functions. It is less computationally intensive and produces results very close to *COA* method. Weighting each function in the output by its respective maximum membership value.

$$X^* = \frac{\sum_{k=1}^{N_y} \mu_{c'}(\bar{x}_k).\bar{x}_k}{\sum_{k=1}^{N_y} \mu_{c'}(\bar{x}_k)}$$ Equation 2-17

Where $\bar{x}_k$ is the length of symmetry axis of $\tilde{C}_k$ and N_y is the number of fuzz output sets.

- *Fuzzy Mean (FM):* this method uses pre-calculated numerical values (Niimura & Tanaka) for each of fuzzy output sets.

$$X^* = \frac{\sum_{k=1}^{N_y} \alpha_k .a_k}{\sum_{k=1}^{N_y} \alpha_k}$$ Equation 2-18

- *Weighted Fuzzy Mean (WFM):* this method is parameterized state of the *FM* method where w_k is the weight associated with fuzzy output set equals to the area of $\tilde{C}_k$ *(K^{th}* fuzzy output). By using this method, a degree of importance can be assigned to each output set.

$$X^* = \frac{\sum_{k=1}^{N_y} w_k .\alpha_k .a_k}{\sum_{k=1}^{N_y} w_k .\alpha_k}$$ Equation 2-19

- *Quality Method* (*QM):* the aim of *QM* is to increase the importance of the "more crisp" output sets. Where, d_k equals the width of the support of $\tilde{C}_k$. It is a special case of *WFM* where $w_k = 1/d_k$.

$$X^* = \frac{\sum_{k=1}^{N_y} \left(\frac{\alpha_k}{d_k}\right).a_k}{\sum_{k=1}^{N_y} \left(\frac{\alpha_k}{d_k}\right)}$$ Equation 2-20

- *Center of Largest Area (COLA):* if the output fuzzy set has at least two convex sub-regions, defuzzifies the largest area using centroid.
- *LOM (Largest or Last of Maxima):* determine the largest value of the domain with a maximized membership degree.
- *MOM or Mean-max membership:* determines the middle of maximum.

- *SOM (Smallest of Maximum) or FOM (First of Maxima):* determine the smallest value of the domain with a maximized membership degree.

Figure 2-21 illustrates outputs of some of various defuzzification methods.

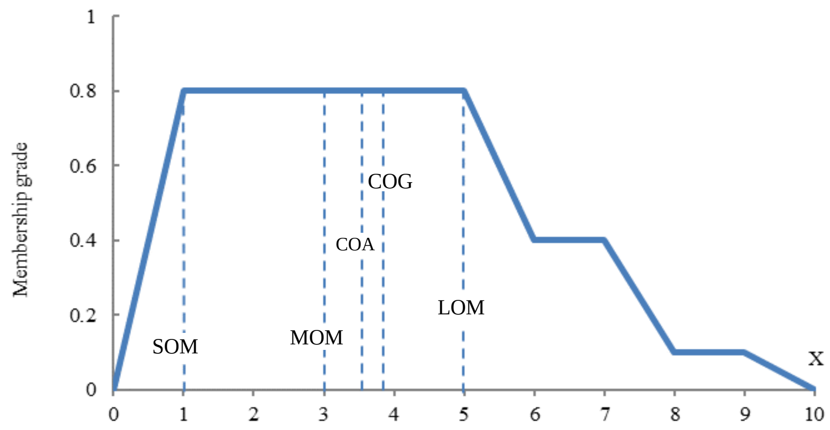


Figure 2-21: Various defuzzification methods for a numeric output

The advantage of Mamdani method can be listed as follows (Sivanandam et al., 2007):

- It is intuitive
- It has widespread acceptance
- It is well suited to human input

Mamdani method has been illustrated graphically in Figure 2-22.

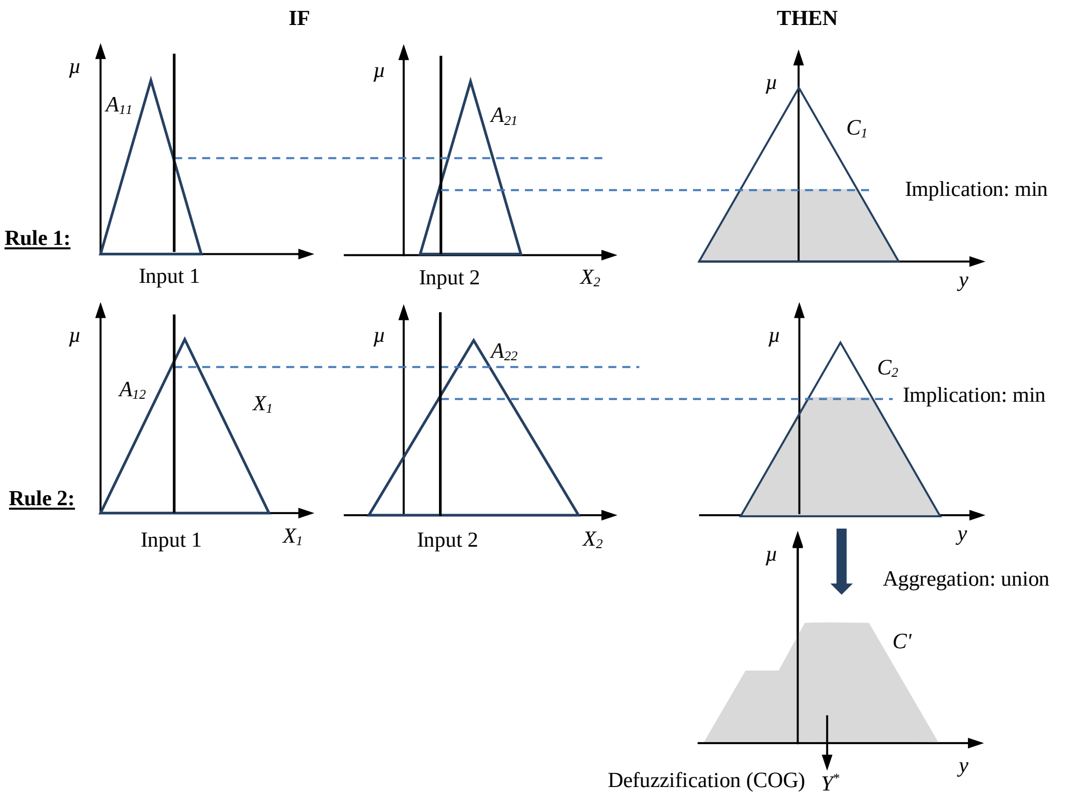


Figure 2-22: Mamdani's inference system

2.10.5. Sugeno fuzzy inference system

Another fuzzy inference system introduced by Takagi-Sugeno in 1985 (Takagi & Sugeno, 1985). The general form of Sugeno inference is as follows:

$$r_k : IF\ x_1 is\ \tilde{A}_1^k\ and\ x_2\ is\ \tilde{A}_2^k\ and \ldots and\ x_{N_x}\ is\ \tilde{A}_{N_x}^k$$

$$THEN\quad y_1 = f_{1,k}(x_1, x_2, \ldots, x_{N_x}), \ldots, y_{Ny} = f_{Ny,k}(x_1, x_2, \ldots, x_{N_x})$$

Where $x_1, x_2, ..., x_{N_k}$ and $y_1, y_2, ..., y_{N_k}$ are linguistic variables and $\tilde{A}_1^k, \ldots, \tilde{A}_{N_x}^k$ are fuzzy sets on the universe of discourses *X*. In Sugeno method the fuzzification of input variables and applying the fuzzy operators are similar to Mamdani method, but as the above relation shows the consequents of fuzzy rules are functions $(f_{j,k})$ in the form of linear or constant functions. This is the main difference between these two techniques. The linear equation of the output function (*y*) for k^{th} rule has been presented by the following relation:

$$r_k : IF\ x_1\ is\ X_1^k and\ x_2\ is\ X_2^k\ and \ldots and\ x_{N_x}\ is\ X_{N_x}^k$$

$$THEN\!: y_k = b_{0,k} + \sum_{i=1}^{N_x} b_{(i,k)}.x_i \qquad \text{Equation 2-21}$$

The zero-order Sugeno model is obtained when the constant output level (y_k) is constant and it happens when:

$b_{i,k} = 0 \;\; i = 1, \dots, N_x \;\; So \;\; y_k = b_{0,k}$

The output level y_k of each rule is weighted by the firing strength $ß_k$ of the rule. In another word $ß_k$ is the support value for rule *k*, the final output of the system is the weighted average of all rule outputs, computed as:

$$\text{Final Output: } y' = \frac{\sum_{k=1}^{N_r} \beta_k . y_k}{\sum_{k=1}^{N_r} \beta_k} \qquad \text{Equation 2-22}$$

$$= \frac{\sum_{k=1}^{N_r} \beta_k .[b_{0,k} + \sum_{i=1}^{N_x} b_{i,k} .x_i]}{\sum_{k=1}^{N_r} \beta_k} = \frac{\sum_{k=1}^{N_r} \beta_k .b_{0,k} + \sum_{i=1}^{N_x} [\sum_{k=1}^{N_r} \beta_k .b_{i,k} .x_i]}{\sum_{k=1}^{N_r} \beta_k} = b'_0 + \sum_{k=1}^{N_x} b'_i .x_i$$

$$\text{So that: } b'_0 = \frac{\sum_{k=1}^{N_r} \beta_k .b_{0,k}}{\sum_{k=1}^{N_r} \beta_k} \quad \text{and: } b'_i = \frac{\sum_{k=1}^{N_r} \beta_k .b_{i,k}}{\sum_{k=1}^{N_r} \beta_k} \quad for \;\; i = 1, \dots, N_x$$

A Sugeno rule operates as shown in the Figure 2-23.

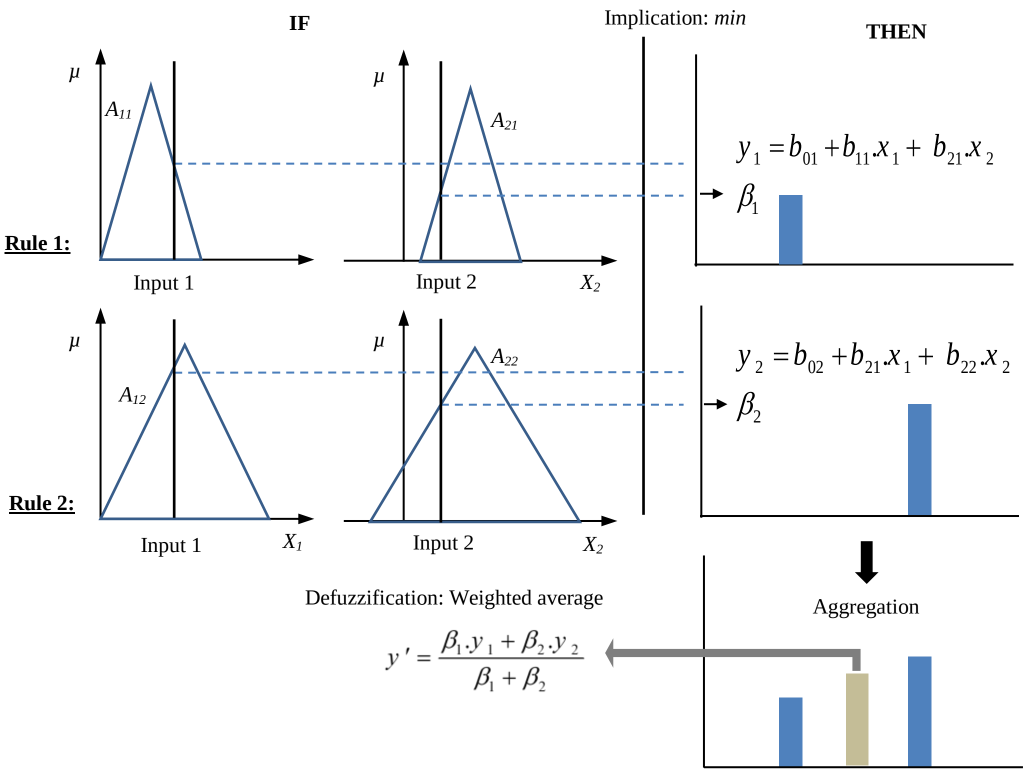


Figure 2-23: Sugeno inference system

The advantages of Sugeno fuzzy inference system can be listed as follows (Sivanandam et al., 2007):

- It is very efficient for computation
- It is appropriate for optimization and adaptive techniques
- The continuity of output surface has been guaranteed in this method
- It is a good option to perform mathematical analysis

2.10.6. Summary of fuzzy inference stages used in this study

This summary can be listed as following seven conditions:

- **Condition 1:** the membership functions of the fuzzy sets on the universe of discourse of the inputs and outputs become set that are triangularly or trapezoidal shaped and normal.
- **Condition 2:** the fuzzy rule base becomes complete through determining a set of if-then rules.
- **Condition 3:** the input variables are crisp values in the form of singletons.
- **Condition 4:** to fine the output consequent sets, Mamdani inference system with a T-norm is used for the implication function (T-implication) the operator for the conjunction in the premises of the fuzzy rules is the minimum operator.
- **Condition 5:** the max-min method is used for the aggregation
- **Condition 6:** the COG method is used for defuzzification

2.11. Oil & Gas Industry

There is no doubt that the oil and gas industry is one of the largest, most important and most complex industries in the world. The significant and vital role of this industry is not limited to provide fuel for transportation, electricity producing plants or heat generation for industrial and non-industrial use. Thousands of petrochemical products, from computers to modern communication facilities, clothing to asphalt that are produced from oil and gas and their derivations have affected everyone’s lives. The oil & gas industry affects global economy, geopolitics, international conflicts, wars, national securities and the process of power transfer in countries. Hardly an industry in the world can be found which is not affected by oil & gas industry directly or indirectly. Lorincz notes that the “*thirst for oil and gas won’t be satisfied any time soon*” (Lorincz, 2008). According to predictions, finding energy supplies that can be replaced by oil and gas will continue to encourage massive capital investment in the industry around the world. The International Energy Agency (IEA) predicts a 55% grow in the world’s primary energy needs between 2005 and 2030 with the demand reaching 17.7 billion tonnes of oil equivalent, compared with 11.4 billion tonnes in 2005. According to IEA statistics, however the share of oil between the years 1973 to 2013 decreased from 46% to 31% it still has the largest share in supplying the total primary energy of the world followed by coal (29%) and natural gas (21%). Even if during the next 40 years oil has been replaced by natural gas and nuclear energy in the power production for electricity (from 25% to 5%), it still keeps the share of 92% of the energy consumption of the transportation in the world ((IEA), 2012). The magnitude and complexity and the unique role of this industry in the lives of this planet's inhabitants face oil and gas industry with following challenges:

- Technical challenges
- Managerial challenges
- Human resource challenges

Accurate and efficient applications of project management practices and techniques help mitigate these challenges. The issue of risk management is kind of the managerial challenges with a high degree of importance that will be discussed in this script.

2.11.1. Background of oil and gas industry

The first phase of oil industry began with producing oil by Colonel Edwin Drake in north-western Pennsylvania in 1859. In those early days John D. Rockefeller became one of the pioneers in industrial organization. He combined his Standard Oil and 39 other affiliated companies that controlled 90% of the kerosene market and create the monopoly of Standard Oil Trust in 1882. Through combining all the refining operations under a single management, he achieved his real goal that was the economy of scale (Inkpen & Moffett, 2011). Historian Alfred Chandler called the staged that was set by Rockefeller the "dynamic logic of growth and competition that drives modern capitalism"(Chandler, 1990).

The new phase of oil and gas industry began in 1901 after discovering of oil at Spindletop in East Texas. Before this phase the main usage of oil was for lamps and lubrications but after that petroleum was considered as the main fuel for new inventions, such as automobiles and airplanes. Even the earlier invented transportation systems like steamships and trains started to switch from coal to oil.

In the 20th century oil and natural gas became the world's most important source of energy. This fact that oil and gas are not renewable energy sources has been a serious concern for oil producers and consumers from the beginning of this industry. The world's conventional recoverable resource estimated by US Geological Survey was about 1 trillion barrels in 1950. This estimation had tripled to 3 trillion barrels in 2000. The "Peak oil" is a concept that has been discussed in recent years. The peak oil is the hypothetical point in time when the global production of oil reaches its maximum rate, after which production will gradually decline. This theory is based on this fact that the amount of oil is finite. In the United States, oil production peaked in 1971 (Inkpen & Moffett, 2011). Some analysts have questioned the authenticity of the peak oil theory. They argued that estimation the amount of oil, which is trapped in porous subsurface rocks is a very difficult. They noted that there are many areas that have not been explored yet, or poorly have been poorly analysed. They believed our knowledge of in-ground oil resources increases dramatically as an oil reservoir is exploited (Maugeri, 2004).

Regardless of the debates about reaching the world's peak production point or not this fact that oil and natural gas are fundamental sources of the world's energy and petrochemical raw materials is undeniable and a complex combination of technology, price, and politics is what forms the amount of "true reserves" of oil and gas. For example, when using new technologies result in discovering new reserves, the fluctuation of prices forces government to control and restrict the access to the resource information. As prices rise the development of those resources that once had been realized noneconomic may become profitable.

2.11.2. Oil and gas industry activities

Three important terms have been defined for every oil and gas industry activities. These terms that existed before appearing the value chain concept in the 1980s are as follows:

1. Upstream (close to raw materials and basic inputs)
2. Midstream
3. Downstream (close to the customer)

A value chain is a device that helps identify the independent, economically viable segments of an industry. It was developed by Harvard Professor Michael Porter to explain how firms created competitive advantage. His generic value chain included primary and support activities. Primary activities included: inbound logistics, operations (production), outbound logistics, marketing and sales (demand), and services (maintenance). Support activities included: administrative infrastructure management, human resource management, technology (R&D), and procurement. The extension of the firm value chain of the industry is logically consistent, especially in the oil and gas industry where the International Oil Companies (IOC) compete across the upstream, midstream, downstream, and perhaps petrochemicals. The term IOC is usually used in reference to large oil and gas companies such as BP, Chevron, ConocoPhillips, ExxonMobil, Shell, and Total and could also include smaller firms such as Eni and Marathon (Inkpen & Moffett, 2011). Figure 2-24 illustrates a global oil and gas value chain.

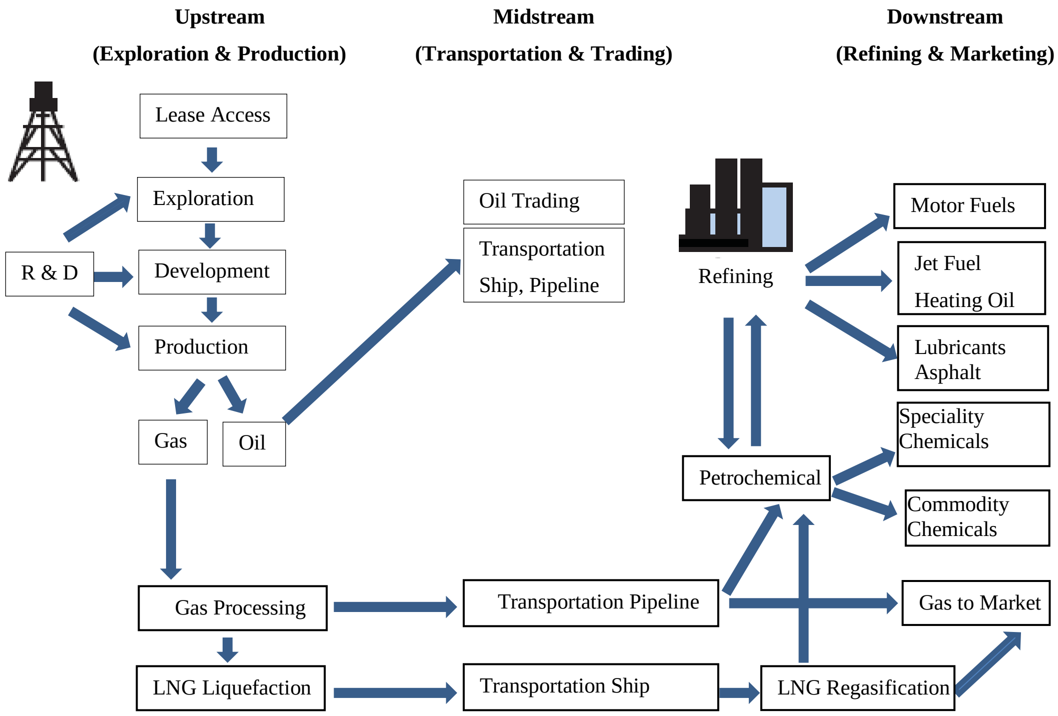


Figure 2-24: Global oil and gas value chain (Inkpen & Moffett, 2011)

In the following sections the major activities of each oil and gas industry terms and the related projects of each term are discussed.

2.11.2.1. Upstream

this term includes the following main activities (Inkpen & Moffett, 2011):

1. Exploration: it is the starting point of the industry. Oil and gas are discovered during exploration. The exploratory drilling fulfils the following tasks (Badiru & Osisanya, 2016):

   - Establishes that hydrocarbons exist
   - Determines the quality; oil and gas ratio
   - Establishes the extent of the reservoir
   - Conducts an economic value of the resource

2. Development: this term is discovery requirement. In this part a development plan is designed that determines the way reservoir should be developed for maximum recovery. Development creates a producing asset.
3. Production: this term is the long term process of drilling and extracting oil and gas. The oil and gas production is involved in following tasks:

   - Designing platform (Substructure, top side facilities)

- Fabrication
- Installation
- Drilling
- Production (separate oil, gas, and water)

2.11.2.2. Midstream

This term the crude oil and natural gas are stored, traded and transported. It includes the following main activities (Inkpen & Moffett, 2011):

1. Trading: The process of selling the produced oil and gas is called trading.
2. Transportation: Crude oil has a low price so the producers need to transport their products to the refineries and refined it into products like gasoline and diesel. Transportation is the process of movement of oil and Liquefied Natural Gas (LNG) from the wellhead to a refinery or market via pipelines, tank trucks, railroads, barges and ships. The transportation of liquid such oil is easy. This is one of the advantages that make oil one of the main sources of energy in the world. Around the world pipelines transport oil and LNG from very far locations to markets. However, their construction and management is full of geopolitical scheming and takes many years to negotiate and build. Terroristic attacks, theft, political conflicts between countries and other environmental and safety issues are threatening risks of conveying oil and gas via pipelines. On the other hand, in recent years, new technologies in shipbuilding and navigation systems have allowed ships to become larger, faster and safer. This issue has reduced the fragment and disorganization of the shipping industry and has increased the importance of this industry in oil and gas transportation.

2.11.2.3. Downstream

This term includes two main parts:

1. Refining: the refining of oil and gas is the industrial process of purification that produces a variety of products from crude oil and natural gas such as gasoline, petroleum naphtha, diesel fuel, jet fuel, heating oil, asphalt base, lubricating oil, kerosene, liquefied petroleum gas and petrochemical products (Gary, Handwerk, & Kaiser, 2007; Leffler, 1985). Safety, environmental issues and corrosion of metallic components throughout refining are the major concerns of this process.
2. Marketing: many players involved in the market of oil and gas. Refineries, speculators, commodities exchanges, shipping companies, IOCs, NOCs, independents, and OPEC are some major players of this industry. The daily price of crude oil is reported frequently every day in the news as the weather report and activities related to market-

making in oil and gas business are one of the most important news parts of front pages (Inkpen & Moffett, 2011).

An alternative definition of the *project* can be obtained by combining the various presented definitions as follows: "*A project is a plan or program performed by the people with assigned resources to achieve an objective within a finite duration*" (Badiru & Osisanya, 2016).

2.11.3. Oil & gas projects' challenges

Most of large oil & gas projects are kind of multinational projects that face with several challenges such as: dependable power supply, reliable procurement process, efficient communication systems, reliable support of government, consistent access to modern technology, continuous industrial climate, reliable risk reduction infrastructure, proper supply of skilled human force, systematic focus on work quality, hassle-free bureaucratic processes, global awareness, comprehensible safety and security system, stable law and order, uniform concentration on customer satisfaction and trustworthy labour relations. Evaluating and resolving concerns about these challenges will contribute significantly to the success of any large project. Oil and gas projects are an integrated collection of interrelated activities, technology, resources, people and work processes that pursue a common goal which can be generating a physical product, providing a particular service or achieving a desired result. The recent description gives a systems view to any oil and gas project thus, a systems project management should be applied to the projects in this industry that through a systems approach to manage and allocate time and resources to achieve enterprise-wide goals efficiently by considering all global ramifications. Figure 2-25 illustrates the world systems view of the various parameters that affect the oil and gas industry (Badiru & Osisanya, 2016). The world systems view is one of the fundamental guidelines for identifying the risks in oil & gas project area.

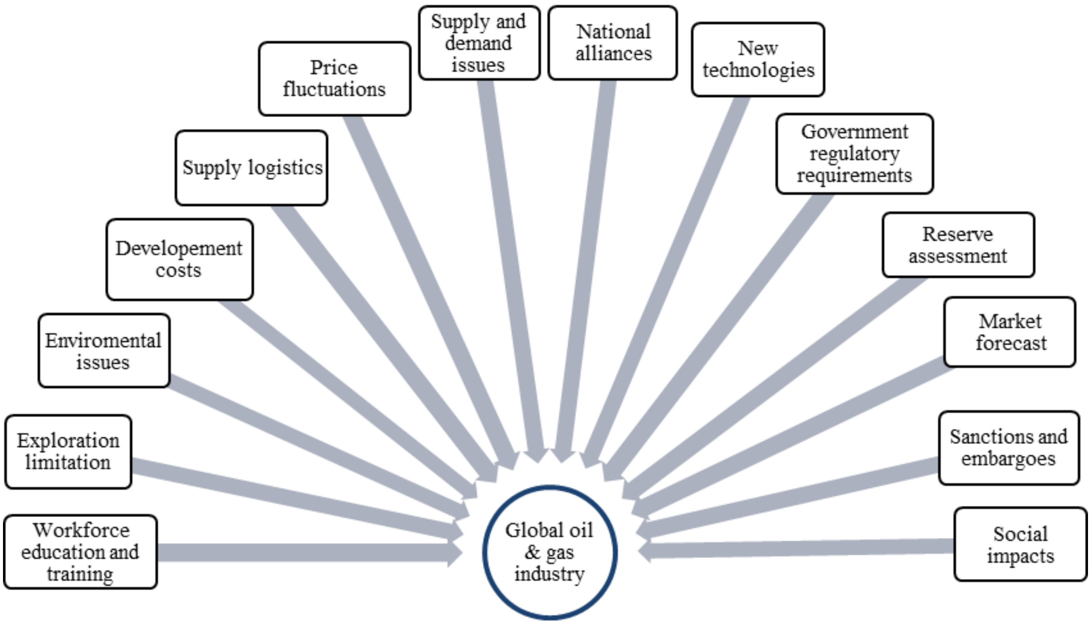


Figure 2-25: World systems view of the oil and gas industry

Because of recent rapid developments in other sources of energies like solar, wind, nuclear, biofuels and also in new technologies of oil and gas, the strategic project management practices have been unavoidable. Huge size, enormous investment, massive interfaces and complex engineering endeavours are characters of projects in the oil and gas industry. These factors make the project management process very sensitive and important. In oil and gas projects a special attention should be paid to project planning, organization, control and risks.

Since there is no risk free activity in oil and gas industry, risk management as a core component of project management portfolio has found a significant importance in every project and activity related to this industry. The Latin statement "Spera optimum para pessimum" which means "Hope for the best, prepare for the worst" can provide a proper ideology for approaching oil and gas projects as there are many unpredictable losses and achievements in this area. For example, one day, Exxon Mobil, the American multinational oil & gas Corporation, is admired as the leader of top 500 companies of Fortune in 2012 first quarter income (Fortune, 2011). The next day, when the Mexican Oil Company, Petróleos, decides to conduct a project to drill at extraordinary depths in the Gulf of Mexico faces widespread opposition (Businessweek, 2012)or in another instance British Petroleum (BP) is blamed for the actions taken in the initial post spill days following the Gulf of Mexico oil spill accident, which occurred in April 2010 (BBC, 2012). All the mixed impressions, emotions, and reactions that result affect the management of oil and gas projects directly.

Risk management policies on oil and gas try to mitigate the risks but not to eliminate. In this way the close cooperation of government regulators with producers and operators for monitoring the data and operations can reduce a big fraction of the potential risks, including accidents due to human errors, incompetence, negligence, and so on. Part of the potential threat to oil and gas projects are due to wrong estimations and judgment about risks and contingencies. Reducing these errors by using fuzzy logic is one of the main objectives that is conducted in this study.

2.12. Risk management of oil and gas projects

Oil and gas projects are considered as infrastructure projects in every country. These projects are very complex and exposed to various risks in all the phases of the project life cycle from the conceptual design phase to the operational phase. Incorporation of risk management from beginning to end of the project life cycle is an essential and inseparable part of effective project management in the oil and gas industry that can be implemented by investigating and identifying the main sources of risks associated with each activity of the project. As mentioned in previous sections these risks need to be measured in terms of likelihood and impact on project objectives. There are various classifications and categorizations for risks regarding to the different activities of the oil and gas industry. In coming parts of this script several classifications and risks extracted from studies done in this area are presented and finally a comprehensive set of risk classifications and factors is presented.

2.12.1. Infrastructure projects' risks

According to ((EPAC), 1995; (OECD), 1991) infrastructure projects can be divided into two main categories: economic infrastructure projects and social infrastructure projects. Most of oil and gas infrastructure projects can be categorized as economic infrastructures beside the projects like power plants that use nuclear, solar, wind, wave and hydroelectric energy, bridges, dams, roads, telecommunication networks, etc. Social infrastructure includes projects like: health, education, tourism and recreational facilities, etc. Nevertheless, all the infrastructure projects have several common characteristics.

Chapman and Ward (C. Chapman & Ward, 2003), Kerzner (Kerzner, 2013) and Thobani (Thobani, 1998) believed that there are nine categories of risks that threaten any infrastructure project that include: technical, construction, operating, revenue, financial, force majeure, regulatory/political, environmental and project default. While Baloi and Price (Baloi & Price, 2003) suggest categorizing risks based on following six characteristics:

1. Dynamic or static
2. Corporate or individual
3. Internal or external
4. Positive or negative
5. Acceptable or unacceptable
6. Insurable or non-insurable

Merna and smith have considered two basic classifications for infrastructure project risks: '*global'* and '*elemental'*. The *global* category includes political which are typically allocated through the project agreement whereas *elemental* risks are normally associated with components of the project like finance, revenue generation, construction and operation (Merna & Smith, 1996).

Miller and Lessard categorized risks into three categories (Miller, Lessard, Michaud, & Floricel, 2001):

- Market-related: The risks which come from markets for revenues and financial markets.
- Completion: risks associated with technical designs, applied technologies, construction cost and time overruns and problems during operation.
- Institutional risks: The risks come from legislations and regulations, struggle with environmental and local groups and argue with the government about revision in contracts' terms and conditions.

Khodeir and Mohamed conducted a research through a questionnaire to identify the latest major risks in construction projects in Egypt (Khodeir & Mohamed, 2015). They analysed both the probability and consequence of sixty-three (63) recognized risks on construction projects' cost, time and quality to detect the top seven key risks. The top ranked risks were: currency price changes, new tax rates, lack of fuel, unsecured roads, official changes, workers' strikes and fire risk.

Martin Loosemore discussed the risk allocation in the private provision of public infrastructure and complexity, fuzziness and consequences of decisions that distribute the risks between private and public sections (Ng & Loosemore, 2007). He chose the 920$ million New Southern Railway project in Sydney, Australia as his case study and provided a risk matrix for this purpose based on Grimsey and Lewis's model (D. Grimsey & Lewis, 2007) that the source of the risks and the responsible section or organization for taking the risks, had been determined. Part of this table corresponding to *construction* risks has been shown in Table 2-9. *Site risks, technical risks, operating risks, revenue risks, financial risks, force majeure risk, regulatory/political risks, project default risks* and *asset* risks were other categories of risk types.

Table 2-9: Construction risk matrix for public/private sector of infrastructure investments

Type of risk: Construction risks	**Source of risk**	**Risk taken by**
Cost overrun	Inefficient work practices and wastage of materials	Construction contractor
	Changes in law, delays in approval	Project company/investors
Delay in completion	Lack of coordination of contractors Failure to obtain standard planning approvals	Construction contractor
	Insured force majeure events	Insurer
Failure to meet performance criteria	Quality shortfall/defects in construction/commissioning tests failure	Construction contractor/project Company

Charoenngam and Yeh classified the risks involved in hydropower construction projects which are kind of infrastructure projects into six major categories of: *Construction related risk*, *Physical risk*, *Contractual and legal risk Performance related risk*, *Financial and economic risk* and *Political and societal* risk (Charoenngam & Yeh, 1999). They identified and prioritized the typical construction risks as construction delay, changes in the work, availability of labour, material and equipment, delayed site access, damage to persons or property, late drawings and instruction, defective design, cost of tests and samples, actual quantities of work.

Wang and Tiong performed an extensive study and preliminary discussion with construction contractors to identify the major risk factors that can affect a BOT power plant project. They categorized the risks to seven major categories of: *political, operating, market and revenue, finance, legal, competition and construction completion* risks that each category included detailed risk factors. For the construction completion risks category twelve risk factors were identified as follows (S. Wang & Tiong, 2000):

1. Land acquisition and compensation
2. Restriction on import equipment/materials
3. Cost overruns
4. increases in financing costs
5. Time and quality risk
6. Contractor default
7. Default by Concession Company
8. Time, cost and scope of identified but related work and variations
9. Environmental damage-subsisting

10. Environmental damage-ongoing
11. Protection of geological and historical objects
12. Force majeure

Leung and Chuah developed a knowledge-based system for identifying potential construction project risks through obtaining the knowledge from previous experience. They divided the risk handling method into two classifications: simple risk adjustment techniques and probabilistic risk analysis methods. While the simple risk adjustment methods rely on intuitive and subjective adjustments, probabilistic methods focus on comprehensive awareness of the risks associated with critical parameters and their likelihood. They define the project risk as an unwanted incident that affects project completion within a planned schedule and estimated budget, with required quality and performance and divide it into two classifications: *Internal* risks and *external* risks which is illustrated by Figure 2-26 (Leung, Tummala, & Chuah, 1998).

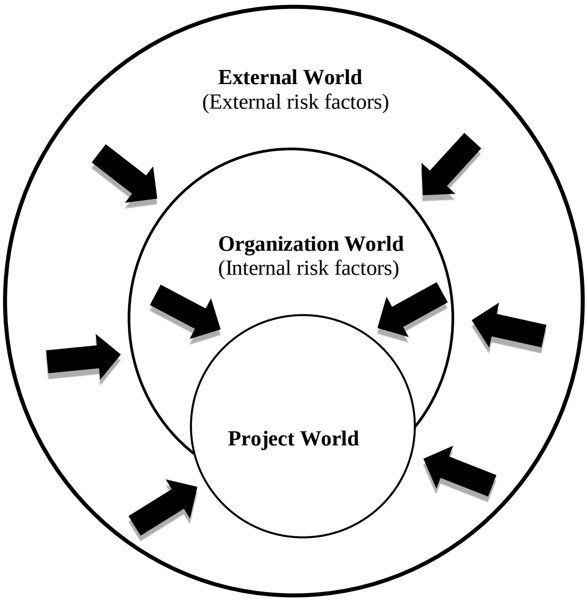


Figure 2-26: The general categories of risks

Figure 2-26 shows how the company strategic plan and management can be affected by variations in the external environment and correspondingly, variations in organization plans can lead to changes in the project area. This picture shows how some major external risk factors such as global stock market crash, changes in exchange rates and inflation are distinct from changes in project scope, technical descriptions, eliminations etc., which can be identified as internal risk factors. Based on this explanation the authors used Figure 2-27 to show the source of external and internal risk factors.

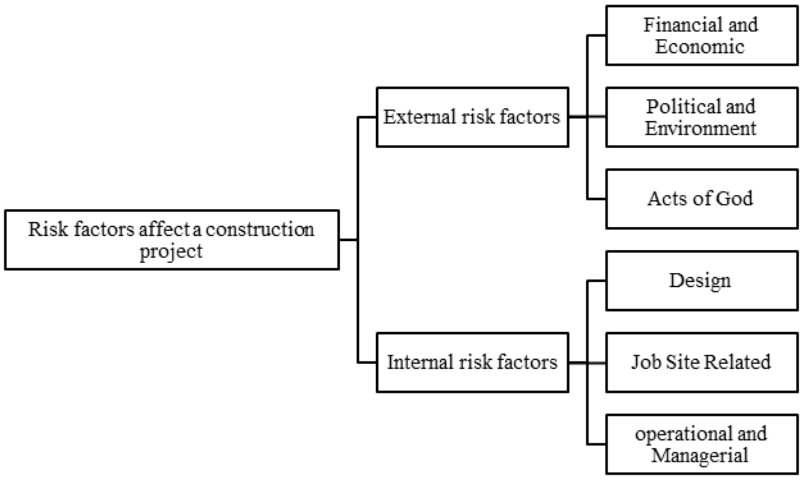


Figure 2-27: The sources of external and internal risk factors

Then in Table 2-10 they presented some of the potential risks of each main risk factor groups collected from previous infrastructure and construction projects.

Table 2-10: The potential risk elements of external and internal risk factors

External risk factors		Internal risk factors	
Financial and economic	▪ Inflation rate fluctuation ▪ Exchange rate fluctuation ▪ Changes in consultant cost ▪ Changes in tender's price ▪ Financial default of subcontractor	Design	▪ Incomplete design scope ▪ Design changes ▪ Errors and omissions ▪ Inadequate specification ▪ Defective design ▪ Lack of standards
Political and environmental	▪ Changes in law ▪ Permits and government approval ▪ Changes in pollution rule ▪ Public consultation	Job-site-related	▪ Different site conditions ▪ Access denied by villagers ▪ Defective work ▪ Bad road condition ▪ Labour dispute and strike ▪ Shortage of labour ▪ Poor Geotechnical condition
Acts of God	▪ Bad weather ▪ Wind damage ▪ Flood ▪ Landslide ▪ Fire	Operational and managerial	▪ Equipment damage ▪ System outages ▪ Lack of techniques ▪ Lack of examinations ▪ Insufficient precaution ▪ Lack of coordination ▪ Lack of communication ▪ Misguidance of client ▪ Poor management control ▪ Shortage of resources ▪ Poor performance of contractors

2.12.2. Sources of project uncertainty

There are uncertainties in every project that are sources of projects' risks. Project main objectives such as time, cost, quality and scope are common factors in almost every project. To reach a better identification and classification of the risks involved in oil and gas projects, possible sources of uncertainty that is common in most of the projects must be identified. Badiru and Osisanya have pointed to some of these sources as follows (Badiru & Osisanya, 2016):

- Poor estimates of time and cost
- Lack of a clear specification of project requirements
- Ambiguous guidelines about managerial processes
- Lack of knowledge of the number and types of factors influencing the project
- Lack of knowledge about the interdependencies among the activities in the project
- Unknown events within the project environment
- Variability in project design and logistics
- Project scope changes
- Varying the direction of objectives and priorities

Figure 2-28 shows a fishbone diagram that was used to illustrate some of the various pathways to project risks that can lead to project failure. In this diagram uncertainty in one factor at one level can affect the prospect of another parameter at a different level.

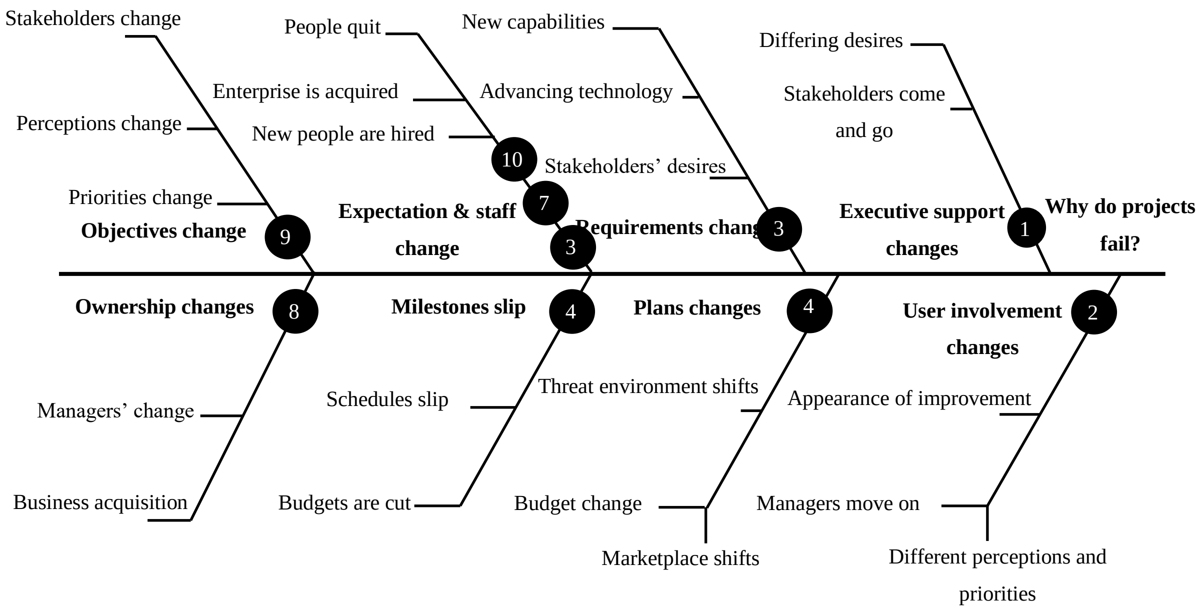


Figure 2-28: Fishbone diagram of risk events leading to project failure

They have provided a master list containing factors that t risk management needs to deal with. These factors are as follows:

- New technology
- Functional complexity
- New versus replacement
- Leverage on company
- Intensity of business need
- Interface existing applications
- Dependability on other projects
- Quality of information available
- Conversion difficulty
- End-date dictate
- Conflict resolution mechanism
- Continued budget availability
- Change budget accepted
- Change process accepted
- Level of client commitment
- Client attitude toward IS
- Readiness for takeover
- Client design participation

• Client information systems (IS) knowledge	• Project standards used	• Client participation in acceptance test
• Commitment of team	• Large/small project	• Client proximity to IS
• Team morale	• Size of team	• Acceptance process
• Applications knowledge	• Geographic dispersion	• Vulnerability to change
• Staff availability	• Reliability of personnel	• Stability of business area
• Technical skills availability	• Availability of support organization	• Availability of champion
• Staff conflicts	• Tight time frame	• Turnover of key people
• Organizational impact		

A possible risk response planning can follow the following options:

- Accept: when the cost of fixing the risk is more expensive than the expectations the best response can be 'doing nothing'.
- Avoid: a part of the project that is associated with the risk is spared.
- Contingency planning: frame plans to deal with risk consequence and monitor risk regularly (identify trigger points).
- Mitigate: Reduce the likelihood of occurrence, the negative consequence, or both.
- Transfer: Outsource

2.12.3. Risk management practices in oil and gas

Andersen and Mostue argued the impact of conventional risk analysis and risk management methods in the Norwegian oil and gas industry. They also discussed the existing challenges in an Integrated Operation (IO) context from the viewpoints of the main players in the Norwegian oil and gas industry. Their empirical findings were based on three separate explorative studies: investigating the risk analysis and risk management approaches in different business sectors, qualitative interviews about the production of knowledge for risky decisions in an operating company and qualitative interviews of experts and professionals involved in risk analysis in different companies to explore their use of risk analysis techniques. Their studies resulted in four main outcomes: Integrated Operations (IO) will improve the risk management process, seeking for other inputs to risk analyses is essential for IO, proper approaches should be established to human and organizational issues and resilience-based approaches should be developed for operational risk assessment. Based on their findings, technical, human, operational and organizational factors are the major items that affect the accident sequence (Andersen & Mostue, 2012).

Stejkal conducted a quantitative environmental risk assessment approach for oil and gas projects in shallow water marine areas in Western Australia. He utilized computer modelling, environment mapping, research and monitoring to evaluate the risks that affect the coastal and marine environment and deal with increasing public concern about the protection of these areas that has become one of the main issues of oil and gas projects in recent years to obtain government approval (Stejskal, 2000).

Risk assessment in the offshore industry in relation to people safety aspects and environmental and property issues was discussed in a paper by Brandsaeter (Brandsæter, 2002). He developed an offshore quantitative risk assessment based on common impact and cooperation between UK regulatory authorities and Norwegian sectors of the North Sea and the oil companies involved in that area projects. He mentions that the main focus of offshore risk management is on:

1. Providing safety for the crew and the installation
2. Prevention of environmental damage
3. Having regular productivity

Like many other researchers, Brandsaeter refers to hazard identification process as the most important step in QRA and believes in this fact that for evaluating and then mitigating a hazard it must be identified first. He emphasizes that retention of knowledge and capability of retrieving information and records from previous experience plays an important role in this process. The hazard identification process used in his study has been illustrated in Figure 2-29.

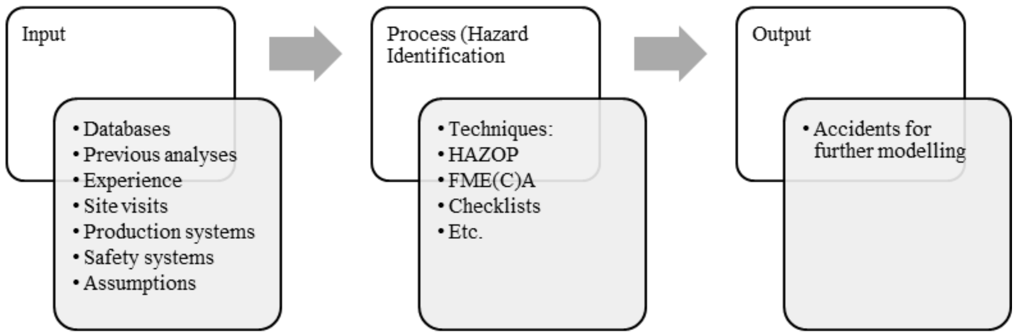


Figure 2-29: Hazard Identification Process

Considering the main hazard sources like extreme environmental conditions, ship traffic, failure of structures, releasing flammable or toxic materials, etc. He provides a checklist of potential undesired outcomes such as blowouts, process leaks, non-process fires, marine collisions, diving accidents, etc.

In this study the hazards with very small likelihood or low consequences or those that were out of the study scope were rejected. The uncertainties that could be expressed by distributions in the input could be estimated in the output by using some uncertainty analysis techniques like Monte Carlo simulation. In the risk evaluation step, the expected frequency of an accident (e.g. the number of blowouts in drilling operation in a year) or the probability of a hazard was used for expressing the likelihood of an effect. The author determines that the risk acceptance criteria must be defined consequently before the risk analysis process begins and it may be quantitative or qualitative. However, the quantitative risks are more preferable to be compared with quantitative criteria. For qualitative risk acceptance criteria, a suitable interpretation should be agreed before initiation of a quantitative risk assessment. Taking into account the public perception of risks in four states of *Low, Medium, High* and *Not sure* is the last section of this paper which has been specified through eight criteria as follows:

1. Probabilities of occurrence
2. Extents of potential damage
3. Incertitude of risk estimate (related to statistical uncertainty, fuzzy uncertainty and ignorance)
4. Ubiquity of potential damage (describes the geographical dispersion of potential damages)
5. Persistency of potential damage (describes the temporal extension of potential damages)
6. Reversibility of post-damage (defines the restore possibility of the current situation to the situation before the damage occurred)
7. Delay between initial event and impact
8. Potential of mobilisation (defines as cultural or social interests that generates social conflicts, violation and psychological reactions by individuals or groups who are exposed to the risk affects.

2.12.4. Identification and classification of the risk factors that affect oil and gas industry and projects

There are numerous studies related to the risks involved in oil and gas industry and projects conducted by researchers and experts around the world. Identifying the risk factors of oil and gas projects was the most time consuming step of this study. To achieve this purpose, the most relevant and the most reputed papers, research studies, articles, books and journals in this area were studied. Then and all the risk factors and risk categories presented in the reviewed sources were extracted. In the next step by combing, eliminating the duplicate factors and summarizing them a final list of classification and risk factors was prepared. This stage took a lot of time and effort and the final list that is presented at the end of this section is the conclusion of hundred pages of preliminary research and investigation that in the coming paragraphs some of the most relevant ones of them are pointed.

BDO USA, LLP (Est. 1910) is a professional services firm with more than 100 years of experience in providing assurance, tax, financial advisory and consulting services to emerging and established businesses in both the traditional and alternative energy industries through a global network of 1,082 offices in 119 countries. In 2011 BDO broke down the top 20 risk factors affecting the world's top 100 oil & gas companies. Each risk factor in the revealed list had a percentage that indicated the amount of companies that cited that risk factor as a serious risk. These top 20 risk factors are as follows (EnergyDigital, 2011):

1. Volatile oil and gas prices-(100%): actualization of more serious tax and environmental legislations and intensification of Middle East conflicts have increased the oil prices and have made current regulatory battles and supply problems in the oil and gas industry more seriously. It is expected that these factor remain top risks and main concerns of oil and gas executives at least for the close future.
2. Regulatory and legislative changes and increased cost of compliance-(100%): tighter safety and environmental guidelines, especially after the BP Deepwater Horizon oil spill incident in the Gulf of Mexico require heavy investment on the industry’s part.
3. Inability to expand reserves or find replacement reserves-(98%)
4. Operational hazards, including blowouts, spills and personal injury-(97%)
5. Natural disasters and extreme weather conditions-(96%): the hazard of hurricanes and tropical storms become a big issue, especially when the operation heads further into deep water areas.
6. Inaccurate reserve estimates-(96%): this risk factor occurs when mid-market Exploration and Production (E&P) companies subcontract the reserve estimates out to independent reserve engineers which may lead to many inaccurate estimations and surprises during the exploration and production phases.
7. Inadequate liquidity or access to capital, indebtedness-(95%): this factor is associated with the financial stability of partners, customers, vendors and suppliers.
8. Environmental restrictions and regulations-(94%): oil and gas industry faces big problems due to the regulations and bills about greenhouse gas emissions and climate change along with concern over hydraulic fracturing.
9. U.S. general economic concerns-(91%)
10. General industry competition-(87%)
11. Inadequate or unavailable insurance coverage-(87%)
12. Reliance upon third party transportation and processing facilities-(83%)
13. Ability to attract or retain key personnel-(78%)
14. Decrease in demand for oil or natural gas-(76%)
15. Credit or financial risk of partners, customers, vendors or suppliers-(75%)
16. Failure to properly execute corporate strategy-(73%)
17. Competition from alternative energy sources-(72%)
18. Shortage of rigs, equipment and personnel-(72%)
19. Impact of climate change and greenhouse gas legislation-(69%)

20. Increased operating costs-(67%)

Once again in 2012, the Energy Digital magazine published the top ten risk factors of oil and gas industry cited by the largest United States Exploration and Production (U.S. E&P) companies according to the 2012 annual report conducted by BDO USA, LLP. This list ranked the risks as the following (EnergyDigital, 2012):

1. Regulatory and legislative changes and increased cost of compliance
2. Volatile oil and gas prices
3. Inability to expand reserves or find replacement reserves
4. Operational hazards, including blowouts, spills and personal injury
5. Natural disasters and extreme weather conditions
6. Inaccurate reserve estimates
7. Inadequate liquidity or access to capital, indebtedness
8. Environmental or health restrictions and regulations
9. General national or global economic concerns
10. General industry competition

Oil and gas projects are kind of infrastructure projects. Investigating the risks that affect infrastructure projects through the studies done in this area (C. Chapman & Ward, 2003; De Marco, Mangano, & Zou, 2012; Darrin Grimsey & Lewis, 2002; Kerzner, 2013; Smith & Walter, 1990; Thobani, 1998) resulted in identifying at least eleven major risk categories. These categories are:

1. Political or regulatory risks: risks due to legal changes and unsupportive government policies
2. Environmental risks: risks due to unfortunate environmental impacts and hazards
3. Financial risks: risks due to the inadequate hedging of revenue streams and financing costs
4. Economic risks
5. Technical risks: risks due to design and engineering failures
6. Construction: risks due to delay in completion of construction, faulty construction methods or cost increase
7. Operating risks: risks due to higher maintenance and operating costs
8. Revenue risks: risks due to transportation problems, failure to extract resources or the fluctuation of prices and demands for products and services that lead to revenue deficiency.

9. Force majeure risks: risks due to disasters or catastrophes like war happening. This category is usually known as acts of God.
10. Supply risks
11. Project default risks: risks due to failure of the project from a combination of any of the above.

Nguyen Van Thuyet et al. conducted a research to identify the major risk factors of oil and gas construction projects in Vietnam (Van Thuyet, Ogunlana, & Dey, 2007). They carried out this study via questionnaire survey by interviewing the project executives of PetroVietnam and statistical analysis of the collected responses. In their paper they considered two classifications of project risks: *internal* risks and *external* risks. Internal risks include *financial, design, contractual, construction, personal, involved parties* and *operational risks* and external risks include *economic, social, political, legal, public, logistical* and *environmental* risks. Then by focusing on oil and gas construction projects in Vietnam they prepared a list of fifty-nine (59) risk factors that affect oil and gas construction projects from middle to downstream and then exposed them to the experts' judgment from two aspects of: the frequency of occurrence and the degree of impact. They sorted 59 risks based on calculated risk index score and classified the identified risks in four groups of ten major risks and another group of nineteen (19) remaining risks.

Based on their findings, top ten identified risks were bureaucratic government system and long project approval procedures, poor design, the incompetence of the project team, inadequate tendering practices, and late internal approval processes, inadequate project organizational structure, improper project feasibility study, inefficient and poor performance of constructors, improper project planning and budgeting and design changes. They pointed the executives suggested strategies to mitigate the identified risks as: reforming the government system, effective partnership with foreign collaborators, training project executives, implementing contractor evaluation using multiple criteria decision-making technique, and enhancing authorities of project people.

Srivastavaa and Gupta developed a Security Risk Factor Table (SRFT) and a Stepped Matrix Procedure (SMP) to assess the security risk of oil and gas projects. While the security risk factors deal with the effects of individual threats the stepped matrix procedure deals with the cascading effects which a single low probability event can cause (Srivastava & Gupta, 2010).

Skogdalen and Vinne conducted a quantitative risk analysis study for offshore oil and gas drilling projects. They used Deepwater Horizon as the case study. They determined four major Risk Influencing Factors (RIF) including: environmental-surroundings, environmental-geological risk, facility-technological risk and operational risks. Each of these main factors included several sub factors (Skogdalen & Vinnem, 2012).

De Marco et al. in a study to find out the influence of environmental risk on the financial structure of Build-Operate-Transfer (BOT) oil and gas projects used a risk breakdown structure as shown in Figure 2-30 (De Marco & Karsybayeva, 2013).

Vinnema et al. investigated the major hazard risk factors that threaten the personnel who work on offshore oil and gas platforms during the installation phase. They presented a general outline of indicators to illustrate these risk components (Vinnem, Aven, Husebø, Seljelid, & Tveit, 2006).

Flanagan and Norman (Flanagan & Norman, 1993)and Thompson & Perry (Thompson & Perry, 1992) classified infrastructure project risks to: technical, construction, legal, natural, logistic, social, economic, financial, commercial and political risks.

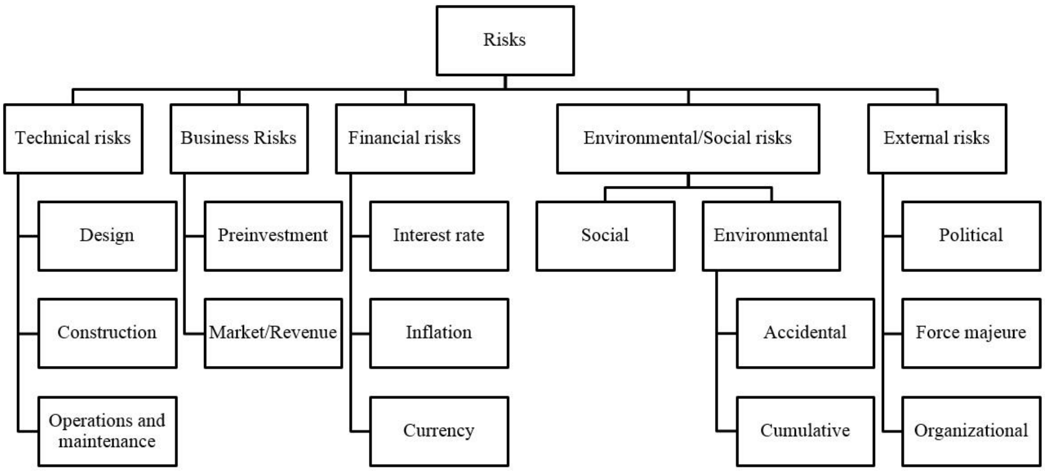


Figure 2-30: Proposed risk breakdown structure for an oil and gas BOT project

In a review paper by Mearns and Flin the top hazards and risks that threat the offshore oil and gas industry personnel, were discussed. They pointed that the offshore environment is a combination of major industrial threats and those dangers which are specific to the oil and gas extraction industry and the marine environment. These risks include: fire, explosion, blowout, falls, accidents associated with drilling operations and diving and hazards to the structural integrity of the structure (Mearns & Flin, 1995).

2.13. Construction projects

In Oxford dictionary '*Construction*' has been defined as the action of building something, typically a large structure or infrastructure (Dictionaries, 2016). Construction differs from manufacturing in that manufacturing typically involves mass production of similar items without a designated purchaser, while construction typically takes place on location for a known client (Halpin, 2010).

2.13.1. Project definition

There are several definitions for the word '*Project'*. PMI defines '*Project'* according to its special characteristics: "*A project is a temporary endeavour undertaken to create a unique product or service*"(PMI, 2013). There are some distinctive terms in this definition. "Temporary" reflects this sense that every project has a definite starting point and a definite ending point. The meaning of '*Unique'* is that the features of product or service are distinguished from all similar products or services. According to this definition, every project has a limited duration, is not a continuing endeavour and it stops when achieves its stated goals. Some common characteristics of projects are:

- Projects are performed by people
- Projects are constrained by limited resources
- Projects are planned, executed, and controlled

Pyzdek in the book '*The Complete Guide to Six Sigma'* (Pyzdek & Keller, 2014) defines '*Project'* as:

- A plan or proposal; a scheme
- An undertaking requiring concrete effort

He defines '*Plan'* with three characteristics:

1. A scheme, program, or method worked beforehand for the accomplishment of an objective; a plan of attack
2. A proposed or tentative projective or course of action
3. A systematic arrangement of important parts

Kerzner considers a project as a set of activities and tasks that (Kerzner, 2013):

- Have a specified objective to be completed within certain specifications
- Have defined start and end dates
- Have funding limits (if applicable)
- Consume human and nonhuman resources (i.e., money, people, and equipment)
- Are multi-functional (i.e., cut across several lines)

2.13.2. Construction project organization

Every construction project has its own unique working environment and culture compared to most working conditions. A normal construction project consists of a group of people, typically with various skills and knowledge from several organizations that are allocated to a project to construct a facility. Many various disciplines are involved in a construction project. There are three main groups in a traditional construction project organization that has been illustrated in Figure 2-31. These groups are as follows:

1. Owner: owner can be a person or an organization that starts or sanctions a project and outlines the requirements of the facility and is responsible for providing the financial resources for creation of the facility. In a traditional construction project organization, the owner heads the team by appointing a project manager for the management of the project as a whole. The project manager tries to convey this concept to the project team that making a long-term relationship is more important in career advancement than accomplishing short-term tasks.
2. Designers (A&E): One or more architects or engineers and consultants from this group. They are appointed by the owner to convert owner’s conceptions and demands into a specific facility with detailed directions through providing drawings and specifications following economic objectives. In special cases in addition to the design of the projects, designers are also responsible for supervision of the projects.
3. Contractors: This group is a construction corporation that is appointed by the owner to build and complete the specific facility by providing skilled work force, required staff, materials, tools, equipment, technics and technologies to the satisfaction of the owner in compliance with the agreement or contract documents. The contractor is responsible for executing the project tasks and achieving the owner’s targets.

In some special cases a construction manager which is a professional firm trained in management of construction procedure is hired by the owner to assist the owner in developing bid documents, and project supervision and coordination. In the construction management type of construction project, consultants are responsible for preparing the complete design drawings and contract documents, then the project is put for competitive bid and the contract is granted to the winner bidder. In the next step the construction manager is hired by the owner to supervise and coordinate the construction project.

American Society of Civil Engineers (ASCE) considers two types of classifications of construction managers as follows (A.S.C.E, 2012):

1. Agency Construction Managers (ACM): in this type of management, all the policies, procedures and practices of the owner’s organization are managed by an ACM.
2. Construction Managers-at-risk (CM-at-risk): the contract of this type of construction managers with the owner is in two stages. In the first stage CM-at-risk act as consultants

or design professionals. In the second stage and after the design is completed, they are involved in the completion of the construction work.

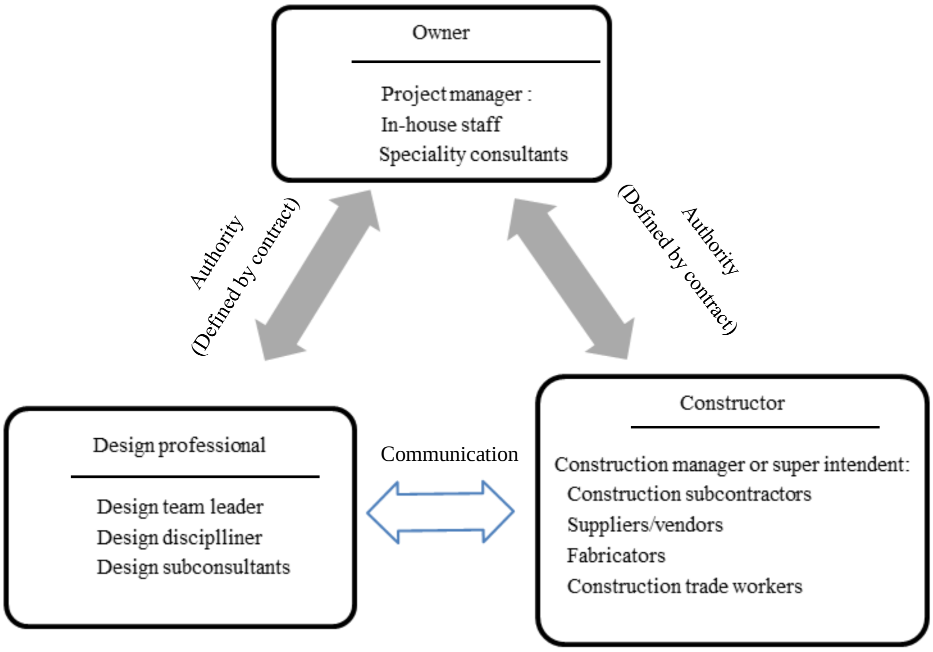


Figure 2-31: Traditional construction project organization (A.S.C.E, 2012)

2.13.3. Phases of civil construction projects

Civil construction projects and commercial/A&E projects can be classified into four types of construction as follows:

1. Residential construction: single-family homes, multiunit town houses, garden, apartments, high-rise apartments and villas are various types of residential construction.
2. Building construction (institutional and commercial): This structure of this category range from small retail stores to urban redevelopment complexes, from grade schools to new universities, hospitals, commercial office towers, theatres, government buildings, recreation centres, warehouses, and neighbourhood centres.
3. Industrial construction: petroleum refineries, petroleum plants, power plants, heavy manufacturing plants, and other facilities essential for the utilities and basic industries place in this classification.
4. Heavy engineering construction: Heavy engineering construction, includes dams, tunnels, bridges, railways, airports, highways and urban rapid transit system, ports and harbours, water treatment and distribution, sewage and storm water collection, treatment and disposal system, power lines, and communication network.

Shtub, Bard, and Globerson have considered five phases for any project as shown in Figure 2-32 (Shtub et al., 1994) while the PMBOK guide knows four stages for any representative construction project life cycle (PMI, 2013). These phases have been illustrated in Figure 2-33. The number of phases depends on the project complexity, degree and the duration of each stage varies from project to project. Nevertheless, evolving a comprehensive life cycle for construction projects, which includes five of the most common phases, is possible. These phases are as follows:

1. Conceptual design
2. Preliminary design
3. Detailed design
4. Construction
5. Testing, commissioning, and handover

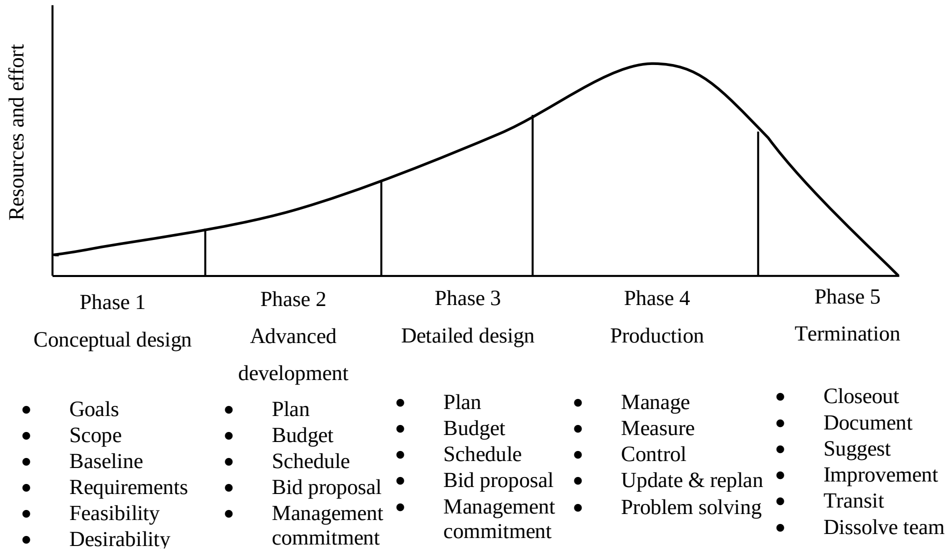


Figure 2-32: Project life cycle from (Shtub, Bard, & Globerson, 1994)

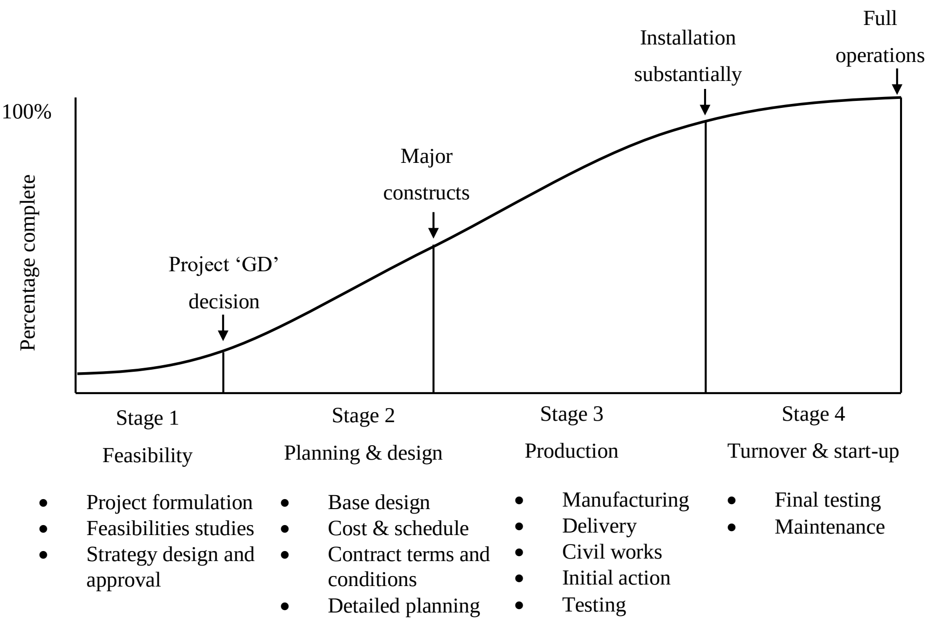


Figure 2-33: Representative construction project life cycle from (PMI, 2013)

Using Work Breakdown Structure (WBS) principle to subdivide each of these phases, results in reaching a level of complexity where each activity can be treated as a single unit that can be managed efficiently. Since WBS provides a systematic and logical breakdown of the construction project stage into its various elements and activities, project manager and its team can handle the planning, budgeting, scheduling and control activities more conveniently. The components/activities of construction project life cycle phases divided on WBS principle have been illustrated in Table 2-11.

Table 2-11: Construction project life cycle

Conceptual design	**Preliminary design**	**Detailed design**	**Construction**	**Testing, Commissioning and Handover**
Identification of need	General scope of work/basic design	Detailed design of the works	Mobilization	Testing
Feasibility	Regulatory approval	Regulatory/authorities' approval	Execution of works	Commissioning
Identification of project team	Budget	Contract documents and specifications	Planning and scheduling	Regulatory/authorities' approval
Identification of alternatives	Schedule	Detailed plan	Management of resources/procurement	As-Built drawings/records
Financial implications/resources	Contract terms and conditions	Budget	Monitoring and control	Technical manuals and documents
Time schedule	Value engineering study	Estimated cash flow	Quality	Training of user's personnel
Development of concept design		Tender/bidding	Inspection	Handover of facility to owner/end user Move-in plan Substantial completion

2.13.4. Oil and gas construction projects

Construction is one of the elemental and inseparable parts of oil and gas industry. There are exclusive aspects of oil and gas business that must be considered from the first stages of office structure construction to the construction of an oil rig platform. The construction project of this industry is very different from that of usual or conventional construction projects or manufacturing. The oil and gas industry epitomize its own exclusive manufacturing and service operations which need a unique construction project management. The focus in oil and gas construction projects is on the accomplishment of the owner's obligations and demands considering the defined scope of work within the accessible funds and the determined schedule.

There are various types of construction projects in oil and gas industry. Basically, they can be categorized into two main groups (Badiru & Osisanya, 2016):

1. Process type projects: this group includes:

- Liquid chemical plants
- Liquid/solid plants
- Solid process plants
- Petrochemical plants
- Petroleum refineries

2. Non-process type projects: this category consist of the following projects:

- Power plants
- Manufacturing plants
- Support facilities
- Miscellaneous (R&D) projects
- Civil construction projects
- Commercial/A&E projects

The existing risks in the oil and gas business affect the arrangement of construction projects and make it unpredictable and risky. Besides the affinity diagrams, flowcharts, Pareto charts and histograms, the management requires several specialized tools to address challenging categories of quality, schedule, and cost. These particular tools are as follows (Badiru & Osisanya, 2016):

- PDCA: Plan, Do, Check, Act
- DMAIC: Define, Measure, Analyse, Improve, Control

- SIPOC: Suppliers, Inputs, Process, Outputs, Customers
- DEJI: Design, Evaluate, Justify, Integrate
- QFD: Quality, Function, Deployment

2.14. Fuzzy risk management

Ross gave details of many methods for assigning fuzzy membership functions or values such as: rank ordering, intuition, inference, neural networks, angular fuzzy sets, genetic algorithms, inductive reasoning, soft partitioning and fuzzy statistics. For example Table 2-12 shows the intuitive method for three types of human judgement that involves linguistic truth values and contextual knowledge about a particular subject (Timothy J Ross, 2009).

Table 2-12: Fuzzy term set definitions

Linguistic variable	Definition
Weak	Less than 40%
Moderate	Between 40% and 60%
Strong	Greater than 60%

Pokoradi mentions that often identifying the probability and the severity of risk factors cannot be done unequivocally and needs to be determined only by using expert's knowledge and experience. In this case using probability and severity categories along with fuzzy logic can be very useful for modelling the inaccuracy and uncertainty of human thinking. Risk can be defined as a logical combination of probability and severity and fuzzy logic can be used for statistical inference of experts' data. He defined different categories of probability and severity that can provide guidance to a broad range of systems and forms a risk assessment matrix by defining four risk rates: Extra High (EH), High (H), Medium (M), and Low (L) as illustrated in Table 2-13 (Pokoradi, 2002).

Table 2-13: Risk assessment matrix due to probability and severity categories

		Probability categories				
		Frequent	Likely	Occasional	Seldom	Unlikely
Severity categories	Catastrophic	EH	EH	H	H	M
	Critical	EH	H	H	M	L
	Moderate	H	M	M	L	L
	Negligible	M	L	L	L	L

2.14.1. Fuzzy risk management of oil and gas projects

In oil and gas industry area Yanga et al. used a hybrid approach using Fuzzy Inference System (FIS) and fuzzy AHP to prioritize the environmental issues in the offshore oil and gas operations. They used this method to deal with vague data involved in multi-attribute decision-making problems and eliminate the limitation of regular FAHP models including: tremendous computations, the obligation to use triangular fuzzy numbers, difficulty of removing or adding criteria and judgment inconsistency because of using fuzzy numbers. A five- level hierarchy structure was developed. The final goal which was the prioritizing of significance of environmental issues was placed on the highest level of the hierarchy. The second level was assigned to major concerns, including three risk factors: risk to marine eco-systems, risk to human health and risk of climate change. The third level and the fourth level correspond to major parameters of environmental risk and sub-parameters of risks respectively, and the lowest level was assigned to environmental issues. To infer the major risk factors they applied the FIS at the lower levels and used the Fuzzy AHP at the higher levels of structure to synthesize the importance scores and finally prioritized the identified environmental issues (Yang, Khan, & Sadiq, 2011).

In a sustainability assessment approach, a fuzzy based bow-tie analysis was utilized by Shahriar et al. for risk analysis of oil and gas pipelines based on three sustainability main factors of social, environmental and economic consequences of gas release from natural gas pipelines. They used a fuzzy approach to deal with the ambiguity of the data involved in the failure of oil & gas pipelines. In their study, they proposed their modified Fault Tree Analysis (FTA) and Event Tree Analysis (ETA) first. Then they used three types of fuzzy based techniques to analyse the risks. The first technique was a fuzzy-based bow-tie analysis to determine the likelihood of each output event. The second fuzzy technique, was using fuzzy synthetic evaluation to determine the multi-dimensional fuzzy consequences. This technique utilizes a linearized weighting procedure for aggregation. The third aspect of using fuzzy logic appeared in creating of a fuzzy rule base for evaluating of the final risk index from fuzzy likelihoods and fuzzy consequences. The required knowledge acquisition to find and develop the relationships between basic risk origins and the impacts of occurrence were performed in four steps: the first step was a pre preliminary analysis for providing a general review of the problem, in the next step an in-depth literature review was performed to determine and categorize the risk items, survey interviews using the questionnaires was the third step. Finally, through solicitations of the opinions of an expert panel or other working professionals the gathered data were discussed and organized. Among various aggregation operators such as minimum, maximum, arithmetic mean, median, quasi-arithmetic means, symmetric sum and t-norm, weighted average method, which is one of the most common was used to provide an agreement among conflicting expert's knowledge (Shahriar, Sadiq, & Tesfamariam, 2012).

Brito and De Almeida employed a multi-attribute utility theory for risk assessment and risk prioritizing of natural gas pipelines which allowed them to incorporate the decision maker's preference and behaviour regarding risk quantitatively. The applied method also took into account the aggregation of multiple objectives like the environmental, human and financial impacts that occur due to an incident in natural gas pipelines. Their proposed model needs an adequate historical data for statistical analyses or a convenient background of the risk assessment team to assess the model components properly so its application is useful for big and leading companies. The outcome of the proposed model is a ranked list of different sections of gas pipelines that allows companies to prioritize the sections for maintenance operation regarding the highest levels of environmental, financial and social consequences of a probable accident (Brito & de Almeida, 2009).

Miri Lavasani et al. used fuzzy risk assessment to evaluate the hazardous risks of offshore oil and gas wells. They conducted their research by proposing a methodology based on three following steps (Lavasani, Yang, Finlay, & Wang, 2011):

- Quantifying each identified Basic Risk Item (BRI) using the Fuzzy Risk Assessment (FRA)
- Evaluating the hierarchy risk structure of oil and gas offshore wells quantitatively by applying a Fuzzy Analytical Hierarchy Process (FAHP) to estimate the weights required for classification of non-proportional risk sources. This step resulted in total estimated risk at the system level.
- Inserting new data and updating the risk estimation by applying Evidential Reasoning (ER).

They truly mentioned in their paper that relying just on classic mathematics during the primary steps or screening phase of decision making is very difficult and ineffective, especially when we are dealing with a complex system involves different risk factors with ambiguous sources. In this case, evaluating the probability and consequences of risks using only the probabilistic theory is not very helpful as many hazardous elements are not expressible in terms of probabilities. For an instance, they mentioned the risk of human-related attacks that are affected by various uncertain parameters such as the accessibility to explosive materials and ability to transporting and implanting them in the place. These factors cannot be represented by a simple probability distribution function. Furthermore, generally there is not sufficient and complete information about the backgrounds of some risk scenarios (e.g. terrorist activity).

Representing the descriptive information through probabilistic variables is limited. Moreover, it may be inevitable to perform a risk assessment based on different hazards which can be in forms of probabilistic data, experts' judgements or linguistic expressions. These characteristics of risk assessment were an encouragement for the authors to develop their proposed fuzzy risk assessment method to deal with insufficiency of traditional risk assessment approaches. However, the proposed methodology followed the previous development of fuzzy aggregate risk assessment, it could update the risk estimation through combining both qualitative and quantitative information. It also could include recent evidence obtained through an Intelligent Decision System (IDS) Evidential Reasoning (ER) incorporating an ER approach. The framework of the proposed methodology by the authors for risk assessment of offshore wells has been shown in Figure 2-38. They considered the risk of failure as the combination of occurrence likelihood and its severity in term of a Trapezoidal Fuzzy Number ($TPFN_{LS}$) that can be obtained through the multiplication of two trapezoidal fuzzy numbers of likelihood ($TPFN_{L=}(a_L, b_L, c_L, d_L)$) and severity ($TPFN_s = (a_S, b_S, c_S, d_S)$) (Equation 2-23).

$$X = TPFN_{LS} = TPFN_L \otimes TPFN_S = (a_L \times a_S,\ b_L \times b_S,\ c_L \times c_S,\ d_L \times d_S) \qquad \text{Equation 2-23}$$

The descriptive Table 2-14 was used for creating the consequent trapezoidal fuzzy numbers of risk out of its antecedent fuzzy numbers using Equation 2-23.

Table 2-14 : Linguistic definitions of likelihood, severity and risk and corresponding trapezoidal fuzzy numbers

Qualitative scale for likelihood of risk (grade of *L*)	Qualitative scale of severity of risk (grade of *S*)	Linguistic Representation of risk	Likelihood and Severity Trapezoidal fuzzy number ($TPFN_S$ or $TPFN_L$)	Risk Trapezoidal fuzzy number ($TPFN_{LS}$)
IF	AND	THEN		
Very low	Extremely Unimportant	Very low	(0,0,0.1,0.2)	(0,0,0.01,0.04)
Low	Unimportant	Low	(0.1, 0.25,0.4)	(0.01,0.0625,0.16)
Medium	Neutral	Substantial	(0.3, 0.5,0.7)	(0.09,0.25,0.49)
High	Important	High	(0.6,0.75,0.9)	(0.36,0.5625,0.81)
Very High	Very Important	Very High	(0.8,0.9,1,1)	(0.64,0.81,1,1)

Figure 2-34 and Figure 2-35 show the graphical shape of trapezoidal fuzzy numbers corresponding to the different linguistic terms of likelihood and severity of a hazard, respectively.

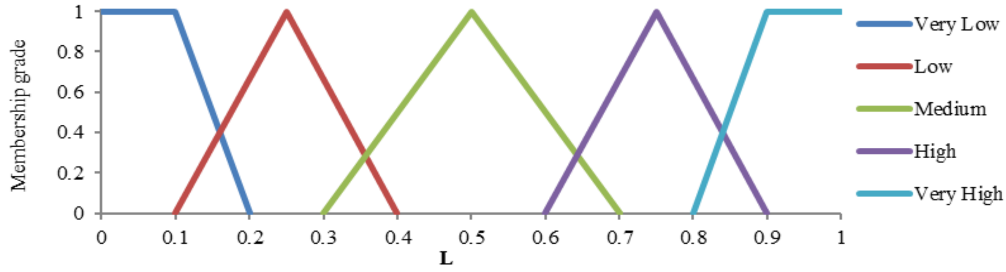


Figure 2-34: Fuzzy numbers corresponding to the linguistic terms of hazard likelihood ($TPFN_L$)

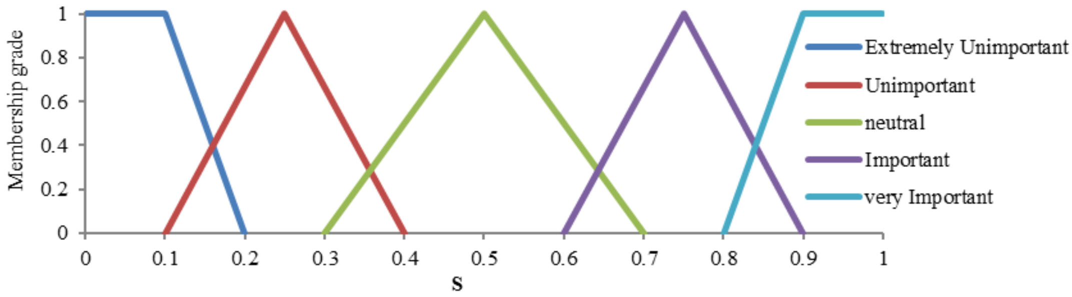


Figure 2-35: Fuzzy numbers corresponding to linguistic terms of hazard severity ($TPFN_S$)

Figure 2-36 shows the different linguistic terms of risks which are the outcomes of Equation 2-23.

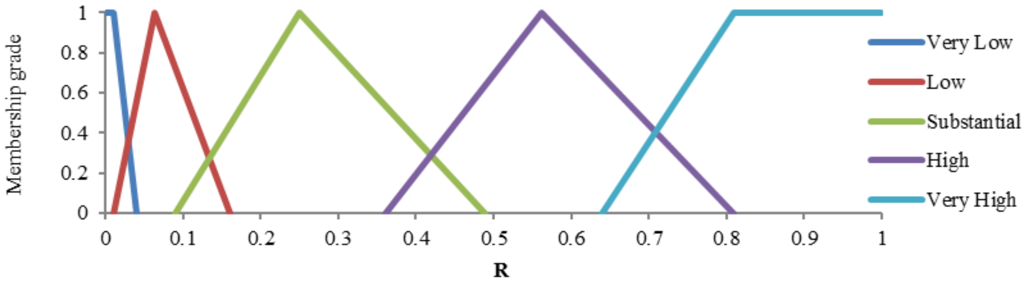


Figure 2-36: Fuzzy numbers corresponding to risk ($TPFN_{LS}$)

For a particular failure event the produced $TPFN_{LS}$ is mapped over the consequent fuzzy numbers of risk (Figure 2-37) and then through a normalization procedure, the corresponding fuzzy risk number of that event (X_R) is determined. All the steps for finding the final fuzzy risk number out of its likelihood and severity with a numerical example, have been illustrated in Table 2-15: Steps of finding the fuzzy risk number of a particular failure event

Table 2-15: Steps of finding the fuzzy risk number of a particular failure event

	Steps	Numerical Example
1	Determining $TPFN_L$ and $TPFN_s$	$TPFN_L$ = (0.1, 0.25, 0.4) $TPFN_s$ = (0.8, 0.9, 1, 1)
2	Finding $TPFN_{LS}$ of *(X)* through multiplying $TPFN_L$ by $TPFN_s$	(0.08, 0.235, 0.25, 0.4)
3	Mapping $TPFN_{LS}$ Over $TPFN_R$ and determining the maximum membership degree of intersection points for each $TPFN_R$ (μ_p) and forming as 5-tupple fuzzy set *(X)*	(0, 0.32, 1, 0.1, 0)
4	Normalizing the 5-tuple fuzzy set by dividing each (μ_p) by the sum of all membership values (X_R)	(0,0.24,0.69,0.07,0)

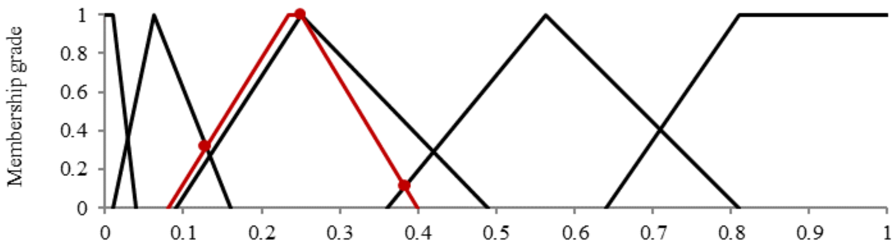


Figure 2-37: Mapping $TPFN_{LS}$ on risk fuzzy numbers

In the next parts of this script, it will be shown that the above method has significant differences with the approach of this study. For example, in above discussed method the fuzzy risk functions $TPFN_{LS}$ are not defined independently based on experts' judgments and perceptions, but they are the result of simple mathematical multiplication of defined fuzzy numbers of likelihood and severity which is then titled by linguistic descriptions. In this way that the multiplied number of likelihood and severity for a particular risk item is mapped directly to the consequent fuzzy risk functions, we don't see the fuzzification step as we can see in usual fuzzy rule-base systems and the applied IF-THEN propositions cannot be considered as fuzzy inference rules.

According to Figure 2-38 another aspect of using fuzzy logic in the applied methodology was employing a fuzzy AHP approach to obtain the weights of risk factors at different levels of hierarchical structure based on Mikhailov method (Mikhailov, 2004).

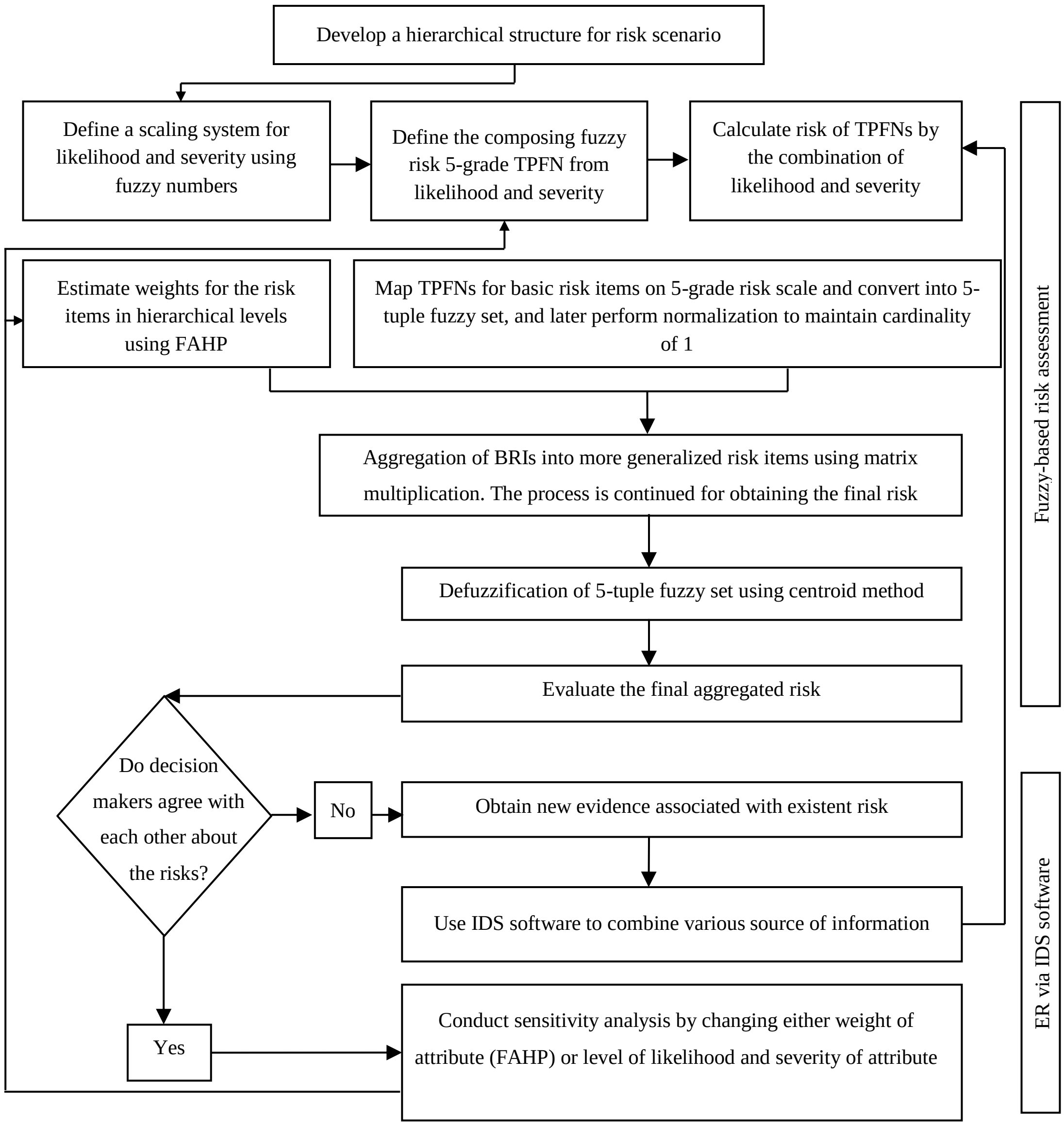


Figure 2-38 **: The research methodology for risk assessment of offshore wells**

2.14.2. Fuzzy risk management of construction projects

One of the best studies in using fuzzy set theory for risk assessment of construction project risks was performed by Nieto-Morote and Ruz-Vila. They applied a fuzzy approach on the Analytical Hierarchy Process (AHP) to deal with subjective judgments, unquantifiable, incomplete or non-obtainable information and to structure a large number of risks (Nieto-Morote & Ruz-Vila, 2011). Their approach allowed the risk management team to express their judgments about risk probability, risk impacts and risk discriminations in terms of linguistic terms instead of real numbers. A hierarchical weighting method was applied to assess the weight of risks using pairwise comparisons. Beside the use of trapezoidal fuzzy numbers to model the mentioned risk items expressed by qualitative scales, their proposed method used an algorithm to handle the inconsistencies in the fuzzy preference relation when the pairwise comparison was necessary. Their proposed algorithm reduced the inconsistency of the comparative judgement through minimizing the difference between the value of preferential judgement expressed by risk assessment team members and the ideal consistent value. They applied their approach on risk assessment of a building renovation project. Their proposed approach can be used in the general fuzzy risk assessment where the problem requires a ranking of risks. They proposed their fuzzy risk assessment model based on this definition of project risk that knows it as a potential problem that can lead to project complications and prevents project' tasks to be completed within the project' planned objectives (M. W. Cohen & Palmer, 2004). According to their proposed model a project risk can only be managed to decrease the effects on the achievement of the project's objectives but it cannot be fully eliminated. They used common characteristics of risk through reviewing some literatures in this area. Some of these characteristics have been mentioned in Chia's paper (Chia, 2006). According to this resource risk must be an uncertain event with a chance of occurrence between zero and 100% with effect on at least one of the project goals such as cost, quality, schedule or scope.

Nieto-Morote and Ruz-Vila mentioned different approaches that are used in classifications of construction project risks. Some these approaches are as follows:

- Classification of risks based on the nature of risks and their magnitude (C. B. Chapman, 1979)
- Classification of risks based on risks origin (Edwards & Bowen, 1998)
- Classifying the risks based on their origin and the location of risk impact by using a hierarchical structure of risks (Tah, Thorpe, & McCaffer, 1993)

The proposed model in their paper also follows three common procedures in all proposed fuzzy risk assessments: definition and measurement of parameters, definition of fuzzy inference and defuzzification. However, the most important difference of their method was using an algorithm to deal with inconsistencies in the fuzzy preference relation when pairwise comparison judgements are essential. Their proposed fuzzy risk assessment model consists of three steps:

1. Preliminary step
2. Risk function and measurement of variables step
3. Fuzzy inference step

The proposed fuzzy assessment model has been illustrated in Figure 2-39.

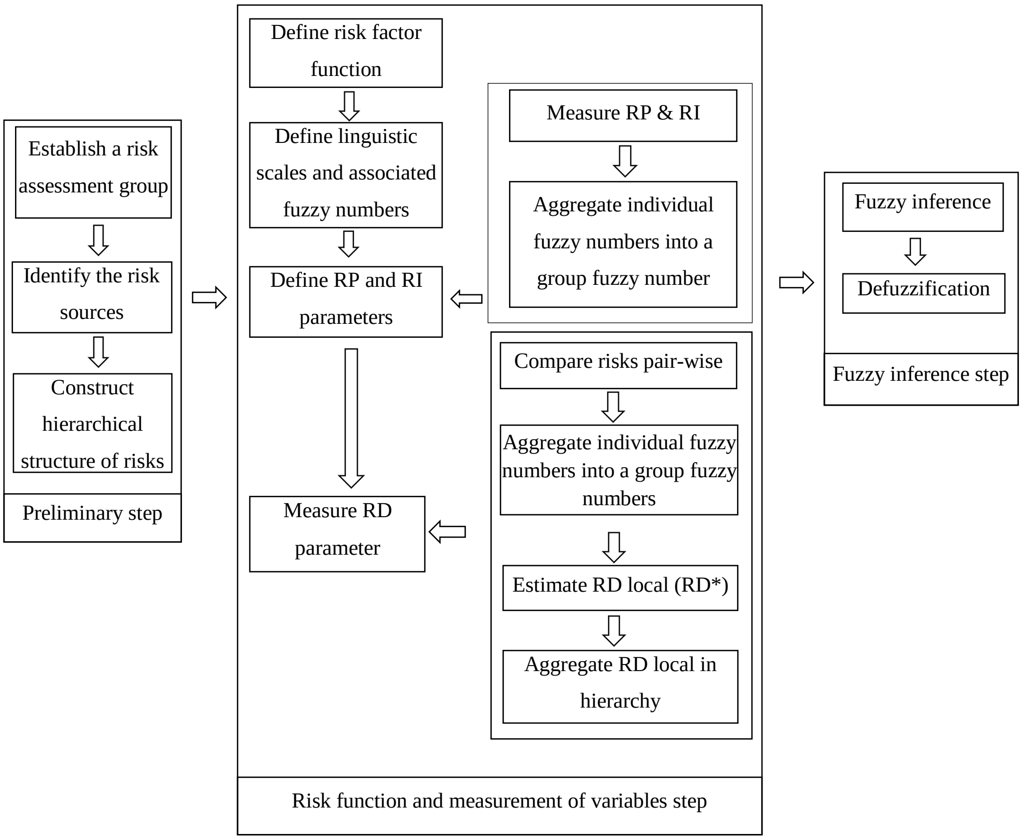


Figure 2-39:Fuzzy assessment model

In the preliminary step they formed a risk assessment group with carefully selected members with a high degree of experience in similar construction projects. The risk assessment team must include project managers, project team members, end users, risk management group, customers, stakeholders and experts with relevant skills who are from outside the project team. The risk assessment team is responsible for identifying the risk factors and measuring the risk function' parameters, even though all the personnel involved in the project cooperate in risk identification. During the risk identification procedure, the risk assessment team may use some tools like checklists, failure mode, fault tree, event tree, influence, effect analysis, diagrams, hazard and operability study and cause and effect diagrams (Koh, Saad, Ahmed, Kayis, & Amornsawadwatana, 2007). To assess the risk factors effectively, after identifying the construction project risks the risk assessment team members decide how to classify the risks by constructing a hierarchical structure and decomposing the risk factors to adequate levels. A hierarchical structure of project risks has been shown in Figure 2-40.

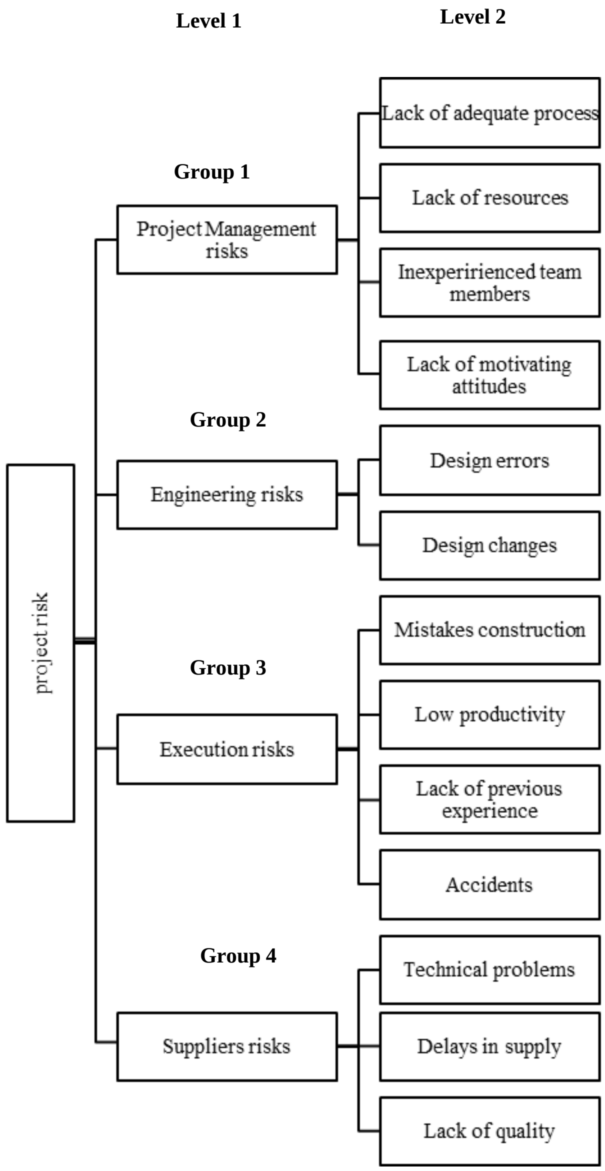


Figure 2-40: Hierarchical structure of project risks

In the second step they needed to calculate the overall risk factor based on three dimensions Risk Probability (RP), Risk Impact (RI) and Risk Discrimination (RDC) using the Equation 2-24.

$$Overall\ Risk\ Factor = \frac{(Risk\ Probability).(Risk\ Impact)}{Risk\ Discrimination} \qquad \text{Equation 2-24}$$

Based on Chen and Hwang researches (Huang, Chen, & Wang, 2001), a numerical approximation system was used to convert linguistic terms of each dimension into corresponding fuzzy membership function. The result of calculations when the fuzzy numbers are being operated significantly depends on the shape of the membership functions. The more irregular membership functions we have the calculations get more complicated. Moreover, simpler shape fuzzy numbers lead to more intuitive and simpler interpretation. For each dimension, different levels of linguistic scales, interpretation of each scale and their corresponding fuzzy numbers are shown in Table 2-16.

Table 2-16: Descriptions of RI, RP and RD Comparison (RDC)

	Description	General Interpretation	Fuzzy number
RI	Critical	Involved very highly impact	(0.8, 0.9, 1, 1)
	Serious	Involved highly impact	(0.6, 0.75, 0.75, 0.9)
	Moderate	Involved moderate impact	(0.3, 0.5, 0.5, 0.7)
	Minor	Involved only small impact	(0.1, 0.25, 0.25, 0.4)
	Negligible	Involved no substantive impact	(0, 0, 0.1, 0)
RP	High	Very likely to occur	(0.7, 0.9, 1, 1)
	Medium	Likely to occur	(0.2, 0.5, 0.5, 0.8)
	Low	Occurrence is unlikely	(0, 0, 0.1,0.2)
RDC	Much more	Much more impact on overall framework of project than	(0, 0, 0, 0.3)
	More	More impact on overall framework of project than	(0, 0.25, 0.25, 0.5)
	Same	Same impact on overall framework of project than	(0.3, 0.5, 0.5, 0.7)
	Less	Less impact on overall framework of project than	(0.5, 0.75, 0.75, 1)
	Much less	Much less impact on overall framework of project than	(0.7, 1, 1, 1)

Each member of the risk assessment group used the descriptive linguistic scale to measure the RI and RP factors at the bottom level of the hierarchy structure and then each linguistic judgement converts to its corresponding fuzzy number. By using the fuzzy arithmetic average and aggregation of the individual fuzzy numbers the total fuzzy numbers of RI and RP factors were obtained. For measuring the RDC parameter each member of the risk assessment team was required to form a risk pairwise comparison matrix for the risks of each main group of risks with fuzzy arrays. The aggregation of judgements using the fuzzy arithmetic average results in a group fuzzy number and the final matrix of group (g) and level (l) of hierarchy structure of risks was determined. By calculating the RD local (RD*) and then aggregated RD* in hierarchy the final value of RD for each risk was obtained.

In the fuzzy inference step which was the last step of proposed fuzzy risk assessment, once all the parameters RI, RP and RD were determined in the form of trapezoidal fuzzy numbers, the overall risk factor of each risk item ($\mathrm{ORF_i}$) was calculated using the Equation 2-25, where $\otimes$ and Ø represent the fuzzy multiplication and the fuzzy division operations.

$$ORF_i = (RI \otimes RP_i)\ \text{Ø}\ RD_i \qquad \text{Equation 2-25}$$

After defuzzification of each fuzzy number (ORF) using the centroid method, a crisp output value for each risk factor was produced and then the construction project risks could be ranked based on the highest to the lowest values.

Fabera and Stewartb explained the functional forms, techniques and methods of utilizing risk assessment in civil engineering. They interestingly addressed the risk acceptance criteria and the parameters that implementation of this issue is involved with, risk aversion and the value of human life in their paper. They followed a general format for risk analysis in their study, which is applied by the Australian and New Zealand code on risk management. (Figure

2-41). The represented flowchart in this figure is independent of risk application or risk acceptance (Faber & Stewart, 2003).

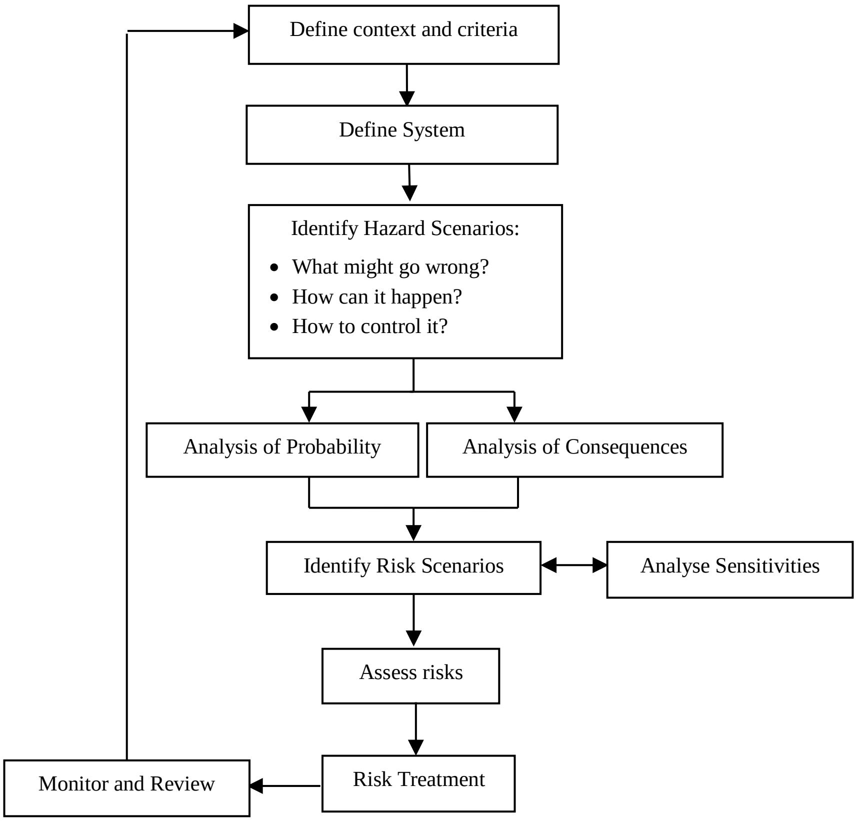


Figure 2-41: Generic representation of the flow of risk-based decision analysis the Australia/New Zealand code on risk management

The most important thing about this generic format is that the risk analysis is not a one-off procedure, but it is clearly a process that needs to be observed and updated regularly. The authors consider the hazard identification as one of the most crucial steps in the risk analysis of civil engineering facilities and mention some hazard identification methods as follows:

- Preliminary Hazard Analysis (PHA)
- Failure Mode and Effect Analysis (FMEA)
- Failure Mode Effect and Criticality Analysis (FMECA)
- Hazard and Operability Studies (HAZOP)
- Risk Screening (HAZID sessions)

The authors pointed to '*human error* as one of the main source of failure of civil engineering facilities which can occur during the design, construction, operation and maintenance stages.

Ebrahimnejad et.al (Ebrahimnejad, Mousavi, & Seyrafianpour, 2010) developed a Fuzzy Multi Attribute Decision Making Model (FMADM) for identification and assessment of common risks in Build–Operate–Transfer projects (BOT) using a novel hierarchical structure of risks. For ranking the high risks of BOT projects Fuzzy Techniques for Order Preference by Similarity to Ideal Solution (FTOPSIS) and Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP) methods were used and effective criteria for risk ranking were presented. They reviewed different classifications of risks involved in BOT projects considering the source criteria through a literature review of relevant studies in this field and finally presented their four-level risk hierarchical structure as shown in Figure 2-42.

They indicate that a lot of factors such as human errors, the wrong data and lack of information affect the nature of risks, increase the uncertainty and complicate the risk assessment process so they believe that relying only on probability and impact of risks are not enough for covering all the aspects of risks in large scale projects. By applying MADM they took advantage of considering more criteria in risk analysis and increased the final risk ranking perception. The presented effective risk criteria were assumed as independent factors as no specific relationship between them can shape the decision maker' mind. These criteria are as follows:

- Probability of risk
- Impact of risk: both positive effects and negative consequences that affect project objectives if the risk happens
- Quickness of reaction: rapidity of response if a risk turns to an event
- Event measure quantity: the resource which is expected to be required to prevent and secure the risk from happening
- Event capability: this factor is defined by Equation 2-26

$$Event\ capability = \frac{Threats\ Outcomes}{Opportunities\ Outcomes} \qquad \text{Equation 2-26}$$

In the above relation, threat outcomes indicate the expected loss value of time and cost if the risk happens and the opportunities' outcomes are the expected benefit value if the risk does not occur. In the next sections of the paper the authors defined a seven levels triangular fuzzy membership functions to interpret the linguistic variables of risk factors and introduced their proposed fuzzy risk analysis model. Table 2-17 shows the relations between the linguistic variables of risks and their corresponding TFN.

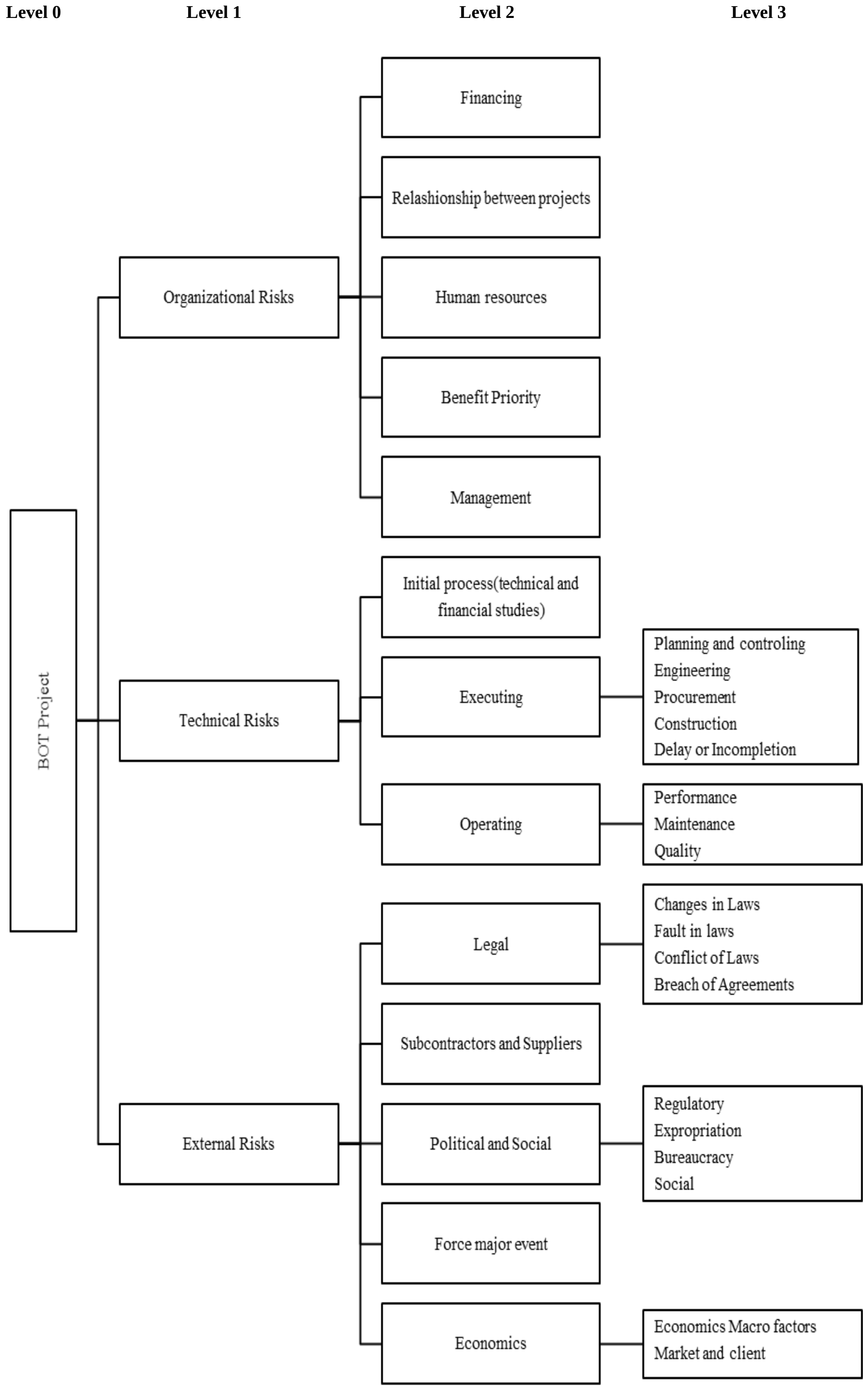


Figure 2-42: level hierarchical structure of BOT project risks

Table 2-17: The linguistic variables of risk factors and their corresponding triangular fuzzy numbers

Linguistic variables	Triangular fuzzy numbers
Very Low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Medium Low (ML)	(0.1,0.3,0.5)
Medium (M)	(0.3,0.5,0.7)
Medium High (MH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very High (VH)	(0.9,1,1)

Two main parts of the proposed fuzzy assessment model have been illustrated in Figure 2-43. The focus of the first part is on identifying and planning the BOT project risks using the historical data, final reports and questionnaires. Risk Breakdown Structure (RBS) is the outcome of this part and ensures the generation of necessary information. In the second part of the proposed model, the risks which have a low probability of occurrence and effect are eliminated from further analysis and the other high risks are being judged by five decision making experts and the primitive fuzzy risk matrix is formed. In this part two FAMDM techniques based on FTOPSIS and FLINMAP are applied and final risk ranking is obtained.

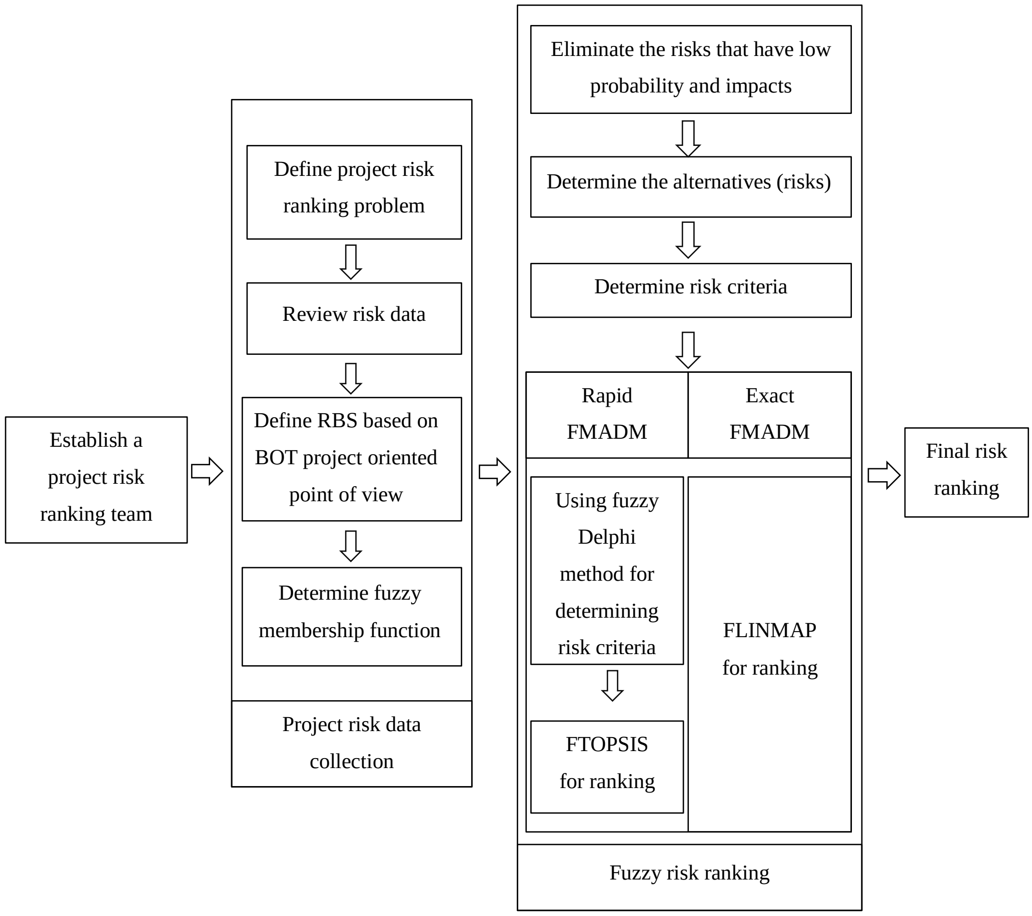


Figure 2-43: BOT project fuzzy risk ranking model

As a part of a larger study conducted for developing a fuzzy decision framework for contractors to deal with global risk factors affecting construction cost performance Baloi and Price discussed the basic risk factors involved in global risk modelling, evaluation and management (Baloi & Price, 2003). The image that they present from the construction project environment can be illustrated by Figure 2-44. They subdivided the project environment into three layers where both general and operational environments were considered as external layers and the general environment comprises five basic areas. The environment that a construction organization operates is not an enclosed space, but it is an open one. It means that there is a constant interaction between environment, construction organization and consequently the construction project, so the way that managers in construction organizations scan the external project environment and identify the threatening factors and the techniques that they choose to adapt their organization accordingly play a big role in organizations' effectiveness and efficiency.

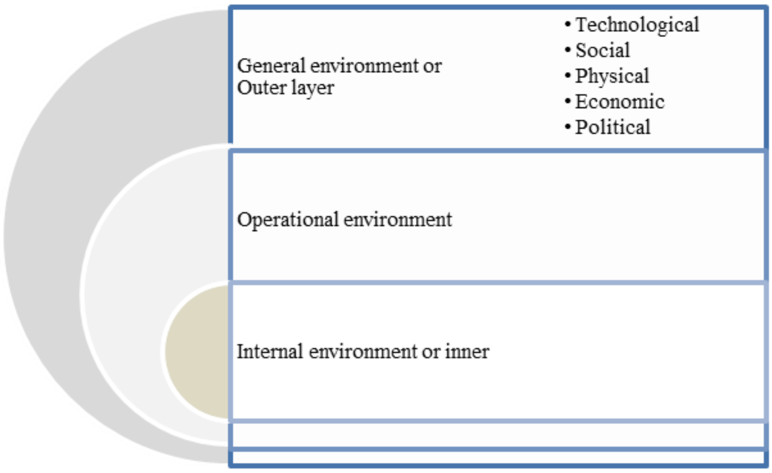


Figure 2-44: The construction project environment layers

They considered three classifications of: Organization-specific, Acts of God and Global for the risks to achieve a more detailed and comprehensive picture of risks factors that affect the cost performance. The internal risks associated with organization's resources and management, such as labour skills and availability, materials delivery and quality, equipment reliability and availability and management efficiency are classified as organisation-specific risks. This kind of risks should be managed by contractors. Acts of God refers to risks with low probabilities of occurrence and high negative consequences on project objectives like earthquake, hurricane, heavy floods, etc. These risks are generally insurable risks. Finally, global risks represent risks that go beyond project boundaries and have significant financial impacts on the project, however, they are not directly present in project cost estimation. The seven main groups of derived global risk categories are: political, estimator related, economic, design, level of competition, fraudulent practices and construction-specific risk through an extensive literature review. In their conducted study, geological conditions, unexpected site conditions, weather conditions, accessibility, client-generated and sub-contractor-generated were identified as construction related risk factors. Practically in many developing countries have to deal with this kind of risks.

Tah et al. applied fuzzy set theory to assess the risks during tender offer preparation in order to assign probabilities. They developed a hierarchical risk breakdown structure of project risks (Figure 2-47) and a model for contingency allocation (Tah et al., 1993). To easily illustrate how fuzzy set concepts can be used to evaluate the total risk of the project, they used a simple hierarchical risk breakdown structure (Figure 2-45) that an illustrative example of it has been shown in Figure 2-46.

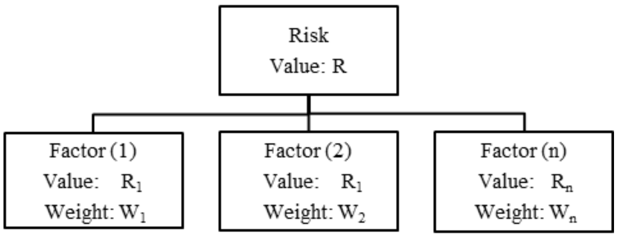


Figure 2-45:Simple hierarchical risk-breakdown structure

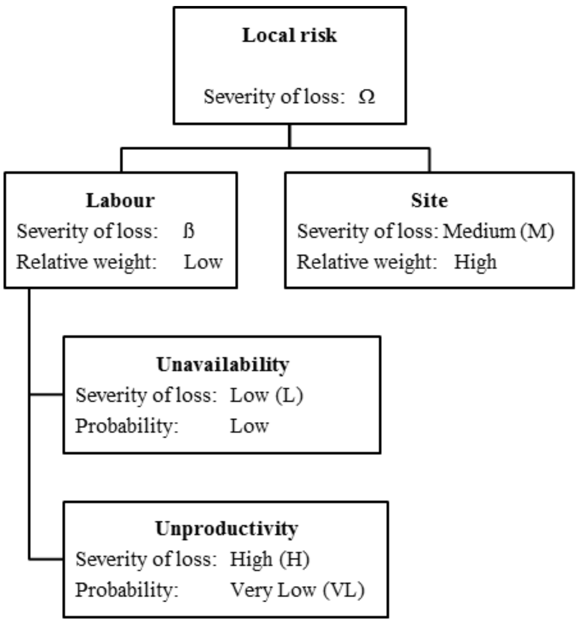


Figure 2-46: Simple hierarchical illustrative example

In Figure 2-45 the higher level indicates the total risk of the project and the bottom level shows the risk factors. For each risk factor at the lowest level the severity of loss (R_i) and the relative weight (in the case of risk components) or the probability of occurrence (in the case of risk factors) represented by (W_i) in three states of high, medium, and low for each of *n* risk

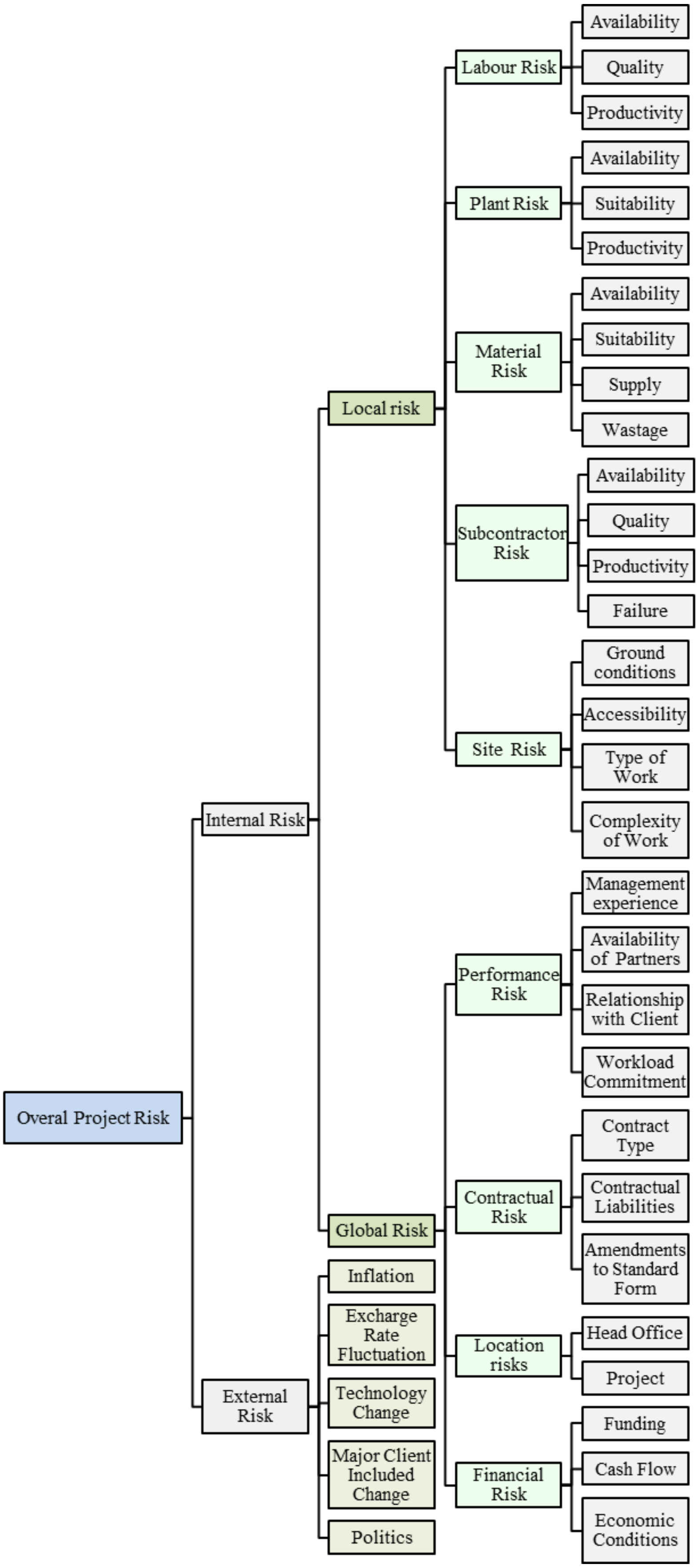


Figure 2-47: Contractor hierarchical risk-breakdown structure

factors or components are estimated by risk manager then the fuzzy risk value of higher level is computed using the fuzzy set mathematical operations and this will continue to obtain the overall risk of the project. The employed model consists of three basic steps:

1. Translation of linguistic expressions into discrete fuzzy sets
2. Risk evaluation through combining the fuzzy sets of severity and probability or relative weight and obtaining the fuzzy set of total project risk
3. Converting the overall fuzzy set of project risk to a natural language (linguistic approximation)

In the recent reviewed paper, the average value for a risk centre was computed using the average weighting method (Equation 2-27)

$$R = \frac{\sum_{i=1}^{n} W_i . R_i}{\sum_{i=1}^{n} W_i}$$ Equation 2-27

Later on Carr and Tah described a hierarchical risk breakdown structure and a fuzzy approach to represent a formal model for qualitative risk assessment in construction projects (Carr & Tah, 2001). They showed the relationships between a given risk magnitude and its likelihood and consequence in a risk assessment matrix illustrated in Table 2-18. The letter L, M, and H in this table refer to the linguistic variables Low, Medium, and High, respectively.

Table 2-18: Risk assessment matrix for construction projects

		Risk Likelihood				
		Low	Low to Medium	Medium	Medium to High	High
Risk Consequenc	High	M	M	MH	H	H
	Medium to High	LM	M	M	MH	H
	Medium	LM	LM	M	M	MH
	Low to Medium	L	LM	LM	M	M
	Low	L	L	LM	LM	M

Figure 2-48 shows the fuzzy numbers of risk magnitude corresponding to five defined linguistic terms of risk.

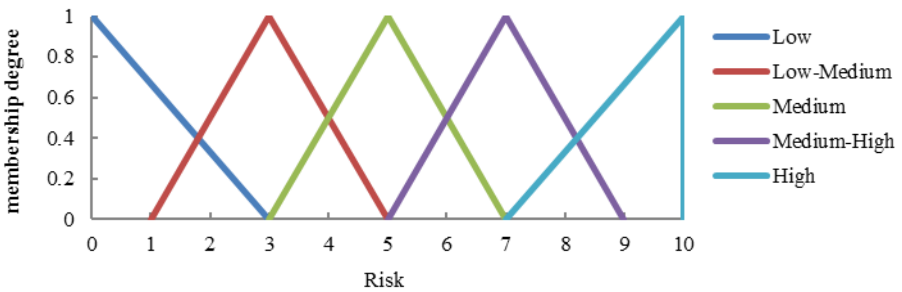


Figure 2-48: Fuzzy numbers of risk magnitude

Dubois and Prade (D.J. Dubois, 1980) and Kaufman and Gupta (Kaufmann & Gupta, 1985) developed several mathematical operations to apply fuzzy sets in practical problems. Some of the most common operations that were used are as follows:

If fuzzy sets *A* and *B* are defined as $A = \{x| \ \mu_A(x) \ \ 0 \le x \le 10\}$, $B = \{y| \ \mu_B(y) \ \ 0 \le y \le 10\}$ then:

$$A + B = \max\{[x + y] \ \min(\mu_A(x) + \mu_B(x)) \ 0 \le x, y \le 10\}$$ Equation 2-28

$$A \times B = \max\{[x \times y] \ \min(\mu_A(x) + \mu_B(x)) \ 0 \le x, y \le 10\}$$ Equation 2-29

$$A \div B = \max\{[x \div y] \ \min(\mu_A(x) + \mu_B(x)) \ 0 \le x, y \le 10\}$$ Equation 2-30

The overall weighted average value for risk of the project, *R*, is a fuzzy set. In the last step this value must be converted to a linguistic expression such as low, medium or high risk through calculating the Euclidean distance using equation 8.

$$\mathrm{d(R, A)} = \left(\sum_{\mathrm{i=1}}^{\mathrm{n}} [\mu_{\mathrm{R}}(\mathrm{i}) - \mu_{\mathrm{A}}(\mathrm{i})]^2\right)^{(1/2)}$$ Equation 2-31

Where *d (R, A)* represents the Euclidean distance between fuzzy sets *R* and *A*, and $\mu_R(i)$ and $\mu_A(i)$ represent membership values of the element (i) of the two fuzzy sets. The lowest value of Euclidean distance is selected and the closest linguistic expression is assigned to it. For example, according to the Figure 2-46 the risks associated with *labour* component (*ß*) and *local* risk (Ω), are computed by applying Equation 2-32 and Equation 2-33as follows:

$$\beta = \frac{(L \times L) + (H \times VL)}{L + VL}$$ Equation 2-32

$$\Omega = \frac{(\beta \times L) + (M \times H)}{L + H}$$ Equation 2-33

Where, *ß*, *L*, *H*, *VL*, *M* and *Ω* are fuzzy sets. The detailed calculations of this method have been shown in the last part of the reviewed paper through a very simple example of risk assessment model.

To provide a more explicit perception of the total risk of a construction project and making the probability planning and assessment easier, Kangari in 1988 developed an integrated microcomputer-based knowledge based system using the fuzzy set theory for risk management of construction projects and evaluating the total risk of a project (Kangari, 1988). This system has been illustrated in Figure 2-49: An integrated construction risk management system. Various relational databases provided the financial and cost data required for risk analysis. The developed system in that time allowed management to focus on more serious risks with significant effects on planning and provided recommendations for risk management before and during the construction.

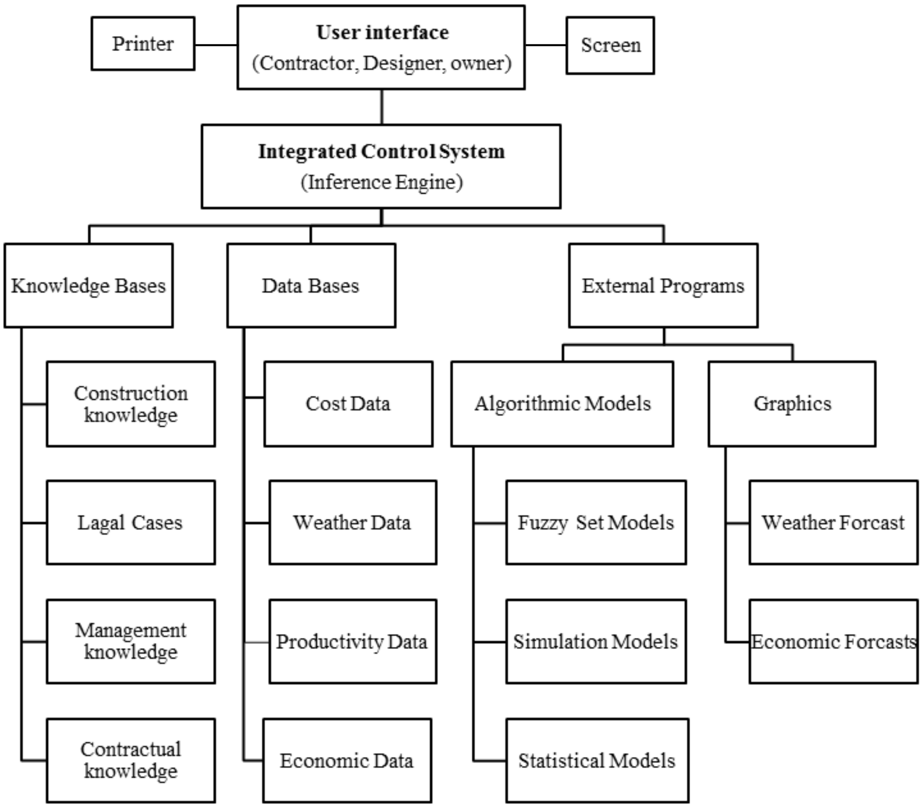


Figure 2-49: An integrated construction risk management system

Tavakkoli Moghaddam et al. applied a comprehensive approach for simultaneous identifying and prioritizing the risks of Engineering, Procurement and Construction (EPC) projects. They proposed a decision making approach in three sections. In the first phase the project potential risk data was collected. In the second step a Multiple Criteria Group Decision Making (MCGDM) approach using fuzzy entropy for weighting the criteria and compromise ranking known as VIKOR techniques was used to rank all the identified risks. Finally a proper threshold was determined simultaneously to separate all the identified and non-identified risks (Tavakkoli-Moghaddam, Hashemi, & Mousavi, 2011).

To assist contractors during the estimation process under uncertainty Paek et al. used a fuzzy set approach to propose a risk-pricing method. Their method consisted of determining risk factors and quantifying their consequences. The fuzzy sets were applied to represent the uncertainty values of quantified consequences and appeared directly in the bidding price calculation process (Equation 2-34) (Paek, Lee, & Ock, 1993).

$$BP = AC + PF + RC \quad \text{Equation 2-34}$$

Where (BP) is bidding price; (AC) represents the actual cost (direct, indirect, and overhead cost) to perform a construction project, (PF) is contractor's profit and RC stands for the crisp value of total net loss. To use the fuzzy set theory, the authors estimated the total net loss value (T) as a fuzzy number by forming the monetary loss estimates related to positive risk elements using the '*most likely range*' and the '*largest likely range*' values. This fuzzy number (T) might be an interval value (trapezoidal fuzzy number) or a non-interval value (triangular fuzzy number). To calculate the crisp value of (T) which is equal to *RC* in the Equation 2-34, a fuzzy ranking method that had been developed by Chen was used (S.-H. Chen, 1985).

Cho et al. proposed a useful methodology for systematic risk assessment of construction project through developing an ETA model based on fuzzy concepts to incorporate the present characteristics of the site and construction conditions. Since estimating the exact rate of an event occurrence is very difficult, in order to consider the uncertainty range, their paper introduced new forms of curved fuzzy memberships incorporating the degree of uncertainties exist in both probabilistic estimates and intuitive judgements. For example, in order to get over the limitations of simple linguistic variables like good/bad or medium/high that are usually used in subjective judgements, they proposed to use statements such as '*higher/lower than analysed value'* or '*close to any value'* that can give more specific value or scale. Their proposed risk assessment model could evaluate the risk probability of an event corresponding to the availability of historical data in three situations as follows (Cho, Choi, & Kim, 2002):

1. Historical data is available and sufficient: using simple frequency analysis to evaluate the probability of each risk on potential failure paths.
2. Historical data is insufficient: using probability theories like Monte Carlo Simulation (MCS) or Bayesian method.
3. Historical data is unavailable: using experts' subjective judgements based on their experience and knowledge to estimate each risk probability.

Then three types of membership curves are used to integrate these three approaches into an ETA model. In the reviewed paper four major factors were selected that can affect the uncertainties of subjective judgements. These factors were classified into two main groups; First, the complexity of working and health conditions for judgments and second, the level of education, assurance and experience. Figure 2-50 illustrated a schematic diagram of ETA modelling.

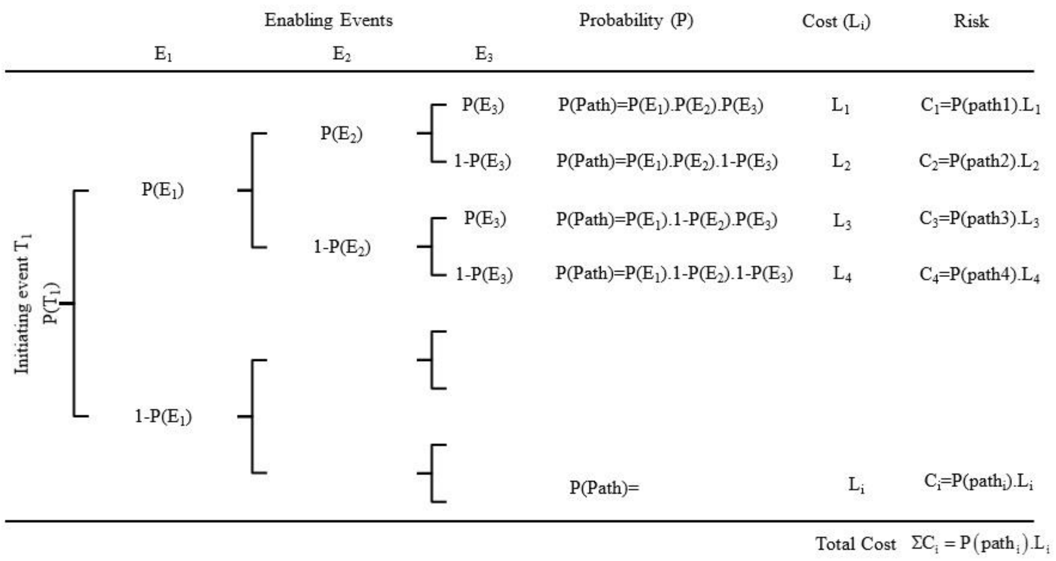


Figure 2-50: Example of ETA modelling

Wirba & Tah mentioned that the amount of extra costs incurred or extra time spent because of a risk happening can define the severity of a risk as the extra spent time for correcting the effect (s) of a risk can be converted into a money amount. Since the budgets of different projects are different from each other, they proposed using a mapping function that determines the severity of a risk as a proportion of the budget for the particular task (Wirba, Tah, & Howes, 1996). For example, an extra cost of $900 on a $100,000 projects leads to a more severe risk compared with an extra expenditure of $1000 on a $200,000 project because of a greater proportion of imposed cost on the total budget of the project. Table 2-19 shows an example of this kind of fuzzy mapping function. In this case fuzzy boundaries like very, relatively, somewhat, extremely, highly, etc. are used to define the intensity of a risk when the evaluated value falls somewhere between the identified percentages. For example, a risk that takes an extra cost of 8% of the project budget to be corrected, can be described as a '*somewhat sever*' risk as it is below the sever point.

Table 2-19: Fuzzy mapping function for determining severity of risk

Description of risk event	Extra cost as % of activity's budget
Severe	Greater than 10%
Moderate	About 5%
Low	Under 2.5%

Wang and Elhag applied a Fuzzy Group Decision Making (FGDM) approach for bridge risk assessment that allowed decision makers in this field to express their judgments independently by using linguistic terms such as High, very high, medium, etc. instead of precise numerical value. They showed that this approach will lead to a more flexible, practical and effective modelling of bridge risks. They mention that defining the membership functions (MFs) of linguistic terms is a very important step in an FGDM procedure and suggest that the decision makers reach a consensus and agreement on defining these MFs otherwise the average value should be used in the definitions. Table 2-20 shows the fuzzy numbers used for linguistic ratings and descriptions of likelihood and consequence of a risk event (Y. M. Wang & Elhag, 2007).

Table 2-20: Linguistic terms of likelihoods and consequences of a risk event and their corresponding fuzzy numbers

Likelihood	Fuzzy Number	Consequence (Safety, Functionality, Sustainability, Environment)	Fuzzy Number
Certain	C = (1.0, 1.0, 1.0)	Very high	VH = (85, 85, 100)
Very high	VH = (0.85, 1.0, 1.0)	High	H = (50, 85, 100)
High	H = (0.7, 0.85, 1.0)	Medium	M = (15, 50, 85)
Slightly High	SH = (0.5, 0.7, 0.85)	Low	L = (0, 15, 50)
Medium	M = (0.3, 0.5, 0.7)	Very low	VL = (0, 0, 15)
Slightly low	SL = (0.15, 0.3, 0.5)	None	N = (0, 0, 0)
Low	L = (0, 0.15, 0.3)		
Very low	VL = (0, 0, 0.15)		

Mokhtari et al. used fuzzy set theory and evidential reasoning approach in proposing a decision support framework for risk management on sea ports and terminals to deal with uncertain and complex environment of these important logistics infrastructures and lack of a convenient technique to support risk management cycle in this area. In their conducted study first the risk factors affecting the ports and terminals operation and management were described and evaluated by using fuzzy set theory, then for synthesising the generated information an evidential reasoning was employed. Finally, the overall risk level of a particular port was calculated by employing the relative global weights accessible from demonstrated pre-assessed and ranked operational risk factors, along with the confidence degree calculated through the proposed methodology using the intelligent decision system software. Table 2-21 shows the linguistic variables of likelihoods, consequences and the risk level due to *IF-THEN* rule in each grade and the assigned Triangular Fuzzy Numbers (TFNs) used in the reviewed study (Mokhtari, Ren, Roberts, & Wang, 2012).

Table 2-21: Linguistic terms of likelihoods, consequences and risk levels and their corresponding TFNs

Grade	Occurrence likelihood (L)	Consequence severity (S)	Risk Level	TFN
	IF	AND	THEN	
1	Very Low(VL)	Slight (SL)	Very high	(0.00, 0.00, 0.25)
2	Low(L)	Minor (MI)	High	(0.00, 0.25,0.50)
3	Medium(M)	Moderate (MO)	Medium	(0.25, 0.50, 0.75)
4	High(H)	Critical (CR)	Low	(0.50, 0.75, 1.00)
5	Very high(VH)	Catastrophic (CA)	Very low	(0.75, 1.00, 1.00)

Idrus et al. used fuzzy expert system in risk analysis to accommodate contractors' subjective judgements and develop a model for estimation of cost contingency in building and infrastructure projects (Idrus, Nuruddin, & Rohman, 2011). The error of their model was less than 20% (±18%) compared to the real project cost contingency values. Figure 2-51 illustrates their conceptual model of project risk hierarchy and the factors involved in cost contingency estimation. Where *CC* denotes the contingency cost, *MR* denotes the major risk category, *RM* denotes the risk magnitude, 1, 2, …, n is the number of risk factors and major risk categories, *RL* is the risk likelihood and *RS* denotes the risk severity. The fuzzy expert system was applied on the third level to calculate the Risk Magnitude (*RM*) of each risk factor comes out of a relation between risk likelihood and risk severity which is defined by *IF-THEN* rule. While a scale between 0 and 100 was selected for the Risk Likelihood (RL), the triangular membership functions of linguistic terms of Risk Severity (*RS*) were set on a scale between 0 to 2% which was a percentage of total project cost. They set a range of 25-50% for the overlap between the fuzzy membership functions of linguistic terms.

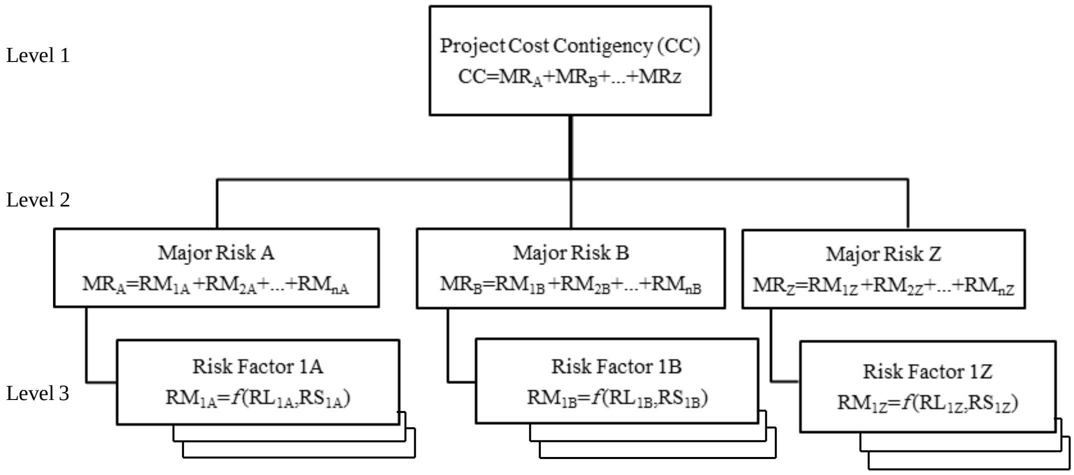


Figure 2-51: Cost contingency model

To evaluate the uncertainties that affect individual and social risk estimates, Bonvicini et al. applied a fuzzy logic in the risk analysis of the hazardous material transportation via both pipeline and road. They used fuzzy numbers to describe the uncertain input parameters and fuzzy arithmetic to perform the risk measures calculations (Bonvicini, Leonelli, & Spadoni, 1998).

Ngai and Wat successfully developed a web-based typical Fuzzy Decision Support System (FDSS) for risk assessment of Electronic Commerce (EC) development. This model could help the EC project managers and decision makers in formalizing the types of thinking and identifying the potential risks of this area more systematically that before (Ngai & Wat, 2005).

Dikmen et al. proposed a methodology based on fuzzy model for cost overrun risk assessment of international construction projects. Their proposed methodology was consisted of two main approaches: an influence diagramming technique for constructing a risk model and a fuzzy risk assessment for estimation of cost overrun risk. They also developed a computer system for fuzzy risk rating to facilitate the risk quantifying procedure and advise the companies' managers about the risk value that should be included in the bidding proposals to cover overhead and profit (Dikmen, Birgonul, & Han, 2007).

Motawa et al. used fuzzy logic to propose a model for evaluating the risk of "change" in construction projects. Their developed model predicted the probability of "occurrence a change" and its consequences on project objectives through analysing the relationships of cause and effect. This analysis used fuzzy numbers to relate the project characteristics (the factors that have an effect on the project and may lead to change such as building regulations, quality issues and external pressures) to the change causes (direct causes of a specific change event when it happens such as lack in design information or delays in decision making) and determines the overall change effects (change consequences) on project objectives (Motawa, Anumba, & El-Hamalawi, 2006).

As another attempt of applying fuzzy logic in risk management, Kuo and Lu used a fuzzy multiple criteria decision making approach instead of a traditional statistical approach to improve the risk assessment of construction projects in metropolitan areas to overcome the risky, competitive and dynamic conditions of these kind of projects. They classified twenty identified risk factors in five risk categories (Engineering design, Construction management, Construction safety related, Natural hazards, Social & Economic) and used consistent fuzzy preference relations to evaluate and investigate their relative effects on projects performance instead of an AHP pairwise comparative matrix. The occurrence likelihood of multiple risk factors was analysed using a Fuzzy Multi Attribute Direct Rating (FMADR) and a synthesized analysis was applied to associate the individual risk factors and evaluate the overall risk level of the project (Kuo & Lu, 2013).

In the civil and construction engineering field, strengthening projects are involved with a wide range of risks, including strengthening specific risks and general risks of construction projects. Shoghli and Abbassnia *(R.I.P)* conducted a risk management study on strengthening projects by using fuzzy analysis to deal with the influences of uncertainties at different phases of the life cycle of these kinds of projects. They used a fuzzy inference system to quantify the identified risks in this area that could affect the project functional objectives, including schedule, cost and quality (Shoghli & Abbassnia, 2010).

To summarize the reviewed approaches for fuzzy risk management it must be noted that most of them do not follow an up to date and integrated definition of risk or risk boundaries (e.g. risk, hazard and opportunities). The investigated studies do not propose a satisfactory approach for constructing the fuzzy membership functions of risk components. The fuzzy risk functions presented in them are not defined independently based on experts' judgments and perceptions, but they are the result of simple mathematical multiplication of defined fuzzy numbers of likelihood and severity which is then titled by linguistic descriptions. More than that in many reviewed sources that investigate the risk management approaches in oil and gas industry, the focus is not on construction risk factors, but the focus is on a particular operation during the construction of an oil and gas project (e.g. pipelines construction). Lack of adequate definition of project objectives, improper interpretation of risk sources and poor hierarchy of risk factors are noticeable in some of the investigated articles as well.

3. METHODOLOGY

3.1. The overview of proposed fuzzy risk assessment model

The aim of this chapter is to establish a methodology for risk management of oil and gas projects according to the objectives of study which should be based on reliable scientific sources. Figure 3-1 illustrates the fuzzy model proposed in this study, which is an overview of a practical model that can be used by the risk management group of companies involved in oil and gas industry. According to this figure the main objective of this study focuses on risk assessment aspects and how fuzzy concepts can be applied to this part so in the next sections of this season, the different steps of this part will be explored. The fuzzy risk assessment part of the proposed model consists of three major steps as follows:

- Preliminary step:
  - Define project' objectives that are affected by the risk factors
  - Identify the risk factors
  - Classify the risk factors into major groups and sub factors
- Defining membership function & fuzzy analysis rules step:
  - Define linguistic terms for Risk Magnitude (RM), Risk Likelihood (RL) and Risk Impacts (RI) on each project' objectives
  - Define a scaling system and determine fuzzy membership functions associated with the linguistic terms of RM, RL and RIs
  - Define the fuzzy analysis rules (IF-THEN rules) and determine fuzzy inference engine operators
- Fuzzy inference step
  - Measure RL & RIs
  - Fuzzy inference system (Mamdani)
  - Defuzzification

The proposed model in this study has all the key steps of every fuzzy analysis, but the arrangement in the diagram has been adjusted with the modelling steps in the MATLAB software. The remarkable point about this model is that, unlike the reviewed models in this research that do not propose a convincible method for constructing the fuzzy membership functions, this model finds a way to consider the uncertainty existed in expert's judgements in constructing the fuzzy membership functions by using the scientific statistical parameters of the collected data. The normality and reliability of data also are checked with advanced programs for statistical analysis like SPSS (Statistical Package for Social Science). In the next parts of this chapter different components of each step will be discussed in detail.

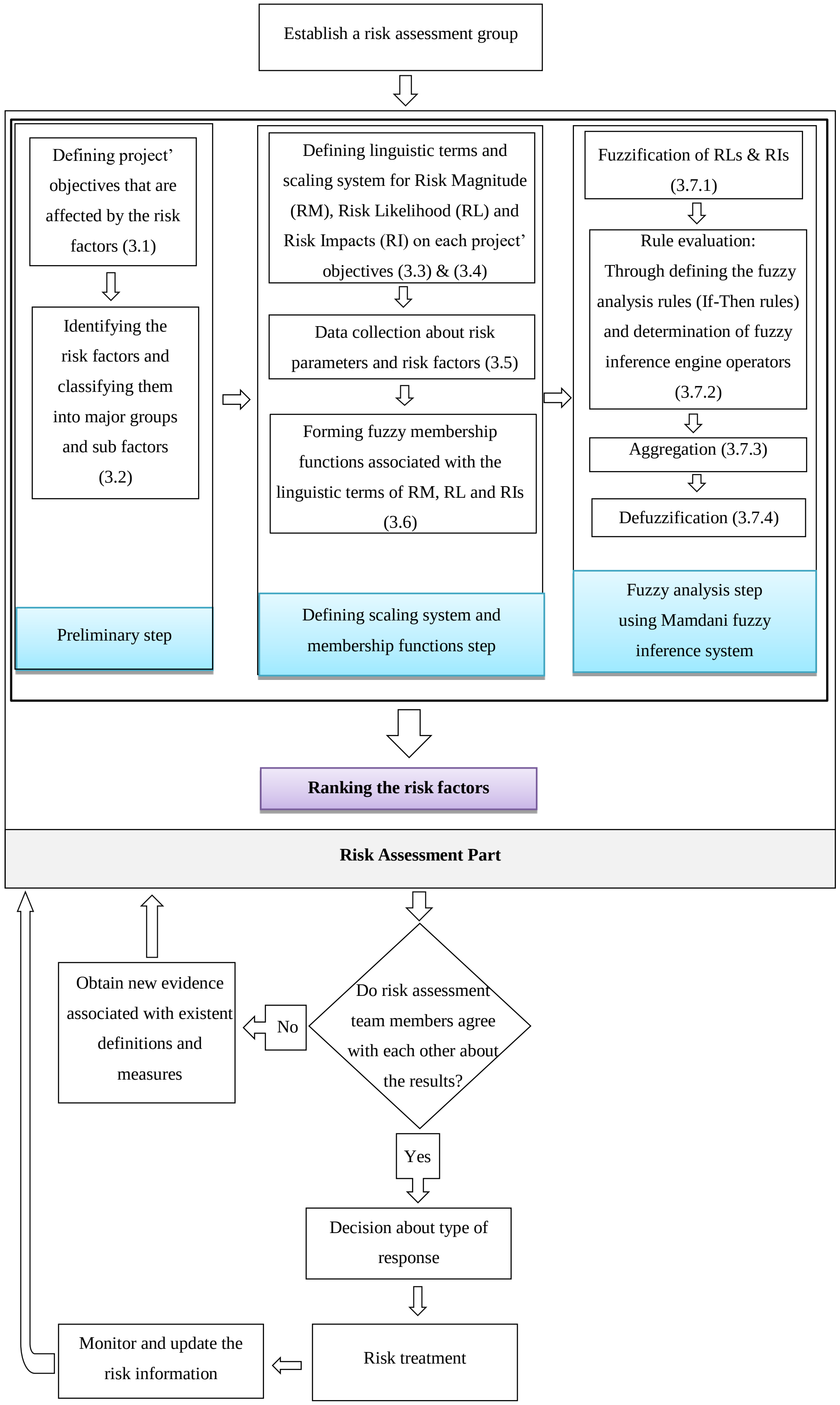


Figure 3-1: Proposed fuzzy risk management model

3.2. Defining project objectives

As mentioned and explained in the previous chapter of this script Project Management Body of Knowledge (PMBOK) guide considers four parameters for any project that can be affected by risk factors. In this study and related investigations these parameters are defined as oil and gas projects' objectives and impact of risk factors on them would be investigated. These four project objectives are:

1. Time
2. Cost
3. Quality
4. Scope

3.3. Identification and classification of the risk factors of oil and gas projects

Classification of risk plays a significant role in risk assessment as it helps to identify the relevant risk assessment experts and facilitates the data collection procedures. There are important factors that must be considered to achieve the final classification of the identified risks. Some of these factors are as follows:

- A precise and clear definition of risk
- Accurate perception of risk inherent and sources
- A clear definition of project objectives that can be affected by risk factors
- Size, type and other specifications of the project
- A precise work breakdown structure (WBS) of the project

As illustrated in Figure 3-2. not considering these factors can lead to tangled strings of risk' cause and effect relationships that make any kind of analysis very complicated and difficult and cause big deviations from the truth.

In this study, based on the findings of a wide literature review and investigation on risk factors of oil and gas projects, considering the various classifications recommend by researchers, managers and experts involved in different parts of this industry, eliminating the duplicates and merging the similar items, two hundred and forty-nine (249) risk factors related to the oil and gas infrastructure projects and industry were identified. To have a clearer demarcation of different risk categories and deal with the complexity of risk analysis, the identified risk factors were classified into seventeen (17) major risk groups that will be presented in the next pages of this chapter by Figure 3-3.

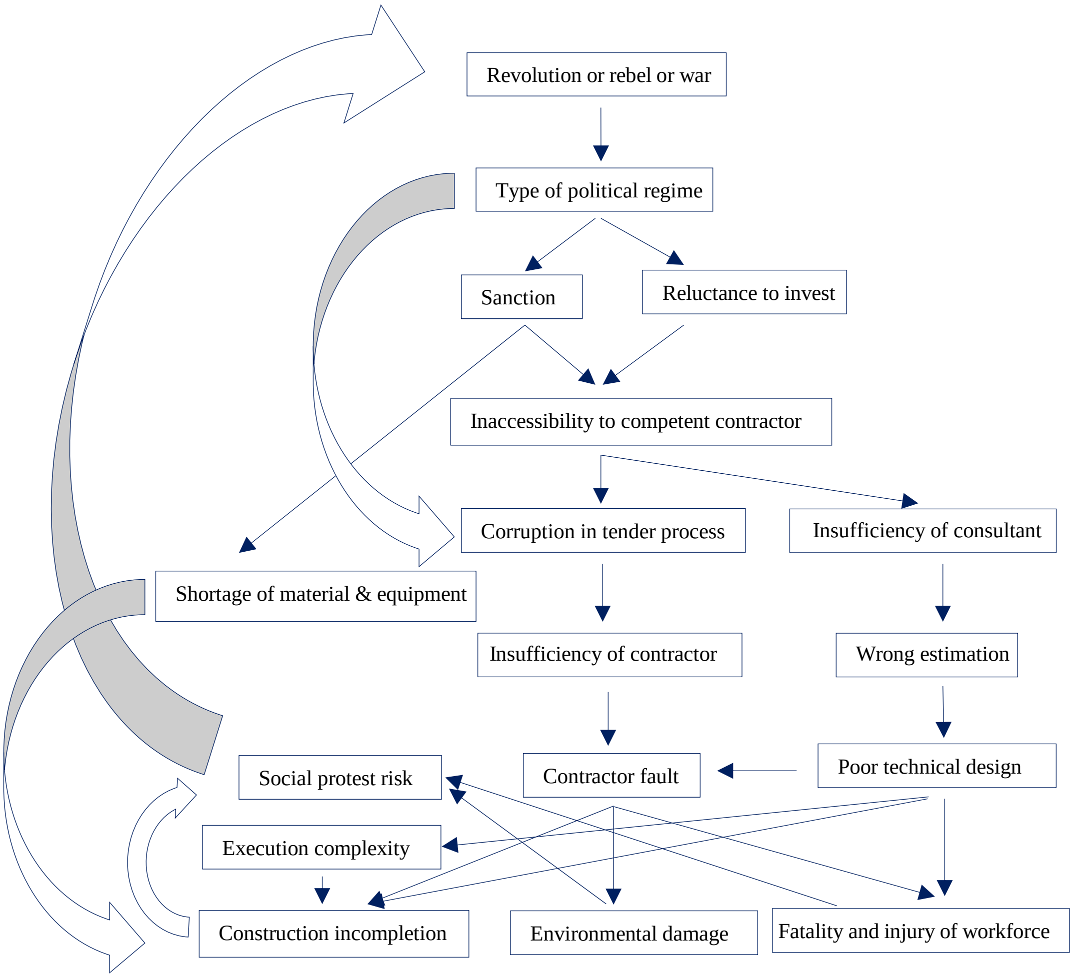


Figure 3-2: Complicated shape of risk' cause-effect relationships

Some risk factors may appear in more than one group; however, their nature would be different. Some of several parameters that were considered to form the major groups of the risk factors in this script are as follows:

- Affecting a big variety of oil and gas projects in different divisions of this industry, including downstream, midstream and upstream
- Affecting various phases of projects: initial stages, construction, operation, etc.
- Interaction of project environment with internal and external environment
- Different definition of risks: hazard or control risk
- Several parties involved in oil and gas projects: owner, consultant, contractor, or ordinary users

Based on these factors the proposed major groups of risks and their sub factors are as follows:

Group 1: Project' Initial Stages Risks

1.1. The lack of a precise definition of the project
1.2. Varying the direction of objectives and priorities of the project
1.3. Project scope changes
1.4. Lack of a clear specification of project requirements
1.5. Lack of knowledge of the number and types of factors influencing the project
1.6. Lack of knowledge about the interdependencies between activities in the project
1.7. Improper project feasibility study
1.8. Defective preparation of feasibility report

Group 2: Financial Risks

2.1. Economic and financial crisis
2.2. Financing costs fluctuation
2.3. Interest rate fluctuation
2.4. Inflation rate fluctuation
2.5. Currency (exchange) rate fluctuation
2.6. Currency convertibility problems
2.7. Tax rate fluctuation
2.8. Changes of labour, material and equipment cost
2.9. Changes of consultant cost
2.10. Changes in tender's price
2.11. Increase in resettlement cost
2.12. Increase of insurance cost
2.13. Increase in storage cost
2.14. Increase in maintenance cost
2.15. Joint venture risks
2.16. Pre investment risks (cancelation of project after bidding, delay in the setting of consortium
2.17. Adverse investment climate
2.18. Delay in investment time
2.19. Low investment return rate
2.20. Cash flow risk (inadequate liquidity or access to capital and indebtedness)
2.21. Development cost
2.22. Security bond problems (lodgement or refund)
2.23. Inefficient and poor performance of constructors budgeting
2.24. Financial constraints of contractors
2.25. Delayed payment from the client to subcontractors

2.26. Lack of financial motivation for contractor (i.e. provisions of incentive or bonuses for early finish)
2.27. Financial default of subcontractors (poor estimation of cost and time)
2.28. Financial problems with consultants
2.29. Financial closure risk
2.30. Low credibility of lenders
2.31. Low credibility of partners
2.32. Low credibility of customers
2.33. Low credibility of vendors and suppliers

Group 3: Revenue and Market Risks

3.1. Low revenue generation
3.2. Failure to extract resources
3.3. Insufficient fare income
3.4. Fluctuating demand of production
3.5. Volatility of prices for products and services sold (e.g. minerals, office space etc.)
3.6. Distribution and transmission failure
3.7. Problem in bill collection
3.8. Fault in market forecast

Group 4: Technical and Engineering Risks

4.1. Design changes
4.2. Design errors and omissions
4.3. Complexity level of design
4.4. Poor design (Incomplete design scope, Inadequate and ambiguous technical specifications, Defective design due to faulty investigations, reports, tests, research, Lack of standards)
4.5. Difference of standards and codes, unfamiliarity with local standards and codes
4.6. Lack of knowledge and experience of consultants about design and construction
4.7. Ineffectiveness and lack of supervision of consultants
4.8. Inadequate technical testing and assessment
4.9. Unrealistic inspection and testing methods proposed in the contract
4.10. Technology selection default
4.11. Lack of usual technology
4.12. Unavailability of new technical and engineering technologies
4.13. Technical and engineering equipment failure and inefficiency
4.14. Cybernetics problems caused by hacking of systems

4.15. Cybernetic systems breakdown

4.16. Inaccessibility to required software

4.17. Inaccessibility to high speed internet

4.18. Hardware and software update problems

<u>Group 5: Construction Risks</u>

5.1. Wrong constructability assumptions

5.2. Complexity level of construction

5.3. Faulty construction techniques

5.4. Construction equipment failure and inefficiency

5.5. Encountering with an incomplete or a defective construction work

5.6. Mistakes in construction because of contractor default

5.7. Waste caused by contractors

5.8. Poor and ineffective construction supervision by consultant

5.9. Delays in stage passing approval

5.10. Construction works variations

5.11. Inconsistency of construction conditions with construction plans

5.12. Inconsistency of construction conditions with construction planning

5.13. Need to protect the geological and historical objects during the construction

5.14. Fatalities and weighted injuries of workforce

5.15. Damage to environment

5.16. Severe temperature and weather conditions during the construction

<u>Group 6: Supply and Logistic Risks</u>

6.1. Shortage of material, equipment and rigs

6.2. Delay in material supply

6.3. Restriction on import equipment and materials

6.4. Poor quality of procured materials

6.5. Shortage of labour, skilled operators for specialized equipment, workforce and personnel

6.6. Inadequate labour skills

6.7. Inability to attract or remain key personnel

6.8. Difficult workforce trainability

6.9. Improper workforce education and training

6.10. Unavailability of subcontractors and suppliers

6.11. Incompetence of subcontractors and suppliers

6.12. Low productivity of subcontractors and suppliers

6.13. Failure of subcontractors and suppliers
6.14. Deference practice among foreign contractors and domestic contractors
6.15. Variability in project logistics

<u>Group 7: Managerial Risks</u>

7.1. Lack or inappropriate risk management
7.2. Changes in WBS (work breakdown structure)
7.3. Lack of comprehensive recognition of WBS
7.4. Incorrect estimation of time, cost and resource in accordance with WBS
7.5. Ambiguous guidelines about managerial processes
7.6. Management inefficiency (Poor or outdated project management methodology)
7.7. Inadequate project organization structure
7.8. Inexperienced and incompetent project management team
7.9. Offering poor solutions from the management team
7.10. Inadequate coordination between contractors and subcontractors
7.11. Improper coordination between project team members
7.12. Poor management control system
7.13. Lack of motivating attitudes
7.14. Poor and slow decision making procedure
7.15. Improper selection of project location
7.16. Late internal approval process by the owner
7.17. Linguistic communication problems (Inaccurate or faulty understanding of duties and responsibilities in a multinational project team)
7.18. Misguidance of client
7.19. Improper and unrealistic project planning, scheduling, controlling and budgeting
7.20. Improper logistic planning
7.21. Lack of constant development planning
7.22. Improper construction planning
7.23. Improper human resource planning
7.24. Delay in approval of detailed project report
7.25. Delay in preparation of control reports
7.26. Poor communications between clients, partners, contractors, head office, etc.
7.27. Poor relationship with client
7.28. Poor relation and dispute with partners
7.29. Poor relation between dependent projects
7.30. Poor relation with government departments
7.31. Cost-benefit prioritization default

7.32. Failure to properly execute corporate strategy

7.33. Poor standard of safety management (site accidents due to negligence)

Group 8: Operational Risks

8.1. Lack of operating techniques

8.2. Inexperienced operational team

8.3. Operating technology selection default

8.4. Complexity level of operating

8.5. System outages

8.6. Water, Gas and electricity supply cut off

8.7. Improper equipment condition and reliability

8.8. Equipment damage

8.9. Poor maintenance and service quality

8.10. Lack of examinations

8.11. Insufficient precaution during operation procedure

8.12. Poor performance of contractors

8.13. Operational hazards, including blowouts, spills, personal injury

8.14. Accidents including marine events, process leaks, non-process fires, dropped objects, marine collisions, transport accidents, structural events, diving accidents, attendant vessel accidents

8.15. Damage to marine echo systems or polluting the environment during the operation

8.16. Lack of adequate process

8.17. Operator liability

8.18. Concession company default

8.19. Low productivity

8.20. Delays or interruption in operation because of prolonged downtime

Group 9: Contractual and Legal Risks

9.1. Inadequate or unavailable insurance coverage

9.2. Change in laws and regulations

9.3. Fault in laws

9.4. Inefficiency of applied laws

9.5. Insufficient laws on projects

9.6. Inefficiency of legal process

9.7. Conflict of laws

9.8. Legal problems of work, employment and residence of foreign workforce

9.9. Amendments to standard form

9.10. Delay in contractual clearances
9.11. Delay in signing contract
9.12. Delay in development approvals
9.13. Property leasing contractual issues
9.14. Insolvency of concession company
9.15. Termination of concession by concession company or government
9.16. Conflict and arbitration problems
9.17. Adverse government action or inaction
9.18. Land expropriation and sequestration
9.19. Contractual violations by government owned
9.20. Contractual violations by private supplier
9.21. Breach of financial documents
9.22. Fraudulent practices
9.23. Inadequate type of contract
9.24. Inadequate tendering price
9.25. Payment failure by the government
9.26. Contractual liabilities
9.27. Changes of policies by government (unsupportive government policies)
9.28. Default by concession company
9.29. Government interference
9.30. Permits and government approval (delay in approval of major utilities like telecom cables, electricity cable, water pipelines)
9.31. Government regulatory requirements
9.32. Bureaucratic government system
9.33. Late approval by lender (bank or money borrower company)
9.34. Lender interference
9.35. Inflexible and complex rules and regulations of lender
9.36. Lack of lender cooperation
9.37. Corruption and bribery
9.38. Exclusivity regulations
9.39. Inadequate tendering the owner
9.40. Creditworthiness and reliabilities
9.41. Ambiguous conditions of contract
9.42. Strict workforce safety policies
9.43. Work conditions deferring from the contract
9.44. Environmental, pollution or health restriction and regulations
9.45. Wrong interpretations of contracts

Group 10: Natural Environment Risks (Natural Hazards and Disasters)

10.1. Extreme weather condition like hurricane, cyclonic storms and wind damage
10.2. Extreme weather condition like heavy rain, heavy snow, hail storm
10.3. Tidal waves
10.4. Landslide
10.5. Volcanic eruption
10.6. Earthquake
10.7. Flood
10.8. Wildfire
10.9. Tsunami
10.10. Contributing to the future natural hazards (sand storm, dust storm, drought)
10.11. Unknown events within the project environment

Group 11: Political Risks

11.1. Changes in political relations
11.2. Sanctions and embargoes
11.3. National and international political force majeure events and crisis like rebellion, revolution, insurrection, military or usurped power and war
11.4. Political interference from the power

Group 12: Social and Cultural Risks

12.1. Social unacceptability
12.2. Faulty social impact assessment (includes the processes of analysing, monitoring and managing the intended and unintended social consequences)
12.3. Uncontrolled immigration
12.4. Public interference for changing the alignment
12.5. Dispute with residents around site
12.6. Lack of coordination among public agencies concerned
12.7. Lack of public consultation
12.8. Damage to the work by a third party
12.9. Environmental protection pressure of other groups
12.10. Ethnic, racial and relationship discriminations
12.11. Failure to understand the customs and traditions of other countries or site location locals

Group 13: Site Related Risks

13.1. Inaccurate specification of site conditions

13.2. Poor site conditions (Poor geotechnical condition, Inadequate supporting structures, etc.)
13.3. Inappropriate accessibility to site (bad road condition, denied access by villagers, lack of access facilities, difficulty of access)
13.4. Geographic limitations (Limitations arising from the far distance)
13.5. Site preparation problems (Site redemption, tenure, pollution/discharge, obtaining permits, community liaison, Pre-existing liability)
13.6. Land use (Native title, cultural heritage)
13.7. Site labour dispute, agitation and strikes
13.8. Unforeseen ground conditions for implementation of Project at project site

Group 14: Security Risks

14.1. Terrorism
14.2. Sabotage
14.3. Insecure location of head office and project site
14.4. Visibility limitations
14.5. Theft from project site
14.6. Defective security structure
14.7. Improper enforceability of security
14.8. Inaccessibility to functional and advance security equipment and technologies
14.9. Inexperienced security forces

Group 15: Asset Risks

15.1. Technical obsolescence
15.2. Facilities lease termination
15.3. Residual transfer value

Group 16: Competition Risks

16.1. High level of competition
16.2. General industry competition
16.3. Competition from alternative energy sources
16.4. Competition from new alternative technology

Group 17: Reserve Risks

17.1. Inability to expand or find replacement reserves
17.2. Inaccurate reserve estimates and assessment
17.3. Default by developer

The determined major risk groups of oil and gas projects has been illustrated in Figure 3-3. It is noticeable that classification proposed in this study is one of the several classifications that can be considered for risk factors. As a matter of fact, the author believes that the classification of risks like the inherent of risk is a dynamic phenomenon and suggesting a specific classification of risk for all oil and gas companies or even similar projects cannot resolve current risk management problems. So it is very rational that the departments involved in risk management consider companies' policies and strategies, size, type and domain of activity and many other parameters to build a proper classification or a hierarchy of risk factors.

Due to the large number of the identified risk factors and major risk groups and in accordance with the framework and objectives of this study, the "*Construction Risk*" group is selected for applying the fuzzy risk management approach using the proposed model illustrated in Figure 3-1. The description of each risk factor of this group and the principles that can be used for categorizing them will be discussed in the next chapter of this script.

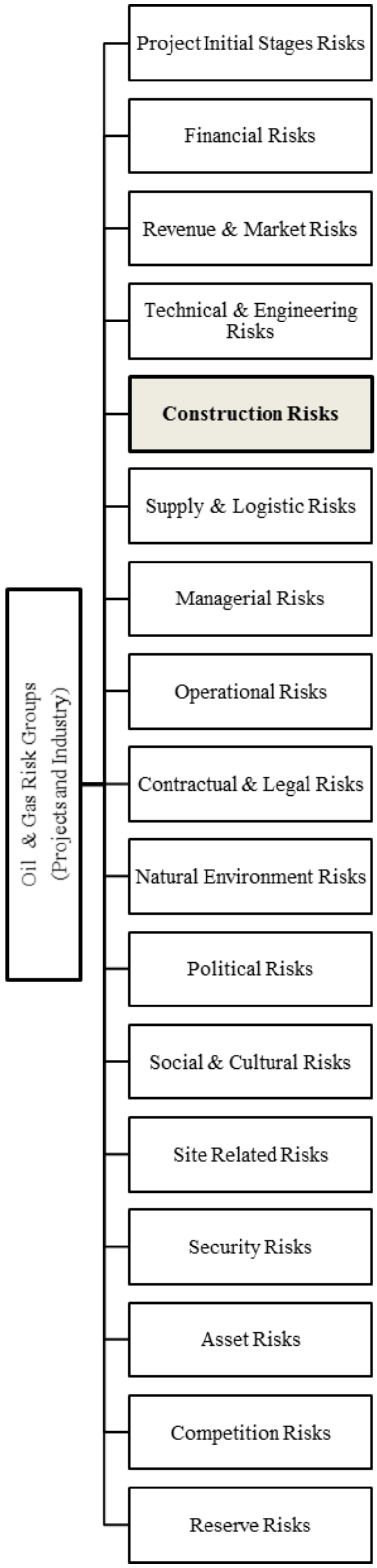


Figure 3-3: Major risk groups of oil & gas projects and industry

3.3.1. Construction Risks Group

As mentioned in previous sections of this script, one of the most important considerations during the risk identification and assessment is to distinguish a risk from an event. Risk and event are completely two independent issues. A risk has a probability of occurrence where if it occurs there will be negative consequences, while an event is an occurred risk. Construction risk groups surveyed in this study included risk factors that may occur during the construction phase. It is inevitable that some of these risk factors appear in other risk groups such as technical or managerial or at several stages of a project such as initial stages or operational phase however, in this case they would have different probability and consequence. For example, the risk of equipment failure, damages to the environment, human fatalities and injuries and extreme weather condition are probable to happen in the operational phase, however, they would affect the project objectives in various ways.

In this study, as illustrated in Figure 3-4, Figure 3-5 and Figure 3-6, the classification of risk factors under construction risk group were performed based on three principles as follows:

- Impact of natural environment on the construction project
- Internal interaction between construction risk factors
- Impact of construction project on environment

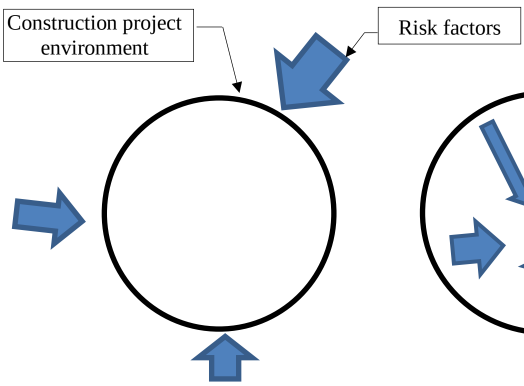


Figure 3-4: Impact of natural environment on construction project

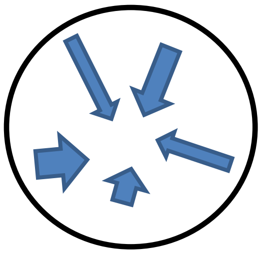


Figure 3-5: Internal interaction between construction risk factors

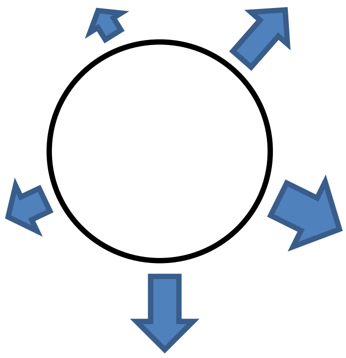


Figure 3-6: Impact of construction project on environment

The structure of construction risk factors' classification using the above principles has been illustrated in Figure 3-7.

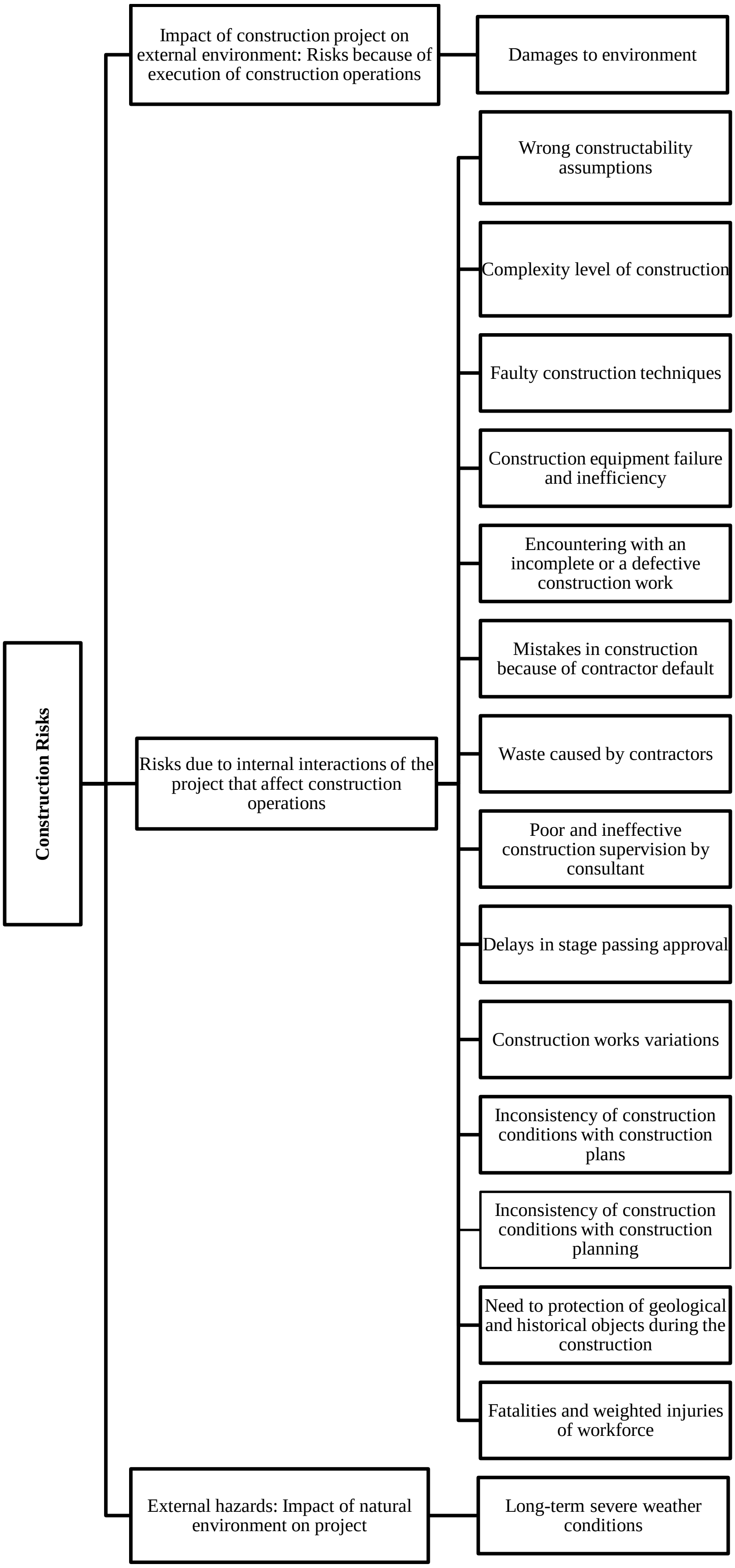


Figure 3-7: Construction risk structure

3.3.2. Description of construction risk factors

To have a reliable and converged assessment of risk factor, it is essential to provide a short description of each risk factor of the construction risk group.

3.3.2.1. Wrong construction assumption

Modern construction management approaches define the constructability term as "*the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels*" (Sanchez, Hampson, & Vaux, 2016). Difficult design documents and incorrect interpretation may result in a wrong constructability assumption that can affect the goals, performance, quality and ease of construction a project.

3.3.2.2. The complexity level of construction

Increasing the size and complexity level of a project can expose its construction stage to significant uncertainties and make it difficult to implement, inspect and managed. Oil and gas construction projects are inherently huge, complex and dynamic, so in this case the risk factor is unknown or unpredicted probable event due to the complexity level of construction that may occur and have negative impacts on the construction process.

3.3.2.3. Faulty construction techniques

Selecting and using any kind of imperfect, false, inaccurate, unreliable or malfunctioning construction method has serious consequences on project objectives.

3.3.2.4. Construction equipment failure and inefficiency

Old or even new construction equipment can fail or be inefficient, which may be as a result of defective design or defective manufacturing or poor maintenance and repair. Corruption, overuse or inappropriate training can also cause failure and inefficiency of equipment. In construction projects failure of motorized equipment like cranes, lifts, forklifts, bulldozers, loaders, trucks, excavators or failure of hydraulic lines, brake lines, cables, bolts, pumps, pressure tanks and compressed air lines are considered as common examples of equipment failure.

3.3.2.5. Encountering with defective or incomplete construction work

Sometimes a construction work activity cannot be completed or is completed defectively because of reasons such as inadequate financial, technical or logistic supports or even legal conflicts. This may lead to dismiss the current contractor by the owner and transfer the job to another contractor. So the new contractor team members encounter with an incomplete or defective work that may have consequences for project objectives.

3.3.2.6. Mistakes in construction because of contractor default

Failure to perform specific characteristics of a construction work indicated in contractor's obligations because of delinquency, negligence, insufficiency or error of the contractor.

3.3.2.7. Waste caused by contractors

In general, any direct or indirect loss produced by contractors' activity that doesn't add any value to the product and has negative impacts on time, cost, resources, and other objectives of a project are called waste. Inefficient work practices and processes, waiting periods for materials, repairs, equipment, instructions and resources, poor performance, wastage of materials because of too much inventory on site, unnecessary material handling, nonstandard specifications, damages and loss of materials because of improper storage of materials are kinds of waste caused by contractors and subcontractors.

3.3.2.8. Poor and ineffective construction management by consultant

Ineffective supervision on contractors and subcontractors' work, inadequate quality control, ineffective coordination between client, contractors and consultant head office, supervising by not an appropriately licenced person, not checking the contractors' licence to make sure that the work is carrying out by a qualified team or person, inappropriate supervision on fixing the defective or nonstandard work by contractors, non-permanent presence of site supervisor or irregular inspection by site supervisor, improper supervision on health and safety regulations, etc. can raise many issues, lead the work doesn't meet the standards and encounter the project objectives with serious dangers.

3.3.2.9. Delays in stage passing approval

Disapproval of job by client or consultant because of low construction quality, failure to meet performance criteria, commissioning tests failure, failure to properly correct the defective work by contractors, disagreements and conflicts between consultant and contractors about statements, job terms and conditions, etc. and failure to complete the extra items are some of reasons that can cause delays in approval of contractors' work and passing the stage.

3.3.2.10. Construction variations

Variations in schedule, scope and specifications of construction activities when the project is in the construction phase due to extra demands by the owner, new required obligations and standards, design reviews, new information, missing data, inability to build as specified and procurement or budget restrictions.

3.3.2.11. Inconsistency of construction conditions with construction plans

Any unexpected inconsistency between construction conditions and construction specifications identified in the construction plans due to wrong implementation or faulty interpretation of construction siting, direction, level, dimension, form, etc.

3.3.2.12. Inconsistency of construction conditions with construction planning

Any unexpected inconsistency of construction conditions with planning due to missing or faulty information about the construction site conditions, inadmissible land use, inability to install the required equipment or using the power supplies, inability to get required permissions, etc. are in this major group.

3.3.2.13. Need to protect the geological and historical objects during the construction

At times due to inadequate investigations, inaccurate or lack of data about an undiscovered location it is required to provide protection for historical or geological objects during the construction phase. This factor can cause delays in completion of the project, cost overrun or even change the scope of the project. In another form, it is possible that oil and gas projects take place in areas inhabited or used by indigenous people. In this case unplanned land use during the construction or development projects may be able to seriously affect the indigenous people, their heritage and culture that requires its special protection needs.

3.3.2.14. Fatalities and weighted injuries of workforce

This item is a criterion to measure the workforce safety. Most of fatalities and injuries of work force during the construction caused by industrial accidents or failure to follow safety procedures. Fire, explosion, improper use of equipment, equipment failure, vehicle accidents, fatigue, failure of individual workers to follow safety procedures, lack of safety knowledge of the present hazards, failure to use PPE, inadequate workplace layout and many other factors can cause serious weighted injuries or fatalities of the workforce.

3.3.2.15. Damage to environment

This category includes negative and destructive short term or long term impacts of oil and gas construction projects on the natural environment including water, soil and air. Seas, rivers, oceans, forests, fertile lands, air and all marine and terrestrial ecosystems can be affected by realising high quantity of exhausted gases and particular matters, deforestation, chemical influences, spills and blowouts, etc. due to construction of oil and gas projects such as exploration and production platforms, pipelines, refineries, etc.

3.3.2.16. Severe temperature and weather conditions during the construction

Very low or very high weather temperature, heavy wind, dust or fog, heavy snow, rain and hail, have adverse effects on construction activities and executing operations, these factors can cause serious injuries to the workers and operators or heavy damages to the construction equipment which may result in completely stop or slowing down the construction procedure. Extremely cold and below freezing temperature can cause the water or even fuel supplies freezing or potentially life threatening conditions such as frostbite, hypothermia. Very hot and dry temperature can cause fatal injuries such as heat stroke, dehydration and heat exhaustion or formation of dry dust that can make breathing very dangerous. Dirt because of dust can damage machinery and equipment and increase the cost of maintenance, cleaning and breakdown repair. Windy conditions can cause load swinging and rotating, backward fall of crane booms, instability and collapse of the structures. Heavy snow, rain and hail can bring down the utility poles and power lines or cut the supply flow and disrupt the construction. Other severe weather conditions such as heavy fog or dust can increase the risk of vision loss and cause serious crashes.

A short description of each construction risk factor has been presented in Table 3-1.

Table 3-1: Construction risk factors and descriptions

No	Risk Factor	Description
1	Wrong constructability assumptions	Ineffective integration of construction knowledge into the construction
2	Complexity level of construction	Increasing the uncertainties due to the huge size and complexity
3	Faulty construction techniques	Choosing imperfect, false, inaccurate, unreliable or malfunctioning construction method
4	Construction equipment failure and inefficiency	Equipment failure due to obsolescence, bad maintenance or wrong use
5	Encountering with an incomplete or a defective construction work	Due to transferring or devolving an incomplete job to another contractor
6	Mistakes in construction because of contractor default	Failure to perform specific characteristics of a construction work indicated in contractor's obligations
7	Waste caused by contractors	Direct or indirect loss of material, time, equipment, etc. due to contractors' activity
8	Poor and ineffective construction management by consultant	Inappropriate, irregular or ineffective supervision by consultant on contractors' work, required coordination and implementation of health and safety regulation
9	Delays in stage passing approval	Delays in approval because of low construction quality, failure to meet performance criteria, commissioning tests failure, etc.
10	Construction work variations	Variations in schedule, scope and specifications of construction activities

11	Inconsistency of construction conditions with construction plans	Unexpected inconsistencies due to wrong implementation or faulty interpretation of construction siting, direction, level, dimension, form, etc.
12	Inconsistency of construction conditions with construction planning	Unexpected inconsistency due to missing or faulty information about the construction site conditions, inadmissible land use, inability to install the required equipment or using the power supplies, inability to get required permissions, etc.
13	Need to protect the geological and historical objects during the construction	Need to provide protection for historical or geological objects during the construction phase due to inadequate investigations, inaccurate or lack of data about an undiscovered location
14	Fatalities and weighted injuries of workforce	Human safety loss due to industrial accidents or failure to follow safety procedures such as fire, explosion, improper use of equipment, equipment failure, vehicle accidents, fatigue, lack of safety knowledge of the present hazards, failure to use PPE, inadequate workplace layout, etc.
15	Damage to environment	Negative and destructive short term or long term impacts of oil and gas construction projects on the natural environment including water, soil and air and their ecosystems
16	Severe temperature and weather conditions during the construction	serious injuries to the workers and operators or heavy damages to the construction equipment due to very low or very high weather temperature, heavy wind, dust or fog, heavy snow, rain and hail

3.4. Defining linguistic terms of risk parameters

For extracting the experts' judgment about the risk parameters which are risk likelihood, risk impact and risk magnitude five linguistic terms of Very Low (VL), Low (L), Moderate (M), High (H) and Very High (VH) were defined. These linguistic terms are supposed to evaluate the following attributes of each risk parameter:

1. The occurrence probability or happening chance of a risk factor
2. The magnitude of impact or the magnitude of consequence of a risk factor on project objectives including time, cost, quality and scope
3. The magnitude of total risk

3.5. Defining scaling system and type of answering to the questions

At this stage we need to define a scaling system for constructing the fuzzy membership functions associated with the linguistic terms of Risk Magnitude (RM), Risk Likelihood (RL) and Risk Impacts (RIs). This scale will be used for setting the questionnaires and measuring the risk factors to each of risk variables. There are different types of answering to the question as follows:

- Multiple choice radio button: respondent can select only one answer
- Multi choice check box: respondent can select multiple answers
- Drag & drop ranking: respondent can drag and drop items to order a list
- Star rating: respondent can select a star rating
- Single text box: respondent can enter text
- Matrix of choices (radio button): respondent can select an answer per row
- Matrix of choices (check box): respondent can rank multiple answers using ranking more than once
- Multiple text boxes: question has multiple text inputs such as address
- Pictures and text/presentation: used to display information
- Order ranking/list of items: respondent can rank answers once using rank once
- Slider: respondent can use a slider to select a value

Some online survey making tools provide various scaling systems and question formats for producing questionnaires. A convenient scaling system presented in a proper graphical format can be a powerful tool for eliciting the qualitative perceptions of the expert's mind. As a very simple example using a slider scale instead of a ten-point scale looks like that we treat the expert's mind as a spectrum of colours instead of a limited number of colours with clear boundaries as it provides a better visualisation for the expert to express his judgment. This comparison has been illustrated in Figure 3-8.

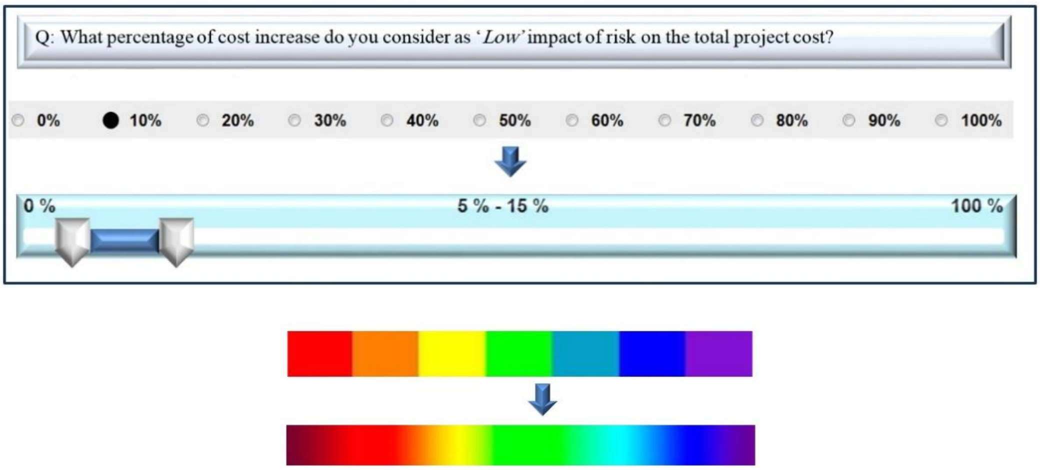


Figure 3-8: Comparison between multi choice answer and slider choice with rainbow colour spectrum

In this study, we use a scale between 0 to 100 with a slider tool to elicit the experts' judgments and assessment about the risk factors and risk variables.

3.6. Data collection about the variables

In the first part of this section we review the different applied methods for collecting the required data about the variables, including, the likelihood of occurrence and the impact magnitude of the risk factors and also the required data for constructing the membership functions of variables' linguistic terms. Then, the formula for calculating the sample size of the study will be discussed.

3.6.1. Methods of data collection

There are several methods for obtaining the required information such as follows:

1. Using current data and documents: In conducting the studies, some of the required data and information are available and can be collected through accessibility to the sources such as relevant standards and guidelines, governmental documents, company's reports and results of previous researches and studies. In this research the mentioned sources were used for constructing the membership functions associated with the qualitative perceptions of different levels of risk probability and risk magnitude (Very low, Low, Moderate, High, Very High).
2. Questionnaire: In this study, a closed questionnaire in two forms of hard copy and online survey version was provided and used to investigate the experts' judgments and assessments about the probabilities and consequences of the identified risk factors. This questionnaire that has been attached to this script as Appendix 1 includes four question regards to each linguistic term of risk impact (VL, L, M, H, VH) on five project objectives (Time, Cost, Quality, Scope) and five questions regards to each risk factor assessment: the probability of construction risk factor occurrence in an oil and gas project and its impact on four project objectives. Thus, each respondent needed to answer one hundred questions.

3.6.2. Statistical population and sample size

Statistical population includes all the elements and people who have one or several attributes in common. If the statistical population is large, due to limited sources, it is inevitable that the researcher takes a definite number among the statistical population as a sample and studies the characteristics and attributes of the whole population through investigating this limited population and calculating its statistical indexes. This limited population is called a statistical sample.

There are several methods for sampling that are categorized under two major groups: probability sampling and nonprobability sampling. Probability sampling methods such as simple random sampling, systematic random sampling, stratified sampling and cluster sampling the selection of individuals are random to make sure that selection is based on chance and there is an equal chance of being selected for any of the sample members. In nonprobability sampling method no random technique is used and the information is obtained from specific people or groups that have required experience or knowledge about the subject of study. This kind of sampling is intentional sampling.

Since the parameters considered in this study included a wide range of variables regard to construction risk factors of oil and gas projects so the statistical population must be consistent of various skills, specialties and diverse disciplines related to this field including contractors, consultants, researchers and employers. Thus a nonprobability sampling technique using the Cochran's formula for calculating the sample size of large statistical population (a population with more than 30 members) (Cochran, 2007), was used to calculate the sample size and providing enough questionnaires to obtaining the required information. (Equation 3-1)

$$n = \frac{z_{\alpha/2}^{2}.p.(1-p)}{d^{2}}$$ Equation 3-1

Where:

n :sample size

α: confidence level. This value indicates that with what confidence the true value of the parameter lies within the confidence interval. With α=0.1 the confidence level would be 90%.

z: z-score. This constant value is obtained from normal distribution curve based on the confidence level (α). The z-score corresponds to α=0.1 is 1.64

p :indicates the existence of an attribute in the population. In this case the reliability of the completed questionnaires is the attribute. This value can be obtained from previous similar studies or based on a conservative estimation. In this study *p=0.9* which means we assume that 90 percent of questionnaires have been completed accurately by the correspondents.

d: Error level. This value indicates the allowed error percentage in the measuring of an index, which in this case is the sample size. As a matter of fact, error interval determines the negligible higher or lower amount of the sample mean from the population mean. In this study, 10% error level has been considered as allowed error level for calculating the sample size.

By replacing the assumed values (α=10%, z=1.64, p=90%, d=10%) in equation 5.1 the sample size is calculated:

$$n = \frac{1.64^{2} \times 0.9 \times (1-0.9)}{0.1^{2}} \approx 24$$

According to the calculated sample size, experts with relevant background and work experience in associated disciplines were surveyed through the hard copy questionnaires and also the electronic version of the questionnaire prepared using one of the most appropriate online survey making software.

3.6.3. Evaluating the linguistic terms of risk parameters and construction risk factors

Sixteen identified risk factors need to be evaluated by each expert of statistical population through questionnaires in two general sections of risk occurrence probability and risk factor impact on project objectives including time, cost, quality and scope. In this study five descriptive expressions and conceptual variables (Very Low, Low, Moderate, High and Very High) have been assigned to each of five assessment situations associated with each risk factor. This assessment can be done in one of the two following conditions:

<u>Condition 1:</u> Predefined intervals of linguistic terms are available

In this condition the intervals of linguistic terms of risk likelihood and risk impacts can be defined using the previous records, experience or through collecting the initial information about oil and gas construction projects. In this case, for converging the experts' judgments the questionnaires are presented with intervals for quantitative parameters like schedule and cost beside the descriptive expressions. In this case the assessment of each risk factor can be done by checking the related box on the same questionnaire.

In this condition, as illustrated in Figure 3-9 and Figure 3-10, the probability and consequence of each risk factor on each project objectives which are the required input values of the fuzzy inference system, are calculated based on the average of frequencies of intervals using Equation 3-2.

Equation 3-2

$$I_{Ci}, I_{Ti}, I_{Qi}, I_{Si}, P_i = \frac{\sum_{k=1}^{n} M_k . f_k}{\sum_{k=1}^{n} f_k}$$

Where:

P_i : Probability of risk factor (*i*)

$I_{Ci}, I_{Ti}, I_{Qi}, I_{Si}$: Impact of risk factor (*i*) on project' Cost, Time, Quality and Scope

M_k : Midrange of k^{th} linguistic term interval

f_k : Frequency of midrange of k^{th} linguistic term interval

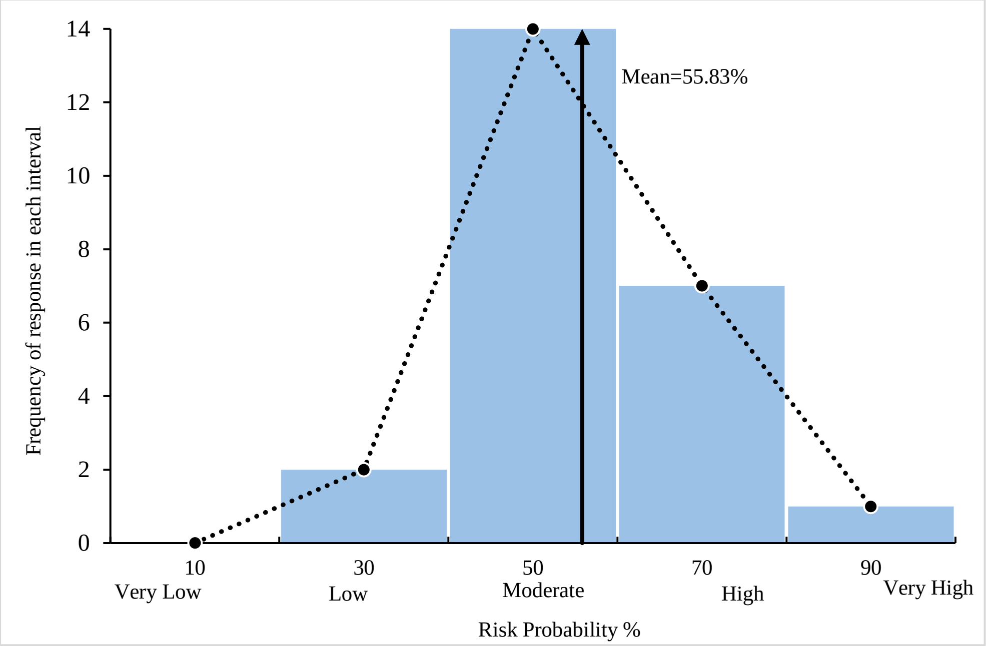


Figure 3-9: Frequency chart for probability of 'Poor and ineffective construction management by the consultant' risk factor

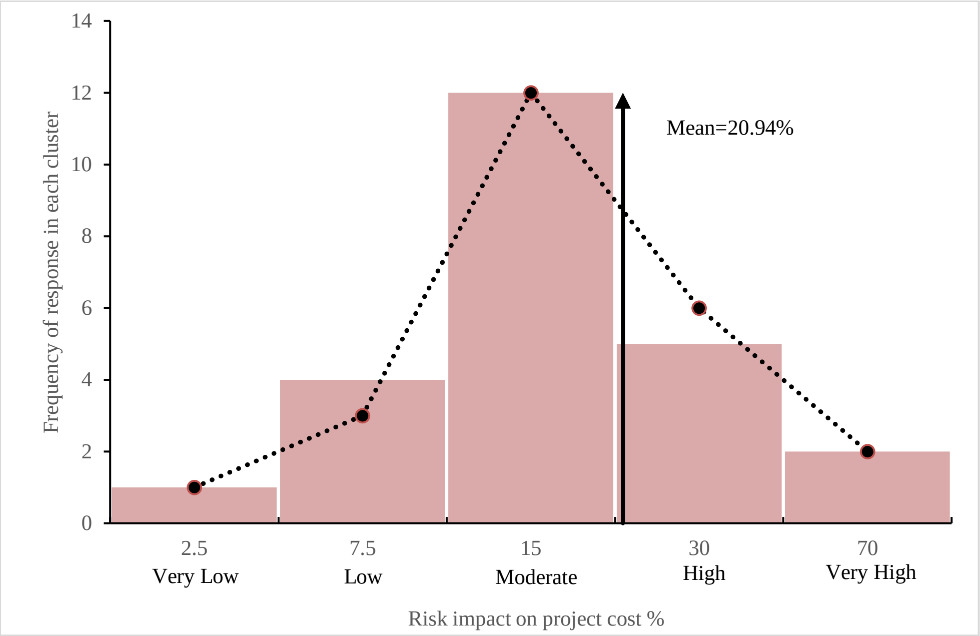


Figure 3-10: Frequency chart for risk impact of 'Poor and ineffective construction management by the consultant' on the project cost

The format of the questionary in this condition has been illustrated in Table 3-2.

Table 3-2: Questionary format when predefined intervals of linguistic terms are available

		Risk Likelihood of occurrence (Midrange%)					Risk impact on project objectives																				
							Time (Schedule Slippage)					Cost (Increase)					Quality (Reduction)					Scope (Change)				
No	Risk Factor	Very Low (10%)	Low (30%)	Moderate (50%)	High (70%)	Very High (90%)	Very Low (<5% contract time)	Low (5-10% contract time)	Moderate (10-20% contract time)	High (20-40% contract time)	Very High (>40% contract time)	Very Low (<5% total contract cost)	Low (5-10% total contract cost)	Moderate (10-20% total contract cost)	High (20-40% total contract cost)	Very High (>40% total contract cost)	Very Low(Quality degradation Barely noticeable: <5% quality reduction)	Low (Only very demanding applications are affected: 5-10% quality reduction)	Moderate(Quality reduction requires client approval: 10-20% quality reduction)	High(Quality reduction unacceptable to the client: 20-60% quality reduction)	Very High(Project end item is effectively unusable: >60% quality reduction)	Very Low(Scope decrease barely noticeable: <2% scope reduction)	Low(Minor areas of scope are affected: 2-5% scope reduction)	Moderate(major areas of scope are affected: 5-10% scope reduction)	High(Scope reduction unacceptable to the client: 10-20% scope reduction)	Very High(Project end item is effectively useless: >20% scope reduction)
1	Wrong constructability assumptions																									
.	.																									
.	.																									
16	Severe temperature and weather conditions																									

<u>Condition 2:</u> Inaccessibility to predefined intervals of linguistic terms

When there is not enough records and information about previous similar projects or when we want to redefine these intervals by a specific group of experts, then the required information should be obtained in two steps: first we need to ask the experts to assign an interval to each linguistic term and descriptive expression associated with each parameter. In this study the usual and predefined intervals using the PMBOK guide have been assigned to risk magnitude and risk probability so in this step only the numeric values corresponding to linguistic terms of risk impacts are investigated (PMI, 2013). The format of the hard copy questionary and electronic survey in this step has been illustrated in Table 3-3 and Figure 3-11 respectively. In the second step the likelihood and impact of each risk factor on project' objectives are evaluated by the experts.

Table 3-3: The questionary for defining the linguistic intervals of risk parameters

What interval do you assign to each linguistic term associated with each risk impact?		
Risk Impact	**Linguistic term**	**Interval (…to… %)**
Schedule slippage	Very Low	**(…to… %)**
	Low	**(…to… %)**
	Moderate	**(…to… %)**
	High	**(…to… %)**
	Very High	**(…to… %)**
Cost increase	Very Low	**(…to… %)**
	Low	**(…to… %)**
	Moderate	**(…to… %)**
	High	**(…to… %)**
	Very High	**(…to… %)**
Quality reduction	Very Low (Quality degradation Barely noticeable)	**(…to… %)**
	Low (Only very demanding applications are affected)	**(…to… %)**
	Moderate (Quality reduction requires client approval)	**(…to… %)**
	High (Quality reduction unacceptable to the client)	**(…to… %)**
	Very High (Project end item is effectively unusable)	**(…to… %)**
Scope change	Very Low (Scope decrease barely noticeable)	**(…to… %)**
	Low (Minor areas of scope are affected)	**(…to… %)**
	Moderate (major areas of scope are affected)	**(…to… %)**
	High (Scope reduction unacceptable to the client)	**(…to… %)**
	Very High (Project end item is effectively useless)	**(…to… %)**

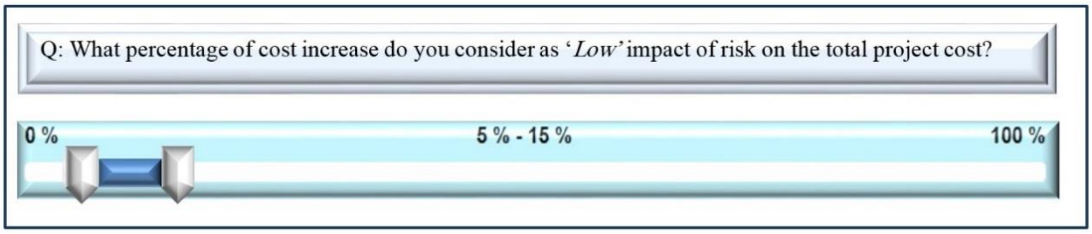


Figure 3-11: Schematic form of electronic survey for investigating the linguistic terms of risk impact

3.6.4. Statistical tests

In this section, before introducing the techniques for constructing the required fuzzy membership functions of risk parameters and starting the fuzzy analysis on the collected questionnaires which is finally will be used for prioritizing the risk factors and determining the numerical values of construction risk factors, first we need to perform some essential statistical tests on the data of collected questionnaires filled by experts using the SPPS (Statistical Package for the Social Sciences) which is a powerful application of statistical sciences. This software systematically performs most of the analyses and tests related to reliability of statistical data.

To investigate the collected data first we need to answer the following questions:

1. Does the collected data follow a normal distribution or not?
2. How much the collected data are reliable?

To perform these tests, all collected data about sixteen construction risk factors assessed by twenty-four experts in probability of occurrence and their impact on time, cost, quality and scope of oil and gas projects was entered into SPSS.

3.6.4.1. Normality test of data

SPSS performs the test of data normality using, Shapiro-Wilk and Q-Q diagram. The results of Kolmogorov-Smirnov test Shapiro-Wilk test for sample risk factor have been presented by Table 3-4 and **Error! Reference source not found.** respectively.

Table 3-4: Kolmogorov-Smirnov test result for normality test of sample risk factor

Risk Factor	Risk Probability (P)	Risk Impact			
Poor and ineffective construction management by consultant		Time	Cost	Quality	Scope
Kolmogorov-Smirnov test coefficient	0.33	0.174	0.139	0.205	0.139
Significance factor	0.000	0.06	0.2	0.01	0.2

Table 3-5:Shapiro-Wilk normality test result of a sample risk factor

Risk Factor	Risk Probability (P)	Risk Impact			
Poor and ineffective construction management by consultant		Time	Cost	Quality	Scope
Shapiro-Wilk test coefficient	0.818	0.88	0.935	0.88	0.928
Significance factor	0.001	0.01	0.125	.008	0.86

For both Kolmogorov-Smirnov test and Shapiro-Wilk test SPSS calculates a significance factor. If this factor is between 0 to 0.05 it means that the data with a probability of 95% obeys from a normal distribution and if the coefficient is greater than 0.05 it means that data doesn't have a normal distribution (L. Cohen & Holliday, 1996). In this study, according to the significance factor calculated by SPSS using the mentioned statistical tests shows that many risk parameters related to risk factors are not normally distributed that demonstrates using merely the simple statistical methods is not efficient.

Figure 3-12 shows the Q-Q diagram for the sample risk factor. This diagram is used for a better presentation of data normality by showing the dispersion of a variable distribution to a normal distribution. If data belong to a normal distribution, then the points fall on a straight line (Norušis, 2008).

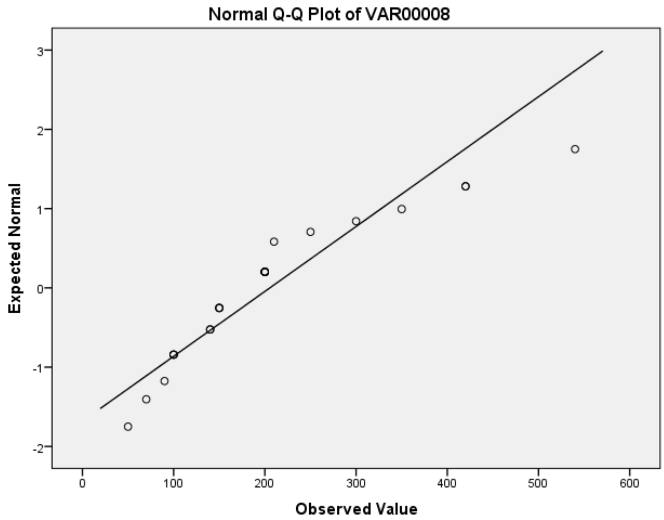


Figure 3-12: Q-Q diagram of normality test of sample risk factor (risk impact on project scope)

3.6.4.2. Reliability test of data

The reliability of a survey reflects its stability, consistency, predictability and accuracy. The reliability of a survey shows that how much the results of a survey stays the same if it is done again on another occasion using the same questions. In this study for investigating the reliability or the internal consistency of surveyed questionary we used Cronbach' alpha test by applying the SPSS software.

Cronbach's alpha (Cronbach, 1951) presented by Equation 3-3 is a measure of reliability. More specifically, alpha is a lower bound for the true reliability of the survey. Mathematically, reliability is defined as the proportion of the variability in the responses to the survey that is the result of differences in the respondents. That is, answers to a reliable survey will differ because respondents have different opinions, not because the survey is confusing or has multiple interpretations. The computation of Cronbach's alpha is based on the number of items on the survey (k) and the ratio of the average inter-item covariance to the average item variance (IBM, 2016)

$$\alpha = \frac{k\left(\overline{cov}/\overline{var}\right)}{1+(k-1)\left(\overline{cov}/\overline{var}\right)} \qquad \text{Equation 3-3}$$

Under the assumption that the item variances are all equal, this ratio simplifies to the average inter-item correlation, and the result is known as the Standardized item alpha or Spearman-Brown stepped-up reliability coefficient presented by Equation 3-4.

$$\alpha = \frac{k\,\overline{r}}{1+(k-1)\overline{r}} \qquad \text{Equation 3-4}$$

The reliability test of data was performed based on this assumption that the questionnaire has five separate sections including the risk factor' probability and risk impact on each project objectives. As each part of questionary focuses on a different factor and investigates an independent parameter, so for each risk parameter, a separate reliability test is needed. Table 3-6: Cronbach's alpha coefficient for risk parameters shows the Cronbach's alpha coefficients of risk parameters.

Table 3-6: Cronbach's alpha coefficient for risk parameters

	Risk Probability	Risk Impact			
		Time	Cost	Quality	Scope
Cronbach's alpha coefficient	0.62	0.76	0.7	0.67	0.71
Number of items	12	16	16	12	13

For evaluating the reliability of most of research tools like questionary a Cronbach's alpha coefficient of 0.7 or more is adequate. However, the acceptable limit of his value depends on many factors like nature of variables, length of survey, format of the response (e.g. true-false or multi choice, etc.) (Groth-Marnat & Wright, 2016). According to Table 3-6 the calculated Cronbach's alpha coefficients by SPSS for risk parameters are acceptable with a good approximation which proves the reliability of the questionnaire survey.

3.7. Defining fuzzy membership functions of risk components

Risk probability, magnitude of risk impact on project objectives and risk magnitude are considered as the three components of every risk. In this section the methods for obtaining the membership function of these components will be discussed.

3.7.1. Construction the membership functions of risk impacts

In this study, we tried to apply some developed tools and techniques to translate the qualitative judgments of experts into quantitative values and decrease the calculation errors as much as possible. These efforts can be summarized in designing an electronic questionary using the scroll bar scale along with applying statistical variables for defining the linguistic terms of risk impact on project' objectives and also for the assessment of each risk factor. Through a simple numerical example, we try to indicate the differences of our applied method with previous attempts.

By using the statistical parameters '*Mean*' and '*Standard deviation'* presented in Equation 3-5 and Equation 3-6, we define the required parameters used in the applied method for constructing the trapezoidal membership functions of risk impacts (Equation 3-7- Equation 3-10) as follows:

$$Mean : \bar{x} = \frac{\sum_{i=1}^{n}(x_i)}{N}$$ Equation 3-5

$$Standard\ deviation : \bar{\sigma} = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{N}}$$ Equation 3-6

$$LL_T = Min\{(\overline{LL}_i - \sigma_{LL}) \geq 0, (\bar{M}_i - \sigma_M) \geq 0, \min(LL_i)\} \quad i = 1, 2, ..., N$$ Equation 3-7

$$M_L = Min\{(\bar{M}_i - \sigma_M) \geq 0, (\overline{LL}_i + \sigma_{LL})\} \quad i = 1, 2, ..., N$$ Equation 3-8

$$M_R = Max\{(\bar{M}_i + \sigma_M) \leq 100, (\overline{UL}_i - \sigma_{UL})\} \quad i = 1, 2, ..., N$$ Equation 3-9

$$UL_T = Max\{(\overline{UL}_i + \sigma_{UL}) \leq 100, (\bar{M}_i + \sigma_M) \leq 100, \max(UL_i)\} \quad i = 1, 2, ..., N$$ Equation 3-10

Where:

M_i : The midrange of i^{th} interval (judgment)

LL_i : Lower limit of i^{th} interval

UL_i : Upper limit of i^{th} interval

LL_T : Total lower limit with μ=0 (Point a)

M_L : Left limit of midrange with μ=1 (Point b)

M_R : Right limit of midrange with μ=1 (Point c)

UL_T : Total upper limit with μ=0 (Point d)

σ_{LL} : Standard deviation of lower limits (LL_i)

σ_{UL} : Standard deviation of upper limits (UL_i)

σ_M : Standard deviation of midranges (M_i)

$\overline{LL}_i = \frac{\sum_{i=1}^{n} LL_i}{N}$: Mean of lower limits

$\overline{UL}_i = \frac{\sum_{i=1}^{n} UL_i}{N}$: Mean of upper limits

$\overline{M}_i \frac{\sum_{i=1}^{n} M_i}{N}$: Mean of midranges

3.7.1.1. Numerical Example 1

If the data of Table 3-7 shows the assessment values of four different experts about the linguistic term of '*Low'* impact on the '*project cost'*, Table 3-8 to

Table 3-10shows the results of the applied technique for obtaining the four points of the trapezoidal number of this linguistic term.

Table 3-7: the evaluation of linguistic term *'Low'* impact on total project cost increase by four experts

What interval do you assign to "Low" impact of risk impact on project cost?	
Expert 1	5-10 %
Expert 2	3- 6 %
Expert 3	2-8 %
Expert 4	4-10 %

Table 3-8: Calculating the lower limit of linguistic impact 'Low'

Parameter	LL_i	$\overline{LL}_i$	σ_{LL}	$\overline{LL}_i - \sigma_{LL}$	$\overline{M}_i - \sigma_M$	**min(** LL_i **)**	LL_T ***(point a)***
Value	5,3,2,4	3.5	1.12	2.38	4.26	2	2

Table 3-9: Calculating the upper limit of linguistic impact 'Low'

Parameter	UL_i	$\overline{UL}_i$	σ_{UL}	$\overline{UL}_i + \sigma_{UL}$	$\overline{M}_i + \sigma_M$	**max(** UL_i **)**	UL_T ***(point d)***
Value	10,6,8,10	8.5	1.66	10.16	7.27	10	10.16

Table 3-10: Calculating the midrange limits of linguistic impact 'Low' on project' increase cost

Parameter	M_i	$\overline{M}_i$	σ_M	$\overline{M}_i - \sigma_M$	$\overline{M}_i + \sigma_M$	$\overline{LL}_i + \sigma_{LL}$	$\overline{UL}_i - \sigma_{UL}$	M_L *(point b)*	M_R *(point c)*
Value	7.5,4.5,5,7	6	1.27	4.73	7.27	4.62	6.84	4.62	7.27

So the final trapezoidal fuzzy number of '*Low'* impact on the '*project' cost increase*' is: (2, 4.62, 7.27, 10.16) that has been shown in Figure 3-13.

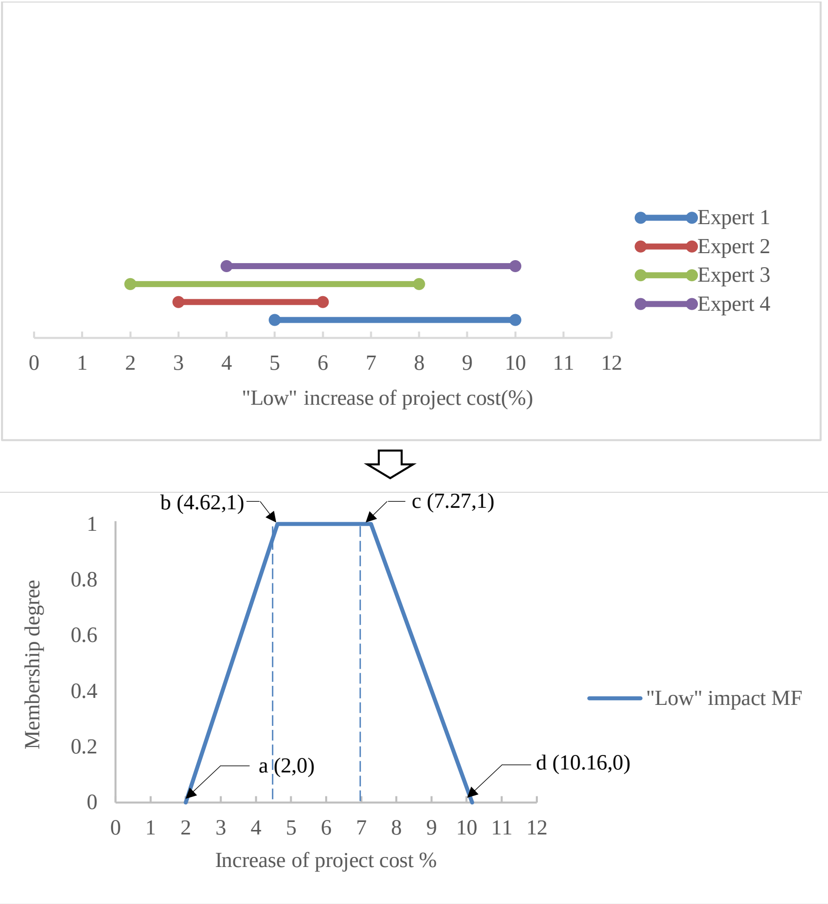


Figure 3-13: the estimated intervals for the linguistic term '*Low*' and corresponding final trapezoidal MF

To examine this method, we imagine an extreme condition when all these four experts determine a uniform specific interval for a linguistic term. For example, if all these experts define an increase between five to ten percent (5-10 %) as '*Low*' impact of project cost increase then the trapezoidal membership function of this linguistic term tends to a rectangular shape (5, 5, 10, 10) as the standard deviation values of low limits, midranges and upper limits of this interval would be equal to zero. In other words, based on these four experts' judgments we have no doubt that (5-10%) interval must be considered as '*Low*' impact of cost increase. In another extreme condition if all these experts don't determine an interval and decide to determine a constant value for a linguistic term (for example, 7.5%) then the trapezoidal membership function tends to singleton. In this case with 100 % certainty the '*Low*' impact of risk factors on the project cost increase would be 7.5%. Figure 3-14 illustrates these extreme conditions.

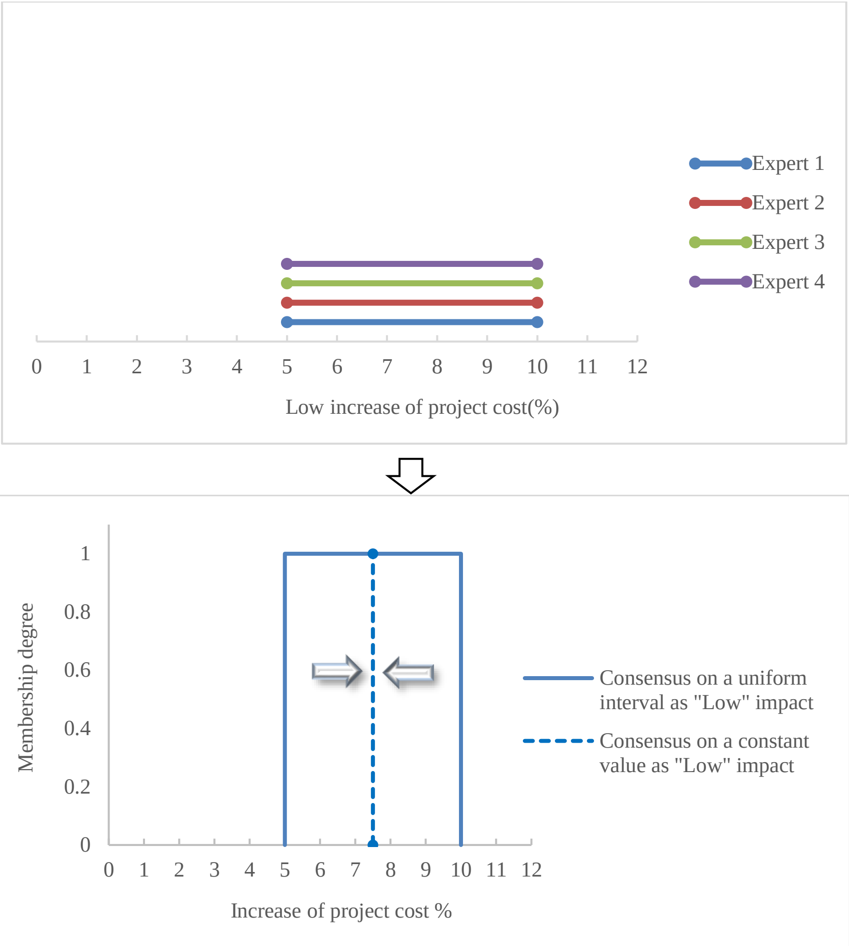


Figure 3-14: Extreme condition

As these examples indicate, we don't receive fuzzy judgments of experts to construct the membership functions of risk impacts. In fact, they provide us crisp sets of their judgments in the form of intervals and we apply mathematical techniques to analyse and aggregate the uncertainties existed in different interpretations of the qualitative concepts and construct the membership functions. When we ask an expert: what percentage of increase in project cost he knows as '*Low'* impact of risk factors and he determines the interval 5-10%, it means he knows all the real numbers in this interval as a '*Low'* consequence of risk factors on the total project cost increase.

In this condition to calculate the crisp inputs to the fuzzy inference system, the experts are asked to determine a quantitative estimation of the probability and consequences of each risk factor on each project objective using a single value considering their previous judgement. In the electronic version of the survey, a scroll bar has been designed for this purpose. The final crisp input would be the average value of estimations.

Since in this study the predefined fuzzy membership functions were not available, the study was conducted in condition 2 and the method described in this condition was used for constructing the required fuzzy membership functions and also collecting the experts' judgments about the probability and impact of risk factors on project objectives.

The error existed in the merely qualitative method during the collecting data for obtaining the crisp inputs was the main reason that we preferred to design a scale for respondents to provide a more accurate value of their estimations. In a merely qualitative method the midrange of interval is finally considered in calculating the average value. In fact, this method is not different from providing a situation for selecting a single option among the five given options that each of them presents the midrange of a predefined interval. This issue is explained through the following numerical example.

3.7.1.2. Numerical Example 2

The data resulted from assessing the impact of two different risk factors on project cost by four experts in conditions 1 and 2 has been shown in Table 3-11 and Table 3-12. All of them considered a 'Low' impact of these risk factors in condition 1 while they have assigned different values to these factors using a scroll bar that still belong to the 'Low' interval defined by them. The crisp input to a fuzzy inference system in condition 1 for both risk factors is equal to the midrange of '*Low*' membership function that determines same points on membership function '*Low'* with *μ=1* and membership function '*Moderate'* with *μ=0*. In condition 2, mapping the risk factors with different average value will result in different outcomes. In this condition and this example '*wrong construction assumption*' risk with an average value (*4.25)* determines one point on '*Very Low*' membership function with *μ=0.28* and one point on '*Low*' membership function with *μ=0.86* while mapping the risk factor '*long term severe weather condition*' with an average value (*7.5)* determines one point on membership function '*Low'* with *μ=0.92* and one point on the membership function '*moderate'* with *μ=0.46*. This difference can change the final ranking of risk factors. Figure 3-15 shows the fuzzification of two risk factors in condition 1 when experts must select one linguistic term among the five and in condition 2 when they can assign their preferred value on five membership functions due to different judgments of four experts about five linguistic terms of risk impact on the project cost presented in Table 3-13.

Table 3-11: Assessment of risk factor 'wrong construction assumption' in condition 1 and 2

What is the impact of '*wrong construction assumption'* risk on increasing the cost of an oil & gas project?				
	Condition 1: using a multi choice of linguistic terms for assessment			Condition 2: using scroll bar for assessment
	Linguistic term	Interval	Interval midrange	Value estimation
Expert 1	Low	(5-10)%	7.5 %	5 %
Expert 2	Low	(3-6)%	4.5 %	4 %
Expert 3	Low	(2-8)%	5 %	3 %
Expert 4	Low	(4-10)%	7 %	5 %
Final risk factor input	1/4(7.5+4.5+5+7) = 6			1/4(5+4+3+5) = 4.25

Table 3-12: Assessment of risk factor 'long term severe weather condition' in condition 1 and 2

What is the impact of '*long term severe weather condition*' risk on increasing the cost of an oil & gas project?				
	Condition 1: using a multi choice of linguistic terms for assessment			Condition 2: using scroll bar for assessment
	Linguistic term	Interval estimation	Interval midrange	Value estimation
Expert 1	Low	(5-10) %	7.5 %	9 %
Expert 2	Low	(3-6) %	4.5 %	5 %
Expert 3	Low	(2-8) %	5 %	7 %
Expert 4	Low	(4-10) %	7 %	9 %
Final risk factor Input	1/4(7.5+4.5+5+7) = 6			1/4(9+5+7+9) = 7.5

Table 3-13: The defined intervals by four respondents for linguistic scales of project cost increase

What interval do you assign to each linguistic term associated with each risk impact?					
Risk Impact	**Linguistic term**	**Interval (…to… %)**			
		Expert 1	Expert 2	Expert 3	Expert 4
Cost increase	Very Low	(0-5) %	(0-3) %	(0-2) %	(0-4) %
	Low	(5-10) %	(3-6) %	(2-8) %	(4-10) %
	Moderate	(10-15) %	(6-10) %	(8-15) %	(10-15) %
	High	(15-20)%	(10-15)%	(15-20)%	(15-25)%
	Very High	>20%	>15%	>20%	>25%

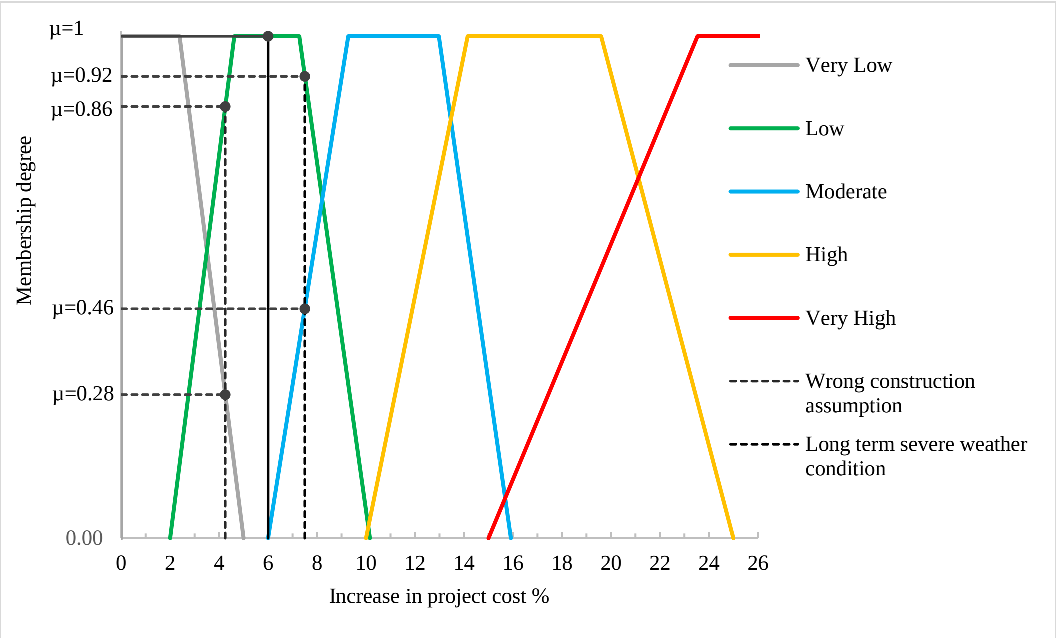


Figure 3-15: Fuzzification of two risk factors in condition 1 and 2 on fuzzy membership functions of risk impact on project cost

3.7.2. Risk probability membership functions

In this study triangular fuzzy membership functions which are one of the simplest forms of fuzzy membership functions were used for mapping the happening probability of risk factors. Five likelihood functions '*Very Low*', '*Low*', '*Moderate*', '*High*' and '*Very High*' were defined with probabilities of happening between 0 to 100 with midranges of 10, 30, 50, 70 and

90 % as shown in Table 3-14 and Figure 3-16. Figure 3-17 shows how constant progress has been assigned to terms '*Very Low*' to *'Very High'* for transition from the probability 0 % to the probability 100 % (fuzzy sets boundaries). The reasonable overlapping of functions ensures the required proper impact during the fuzzy inference.

Table 3-14: Risk likelihood membership functions limits

	Fuzzy membership functions range		
Linguistic Variable	The lowest limit of risk probability	The upper limit of risk probability	Interval midrange with μ=1
Very Low (VL)	0	40	10
Low (L)	0	60	30
Moderate (M)	20	80	50
High (H)	40	100	70
Very High (VH)	60	100	90

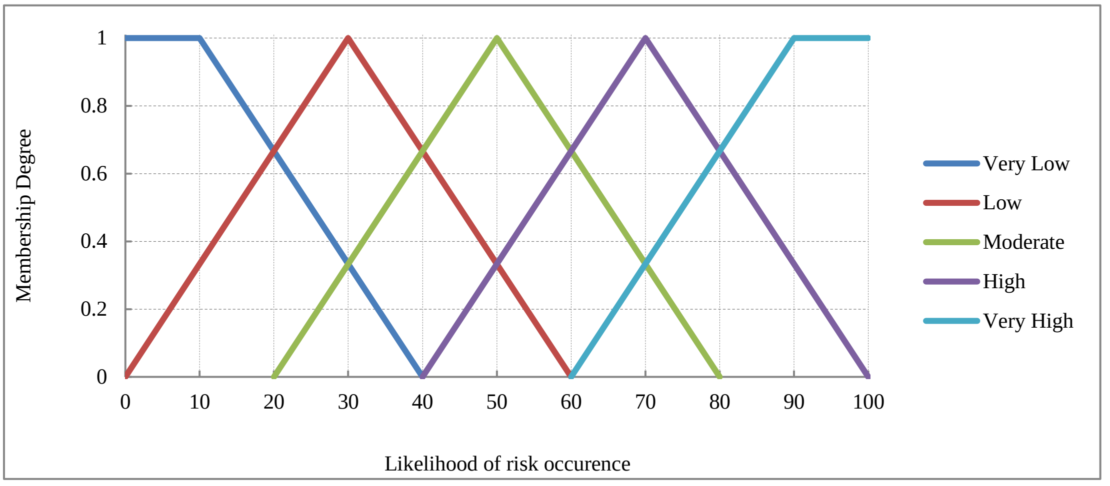


Figure 3-16: Risk occurrence likelihood membership functions

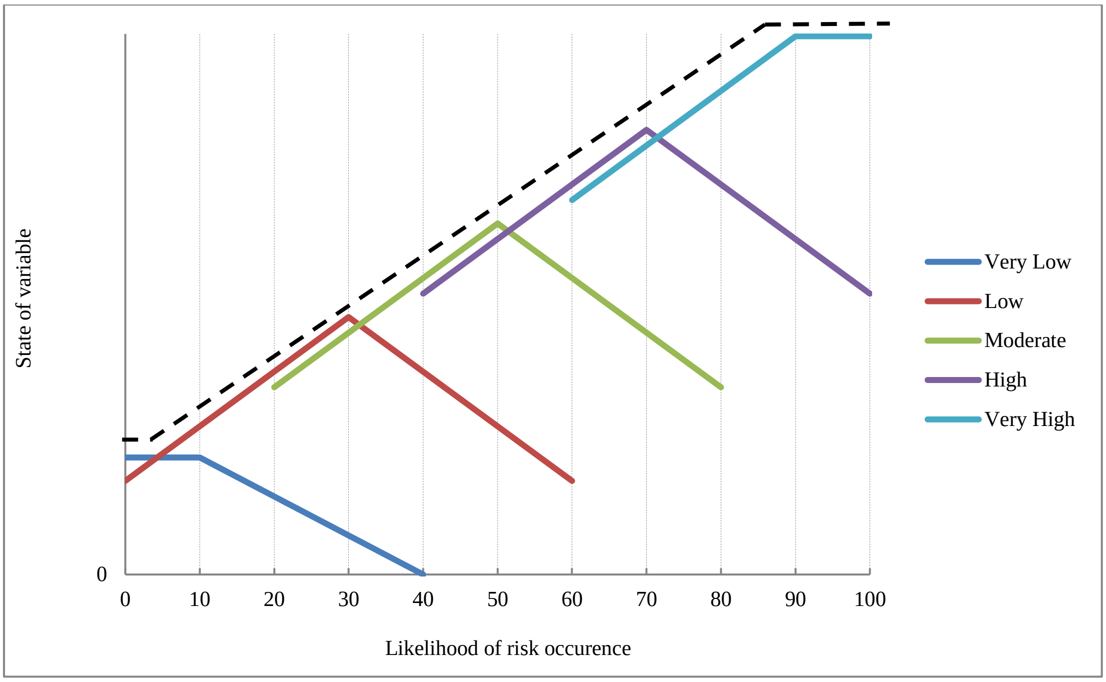


Figure 3-17: Using a constant progress for defining the risk likelihood membership functions

3.7.3. Membership functions of risk impact on project time

To construct the membership functions of risk impact on project time, the significance of impact was categorized to five linguistic terms from '*Very Low*' to *'Very High'* and experts were asked to estimate an interval for each of these five qualitative terms. After collecting all of the estimations the proposed method for constructing the trapezoidal membership function applied to calculate the fuzzy limits of each qualitative term. The final results of these calculations have been presented in Table 3-15 and corresponding membership functions have been illustrated in Figure 3-18. Figure 3-19 indicates how defining the membership functions of risk impact on the project time follows an inconstant progress.

Table 3-15: Membership functions of risk impact on project time

		Fuzzy membership functions range		
Linguistic Variable	Final estimated intervals	The lowest limit of schedule slippage	The upper limit of schedule slippage	Interval with μ=1
Very Low (VL)	< 5%	0 %	5 %	0-2.7 %
Low (L)	2 % -10 %	2 %	10 %	4.8 %-6.68 %
Moderate (M)	5 %-20 %	5 %	20 %	9.32 %-13.23 %
High (H)	10 %-30 %	10 %	30 %	18.15 %-22.91 %
Very High (VH)	> 20 %	20 %	100 %	28.68 %-100 %

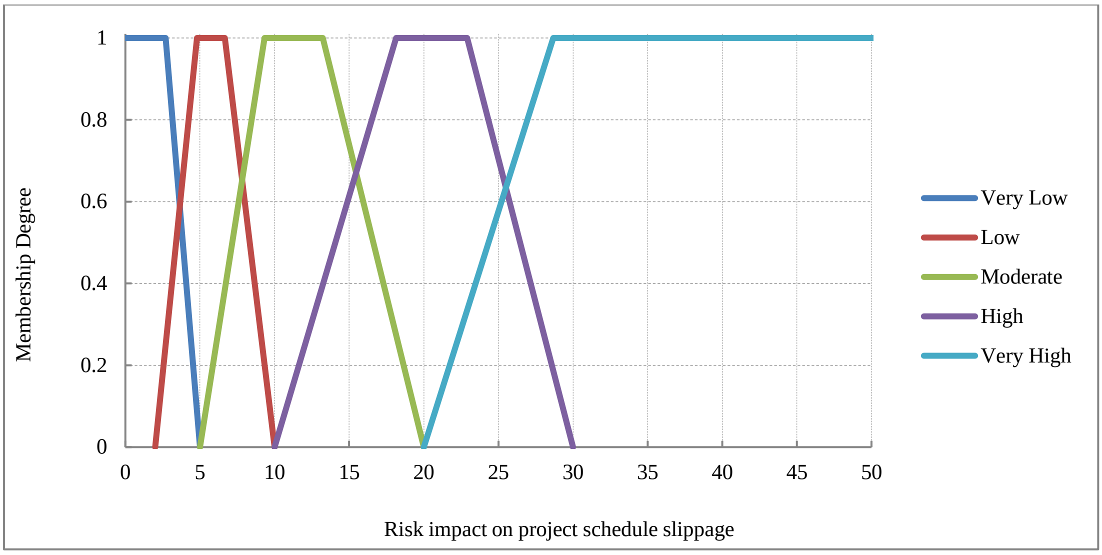


Figure 3-18: Risk impact on project time membership functions

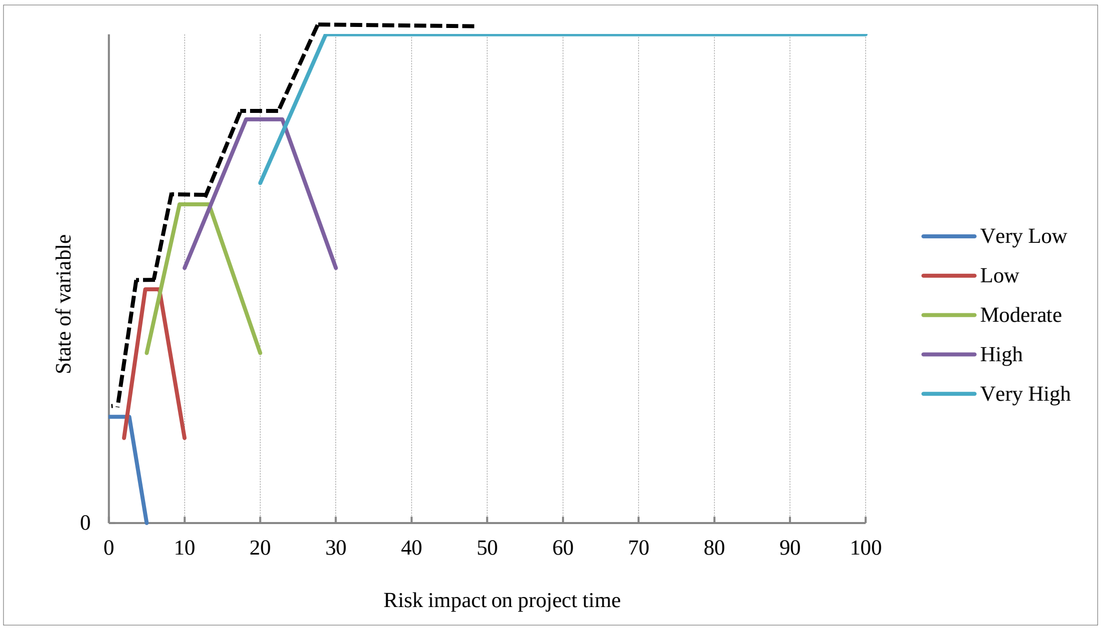


Figure 3-19: Inconstant progress in defining the membership functions of risk impact on project time

There are two general differences between the membership functions of risk probability and risk impact:

1. The membership functions of risk probability have a triangular shape while the risk impact membership functions are trapezoidal. The reason for this difference is that in this study the qualitative method was used for evaluating the probability of risk. So we expect that the probability function of a linguistic term (for example '*Low*') starts from the minimum probability and reaches to its most probable value with membership degree *one (1)* and then with a decreasing trend ends in membership degree *zero (0)*. In

another word when we ask an expert about the probability of a risk, and the options from '*Very Low*' to *'Very High'* are presented to him, the most rational assumption is that a linear relation of risk probability forms in his mind from 0 to 100 %. But for the risk impact functions, experts use a quantitative interval to estimate each qualitative variable and eventually round a number in the estimated interval and determine it as the impact of a particular risk factor on each project objectives which evokes a variable fuzzy situation and justifies the constant part of the risk impact changing mode in the graph of Figure 3-18 and forming the top side of the trapezoid. This concept can be understood better by comparison the Figure 3-17 and Figure 3-19.

2. Five membership functions of risk probability have been distributed uniformly between 0 to 100%, but the membership functions of risk impacts don't have this attribute, but their closeness is more at the beginning of the horizontal axis, which indicates a desire to avoid the threats with high effects even their likelihood of happening is low. In another word, for example, 20 % of time increase (schedule slippage) that is placed in '*Very Low*' or '*Low'* zone in the uniformly distributed mode, would be placed in the '*High'* zone of risk consequence functions.

3.7.4. Membership functions of risk impact on project cost

Based on a similar explanation in the previous section, the required information for constructing the membership functions of risk impact on project cost illustrated in Figure 3-20 has been summarized in Table 3-16.

Table 3-16: Membership functions of risk impact on project cost

	Fuzzy membership functions range			
Linguistic Variable	Final estimated intervals	The lowest limit of cost increase	The upper limit of cost increase	Interval with μ=1
Very Low (VL)	< 5 %	0 %	5 %	0-2.73 %
Low (L)	2 % -15 %	2 %	15 %	4.94 %-9.02 %
Moderate (M)	5 %-25 %	5 %	25%	12.77 %-17.11 %
High (H)	15 %-35 %	15 %	35 %	22.81 %-27.66 %
Very High (VH)	> 26 %	26 %	100 %	34 %-100 %

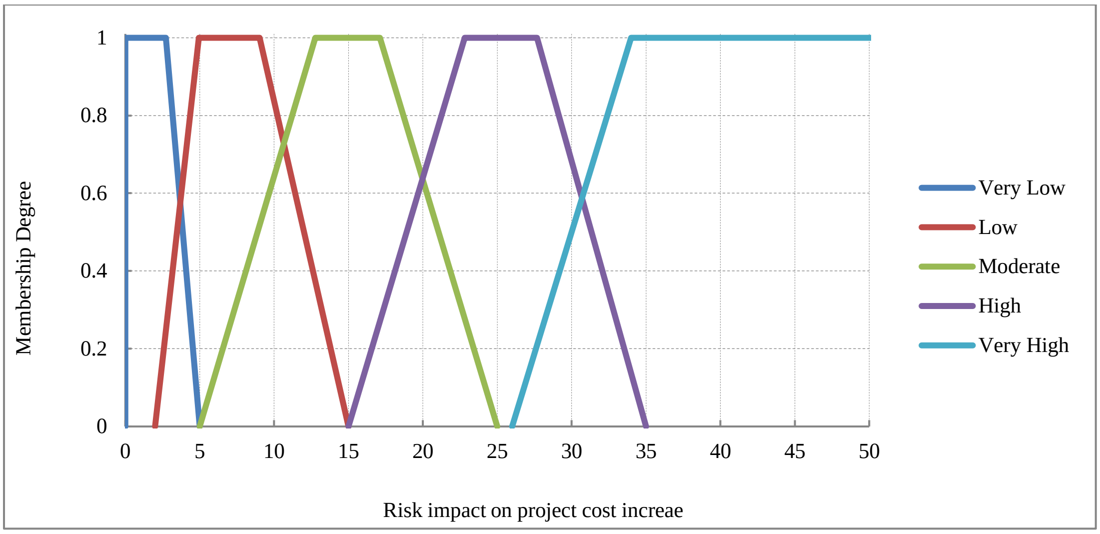


Figure 3-20: Risk impact on project cost increase membership functions

3.7.5. Membership functions of risk impact on project quality

Following descriptions were given to the linguistic terms of risk impact on project quality reduction:

1. Very Low: Quality degradation Barely noticeable
2. Low: Only very demanding applications are affected
3. Moderate: Quality reduction requires client approval
4. High: Quality reduction unacceptable to the client
5. Very High: Project end item is effectively unusable

The experts were asked to determine a specific range for each of these terms based on the given descriptions. The limits needed for constructing the membership functions of risk impact on project quality using the proposed technique have been summarized in Table 3-17. Based on the information presented in this table, the corresponding membership functions have been illustrated in Figure 3-21**.**

Table 3-17: Membership functions limits of risk impact on project quality reduction

	Fuzzy membership functions range			
Linguistic Variable	Final estimated intervals	The lowest limit of quality reduction	The upper limit of quality reduction	Interval with μ=1
Very Low (VL)	< 3 %	0 %	3 %	0-1.34 %
Low (L)	0.98 % -6 %	0.98 %	6 %	2.43 %-3.95 %
Moderate (M)	3 %-10 %	3 %	10 %	5.42 %-7 %
High (H)	6 %-15 %	6 %	15 %	8.97 %-11.24 %
Very High (VH)	> 10 %	10 %	100 %	14.06 %-100 %

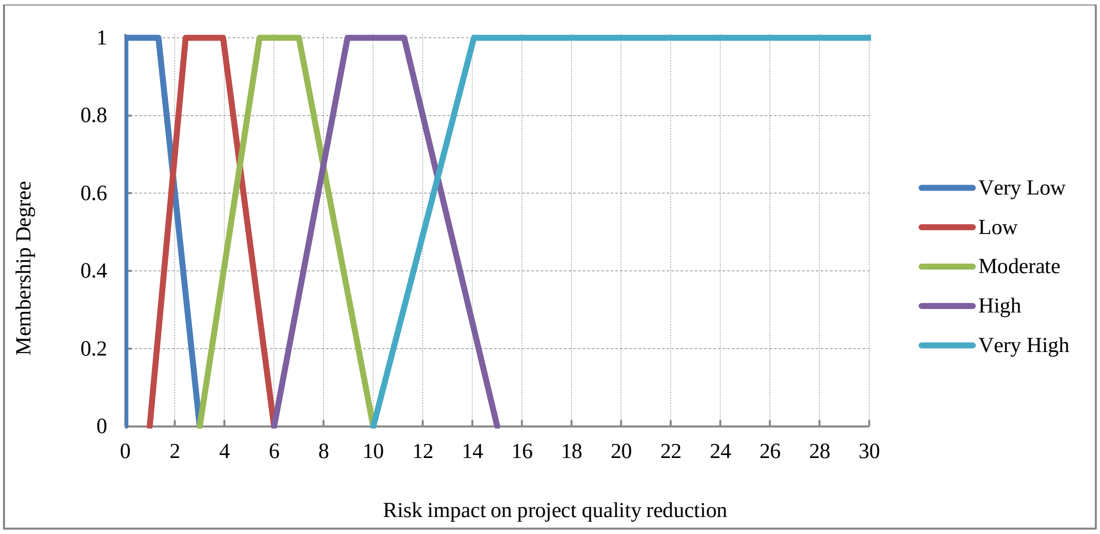


Figure 3-21: Risk impact on project quality membership functions

3.7.6. Membership functions of risk impact on project scope

For each linguistic term of risk impact on the project scope change, following description was given:

1. Very Low: Scope decrease is barely noticeable
2. Low: Minor areas of scope are affected
3. Moderate: Major areas of scope are affected
4. High: Scope reduction unacceptable to the client
5. Very High: Project end item is effectively useless

Figure 3-22 illustrates the constructed membership functions of risk impact on project scope based on the presented information in Table 3-18 that shows the calculated limits of trapezoid fuzzy number of each qualitative term of scope change.

Table 3-18: Membership functions limits of risk impact on project scope change

		Fuzzy membership functions range		
Linguistic Variable	Final estimated intervals	The lowest limit of scope change	The upper limit of scope change	Interval with μ=1
Very Low (VL)	< 2 %	0 %	2 %	0 %-0.95 %
Low (L)	0.92 % -4 %	0.92 %	4 %	1.67 %-2.54 %
Moderate (M)	1.98 %-6 %	1.98 %	6 %	3.33 %-4.42 %
High (H)	4 %-10 %	4 %	10 %	5.7 %-7.13 %
Very High (VH)	> 6 %	6	100	9.3 %-100 %

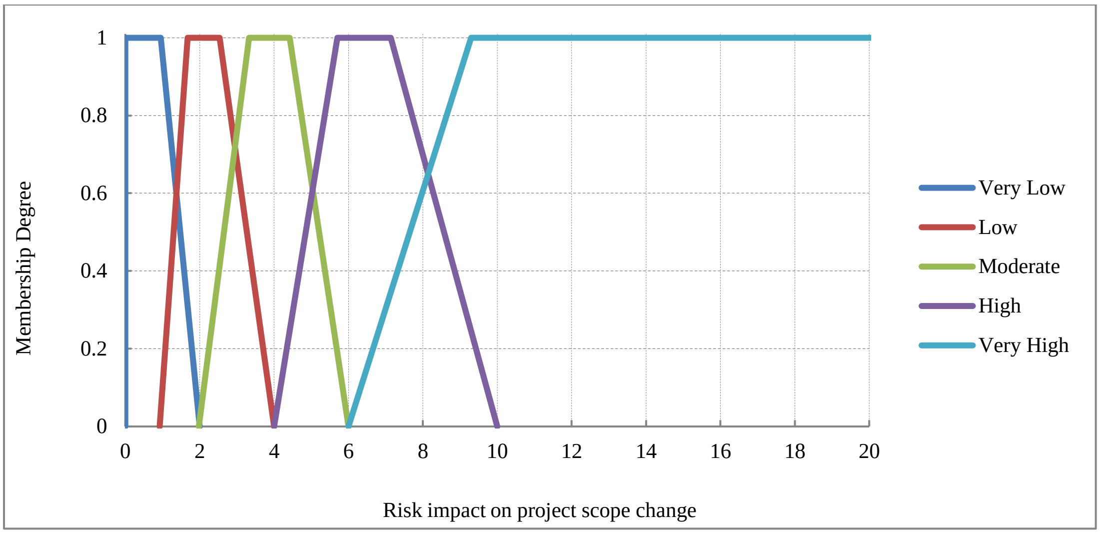


Figure 3-22: Risk impact on project scope change membership functions

3.7.7. Membership functions for evaluation of risk magnitude

The previous investigated membership functions (one set of probability MFs and four sets of impact MFs), are the input functions of the fuzzy analysis. In each fuzzy analysis the outcome of fuzzy rule that combine the antecedent membership functions must be mapped on consequent or output fuzzy membership functions. In this research five uniformly distributed functions have been defined for five qualitative terms of our output fuzzy membership functions that represent the 'Risk Magnitude'. Figure 3-23 shows the fuzzy functions of risk magnitude based on limits presented in Table 3-19.

Table 3-19: Membership functions of risk magnitude

	Fuzzy membership functions range		
Linguistic Variable	The lowest limit of risk magnitude	The upper limit of risk magnitude	Interval midrange with μ=1
Very Low (VL)	0	40	10
Low (L)	0	60	30
Moderate (M)	20	80	50
High (H)	40	100	70
Very High (VH)	60	100	90

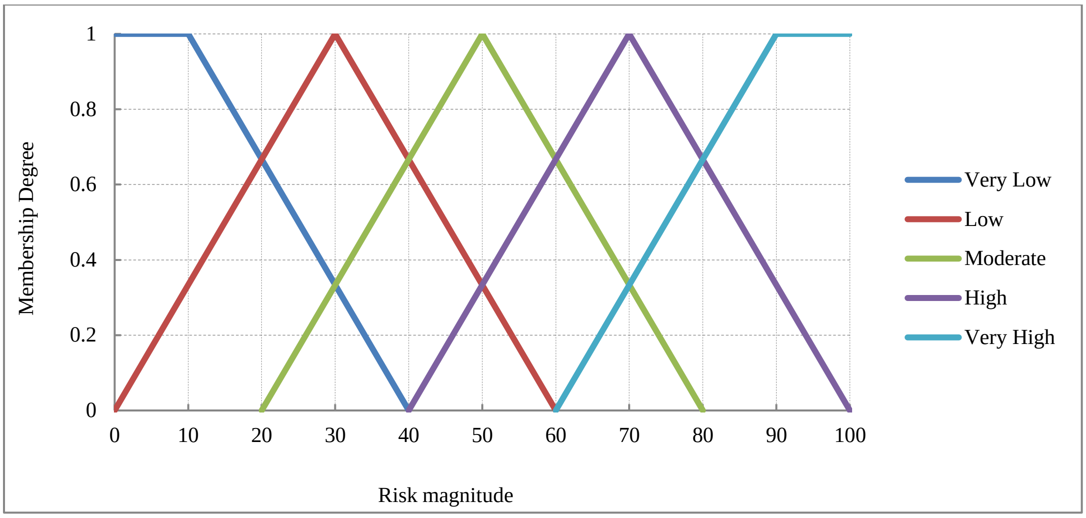


Figure 3-23: Risk magnitude membership functions

So at the end of this stage following linguistic variables are defined:

1. Risk Likelihood & Risk Magnitude= RL & RM = {VL, L, M, H, VH}
2. Risk impact on project' Time= T = {VL, L, M, H, VH}
3. Risk impact on project' Cost = C = {VL, L, M, H, VH}
4. Risk impact on project' Quality = Q = {VL, L, M, H, VH}
5. Risk impact on project' Scope = S = {VL, L, M, H, VH}

Where {VL, L, M, H, VH} denotes {Very Low, Low, Moderate, High, Very High}.

3.8. Fuzzy analysis step

Each Fuzzy analysis has consisted of four general steps. These steps for a fuzzy analysis system that uses Mamdani inference method has been explained in chapter two of this script. In this stage we review these steps for a sample risk factor: '*Poor and ineffective construction management by consultant*'.

3.8.1. Step 1: Fuzzification of inputs

During the fuzzification procedure a real scalar value is converted into a fuzzy value. This is achieved through different types of fuzzifiers which are our defined input fuzzy membership functions. Our fuzzy analysis system has two antecedent parts. The probability of occurrence and the magnitude of impact. So for obtaining the risk of a sample risk parameter (*Poor and ineffective construction management by consultant*) on a project objective (time), first we need to obtain two input values which are the mean values of these parameters. The input value of probability of occurrence is obtained through forming the frequency histogram for probability intervals and calculating the mean value of intervals midranges (Figure 3-9) while the mean value of risk impact on project time is obtained through calculating the average value of the collected estimations. In the next step the input values are mapped into their fuzzy membership functions and the membership degree of each input on each membership function is obtained. This step has been illustrated in Figure 3-24.

3.8.2. Step 2: Rule evaluation

In the first section of rule evaluation step, the conditional rules need to be defined. These rules are called fuzzy inference rules or IF-THEN rules. fuzzy operators (AND & OR) are used in the *IF* section of the fuzzy rule base to make a connection between two or more parts of antecedents and generate one output value for each rule. In this study the '*AND'* operator has been used for making this connection. For assessment of each identified risk factor to each defined project objective there are two inputs (Risk Likelihood and Risk Impact) and one output (Risk Magnitude).

The second section of this step that may recognize as a separate step in some sources is known as '*Implication'* stage. However, we preferred to consider it as the second section of rule evaluation step. Through the implication procedure the obtained value from the previous section is mapped to the consequent membership function and cut it which result in a fuzzy set for each rule. In another word '*THEN'* parts of the rules are implicated from '*IF'* parts by using appropriate fuzzy operators. In this study Mamdani implication method based on conjunctions (T-norm) was applied that uses minimum operator for implication. This step has been illustrated on the left side of Figure 3-24.

Table 3-20 illustrates the Likelihood-Impact matrix that is the reference chart used in this study for defining the IF-THEN rules. For example: *IF* the Likelihood of a risk factor is 'Moderate' *AND* its Impact is '*Very High*', *THEN* its Magnitude would be '*Very High*'. This chart is an adjusted format of the matrix introduced in the PMBOK guide that through a conservative approach uses the conditional formatting feature of EXCEL software and a five grade colour spectrum to determine the linguistic term of risk magnitude due to each likelihood and impact. In this study, according to five risk likelihood function and five risk impact functions, there will be '***twenty-five'*** (25) 'IF-THEN' rules.

Table 3-20: IF-THEN rules defining matrix

		Risk Likelihood				
		Very Low	Low	Moderate	High	Very High
Risk Impact	Very High	M	H	VH	VH	VH
	High	M	M	H	H	VH
	Moderate	L	M	M	H	H
	Low	VL	L	M	M	M
	Very Low	VL	VL	L	M	M

According to Table 3-20 the rules for risk likelihoods with impact '*Very High*' (VH) are as follows:

1. *IF* (Risk Probability is VL) *AND* (Risk Impact is VH) *THEN* (Risk Magnitude is M)
2. *IF* (Risk Probability is L) *AND* (Risk Impact is VH) *THEN* (Risk Magnitude is H)
3. *IF* (Risk Probability is M) *AND* (Risk Impact is VH) *THEN* (Risk Magnitude is VH)
4. *IF* (Risk Probability is H) *AND* (Risk Impact is VH) *THEN* (Risk Magnitude is VH)
5. *IF* (Risk Probability is VH) *AND* (Risk Impact is VH) *THEN* (Risk Magnitude is VH)

3.8.3. Step 3: Fuzzy aggregation

Making a decision in fuzzy inference systems is based on considering all the rules. So in this step all the output fuzzy sets of rules are combined to form one single fuzzy set. For this purpose, the disjunctive system of rules is used to unify the maximum output of each membership function (for example, the maximum cut of '*Moderate'* membership function) and combine it with other functions.

3.8.4. Step 4: Defuzzification

However, fuzzifying and conceptual valuating mainly includes qualitative analyses, but the outcome of a fuzzy analysis must be a crisp number. The output of the fourth step is a fuzzy set which is the combination of several fuzzy sets. Defuzzification is a procedure that accepts a fuzzy set as input and through mathematical operations converts it to a crisp number as output. The general method of defuzzification is Centre of gravity (COG) or Centroid method which is used in this study and has been presented by Equation **2-15** in the previous chapter. In this method the center of the area under the final diagram of aggregation step is determined as the final output of fuzzy analysis. This step has been illustrated in the right side of Figure 3-25.

3.8.5. Summary

The summary of fuzzy inference stages used in this study can be listed as following conditions:

- **Condition 1:** the membership functions of the fuzzy sets on the universe of discourse of the inputs become set that are triangular or trapezoidal in shape and normal.
- **Condition 2:** the fuzzy rule base becomes complete through determining a set of *if-then* rules.
- **Condition 3:** the input variables are crisp values in the form of singletons.

- **Condition 4:** to fine the output consequent sets, Mamdani inference system with a T-norm is used for the implication function (T-implication). The operator for the conjunction in the premises of the fuzzy rules is the *minimum* operator.
- **Condition 5:** the max-min method is used for the aggregation
- **Condition 6:** the COG method is used for defuzzification.

Fuzzy membership functions overlap each other so as we can see in the Figure 3-24 each crisp input of risk probability and risk impact will cut different fuzzy membership functions of the antecedents and combination of different situations leads to several output fuzzy functions which should be aggregated and defuzzified to obtain the magnitude of each risk for only one of the project objectives. So for each risk factor four analyses and for all sixteen construction risk factors 16×4=64 fuzzy analyses are needed which is a huge amount of calculations. This procedure needs a computer program that includes a flexible fuzzy logic module with the capability of receiving, managing, modifying and analysing the data in a dynamic way. One of the best and most modern programs for analysing the fuzzy control system is “MATLAB”.

MATLAB software has a fuzzy toolbox which is one of the most powerful programs for fuzzy analysis. The fuzzy logic toolbox provides functions, operators and applications for analysing, designing, and simulating systems based on fuzzy logic. The toolbox lets modelling of complex system behaviours using simple logic rules, and then implement these rules in a fuzzy inference system.

In Figure 3-24 and Figure 3-25, the regular fuzzy risk assessment procedure has been illustrated for the sample risk (Poor and ineffective construction management by consultant). The aggregation method is Maximum and the defuzzification method is the centroid (centre of gravity) which is one of the most popular methods. The scalar inputs are the ‘*Mean’* values of probability and impact which is calculated 55.83% for probability and 15.92% for magnitude of impact. These values are the inputs of a fuzzy inference system. The 55.83% line cuts Low (L), Moderate (M) and High (H) membership functions of probability of occurrence and the 15.92% line cuts Moderate (M) and High (H) membership functions of magnitude of impact on project time.

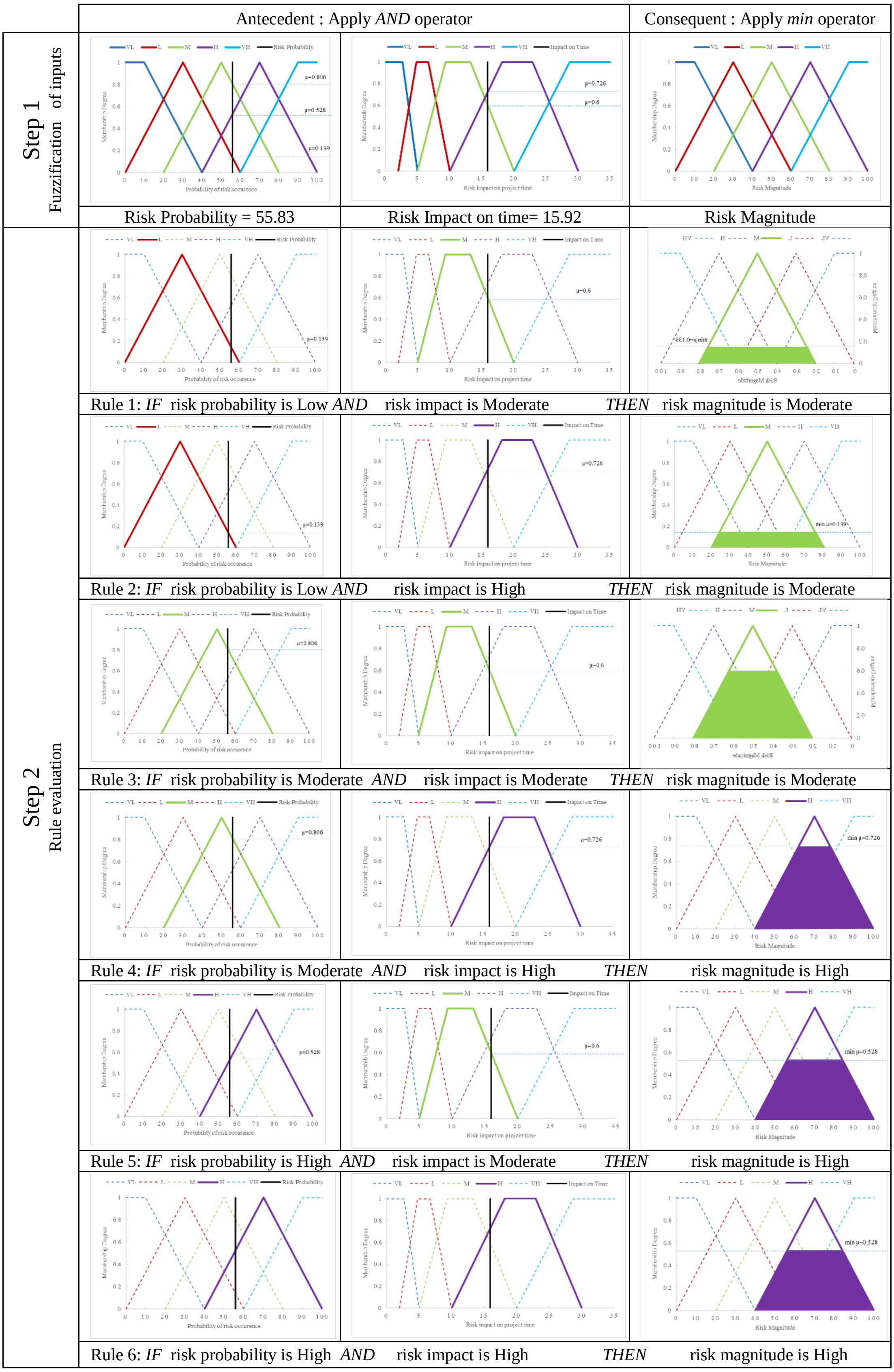


Figure 3-24: Step 1 & 2 of fuzzy analysis for calculating the time risk of risk sample ‘Poor and ineffective construction management by consultant’

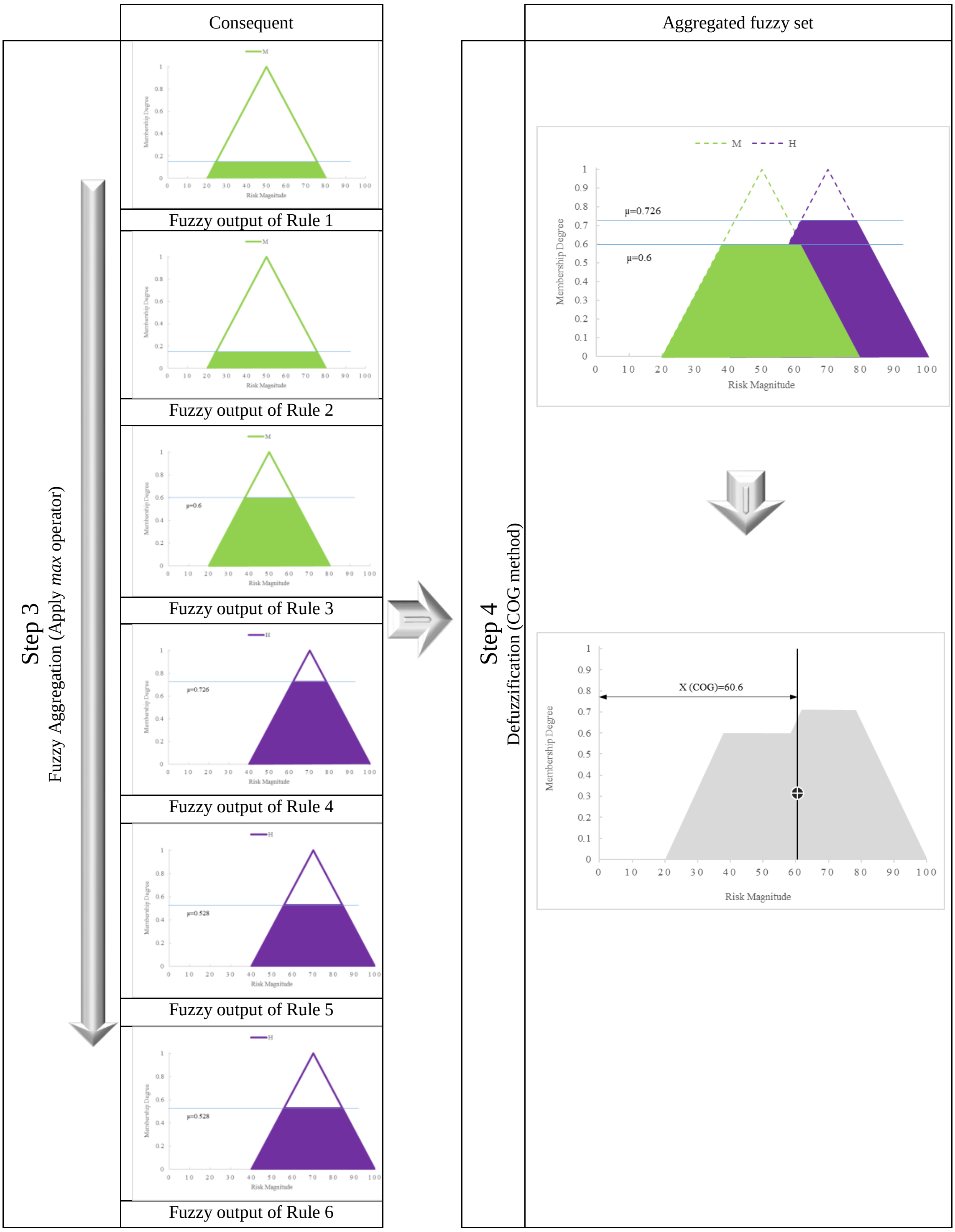


Figure 3-25: Step 3 & 4 of fuzzy analysis for calculating the time risk of risk sample 'Poor and ineffective construction management by consultant'

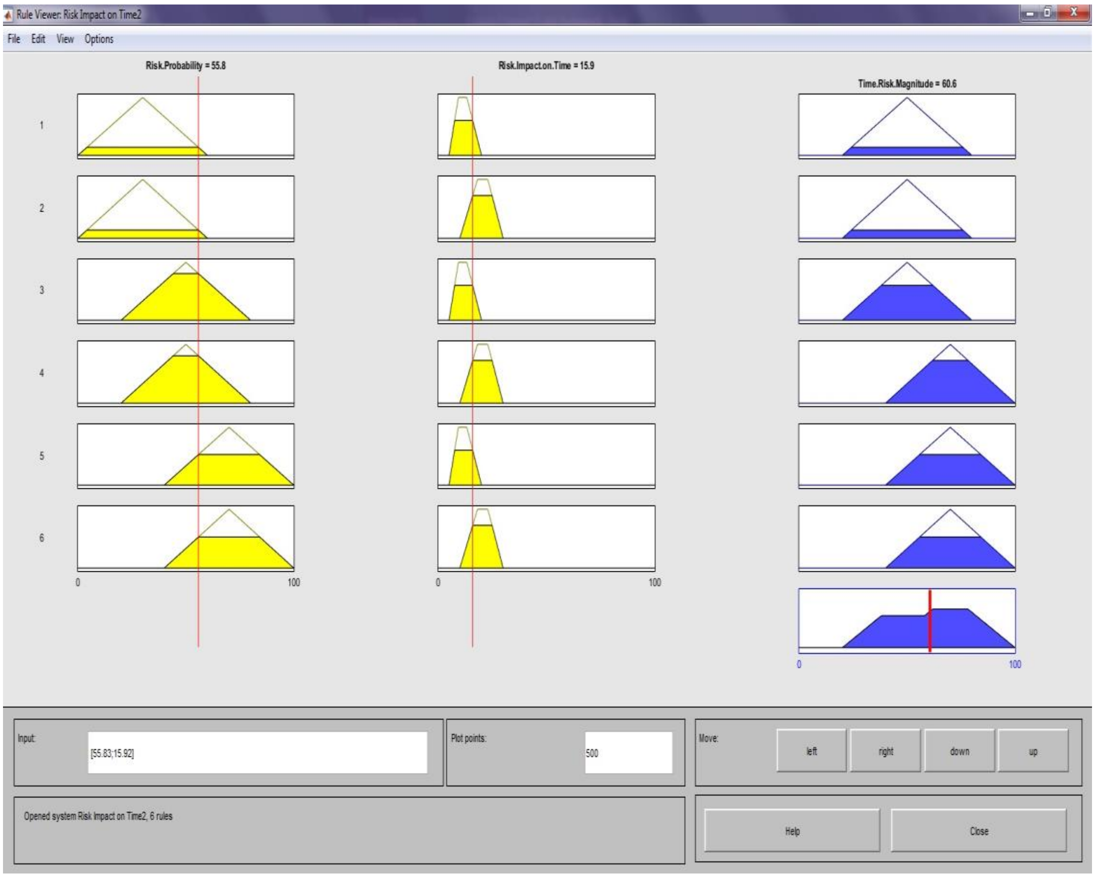


Figure 3-26: Graphical display of MATLAB Fuzzy Inference System (FIS) for calculating time-related risk of the sample risk factor 'Poor and ineffective construction management by consultant'

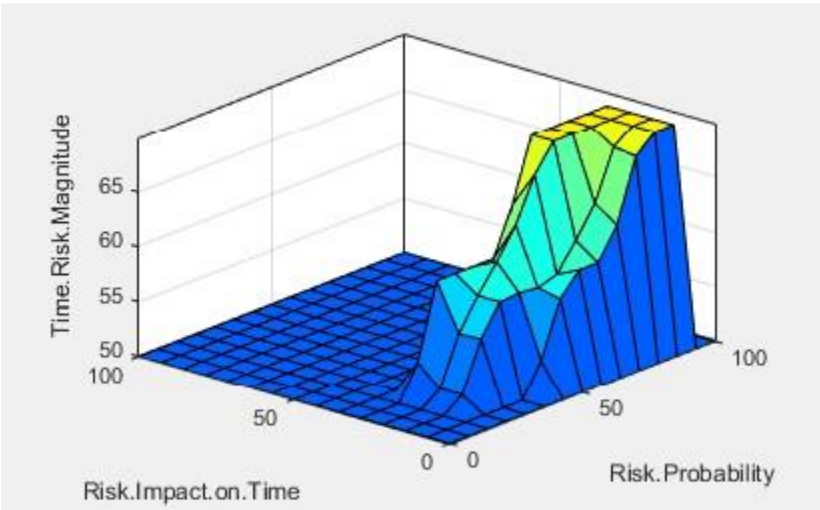


Figure 3-27: 3D fuzzy function of time-related risk of sample risk factor 'Poor and ineffective construction management by consultant' using MATLAB FIS

Fuzzy risk analysis would be executed for all construction risk factors and then all the output results would be prioritized. As a part of risk management procedure, monitoring the risks, modifying or updating the input data and doing a reasonable reaction to the risks can be performed.

4. RISK ANALYSIS RESULTS

As mentioned in the previous chapter MATLAB software was applied in this study to calculate the construction risks of oil and gas projects in a fuzzy way on four project objectives of time, cost, quality and scope. For this purpose, first we defined six sets of membership functions (MF) that five sets of them belonged to the antecedent inputs and one set belonged to the consequent output of the fuzzy rule base system. The antecedents of fuzzy inference system included one set of MF for probability of risk (P) and four sets of MFs corresponding to the impact of construction risk on time (I_T), cost (I_C), quality (I_Q) and scope (I_S) of the project. The consequent of fuzzy inference system included one set of MFs which represented the magnitude of risk. Each set of antecedents and consequent consisted of five membership functions corresponding to five linguistic terms of qualitative judgements (VL, L, M, H, VH).

In the next step the IF-THEN rules of fuzzy inference system were defined using a risk matrix and collected information about probability and impact of risk factors were entered into the software in the form of crisp numbers.

MATLAB software was utilised to perform a step by step fuzzy analysis on the input information and generate a crisp number as output for each of the sixteen construction risk factors that represents the magnitude of that risk on a specific project objective (Time, Cost, Quality or Scope). This operation repeats 64 times to calculate the four objectives' risks. In the upcoming sections of this chapter the risk analysis results have been presented in separate tables and discussed for each of the project objectives. These tables use a colour scale for displaying the intensity of risk from green for very low to red for very high risk value. This conditional formatting option makes the comparison between all risk factors easier for both fuzzy and non- fuzzy analysis. As mentioned in the previous sections of this study the non-fuzzy analysis, which is known as *Probability by Impact* method (P.I) has been introduced by project management and risk management standards such as (PMI, 2013) and (Hopkin & IRM, 2014). This method in the form of multiplying the fuzzy numbers of risk probability and risk impact has also been used in many fuzzy risk assessment approaches that some of them were reviewed in this script (Huang et al., 2001)

4.1. Time-related construction risks of oil and gas projects

Each of the sixteen identified construction risk factors of oil and gas projects were investigated for the probability of occurrence and the magnitude of impact on project schedule slippage. The results of fuzzy analysis of these risks have been presented in Table 4-1. In this table the risk factors have been ranked from highest to lowest based on fuzzy degree. The right side of the table shows the priority of time-related risks. According to this table '*Delays in stage passing approval*' and *'Damage to environment'* have been prioritized, as the top time risks and '*Faulty construction techniques*' and '*Waste caused by contractors*' are placed at the bottom of the time risk ranking. It can be concluded that based on overall judgments of experts '*Delays in stage passing approval*' plays as the most significant risk in completion of an oil and gas project out of its planned schedule. Figure 4-1 shows two diagrams that present the comparison between the fuzzy ranking and the multiplication of probability by impact ($P.I_T$) ranking of time-related construction risk factors. The main purpose of selecting this style of chart was showing the difference between the two methods by illustrating the degree of non-compliance of the ranking diagrams.

Table 4-1: Prioritizing the time-related construction risk factors based on fuzzy analysis and probability by impact ($P.I_T$)

		Time-related					
No	Risk Factor	Probability (P)	Impact (I_T)	$P.I_T$	Fuzzy Risk	**Risk Ranking** $P.I_T$	**Risk Ranking** Fuzzy
1	Wrong constructability assumptions	20.00	11.33	2.27	40.00	12	13
2	Complexity level of construction	45.83	10.92	5.00	54.30	5	6
3	Faulty construction techniques	15.00	9.96	1.49	38.30	15	15
4	Construction equipment failure and inefficiency	46.67	5.92	2.76	46.70	7	7
5	Encountering with an incomplete or a defective construction work	22.50	10.71	2.41	42.80	10	9
6	Mistakes in construction because of contractor default	40.00	12.29	4.92	56.20	6	4
7	Waste caused by contractors	53.33	2.71	1.44	36.90	16	16
8	Poor and ineffective construction management by consultant	55.83	15.92	8.89	60.60	2	3
9	Delays in stage passing approval	50.83	22.00	11.18	64.80	1	1
10	Construction work variations	20.83	12.29	2.56	40.90	9	11
11	Inconsistency of construction conditions with construction plans	15.83	11.92	1.89	38.60	14	14
12	Inconsistency of construction conditions with construction planning	47.50	11.17	5.30	55.20	4	5
13	Need to protect the geological and historical objects during the construction	22.50	11.67	2.63	42.80	8	8
14	Fatalities and weighted injuries of workforce	66.67	3.33	2.22	41.90	13	10
15	Damage to environment	70.83	11.08	7.85	64.30	3	2
16	Severe temperature and weather conditions during the construction	20.83	11.38	2.37	40.90	11	12

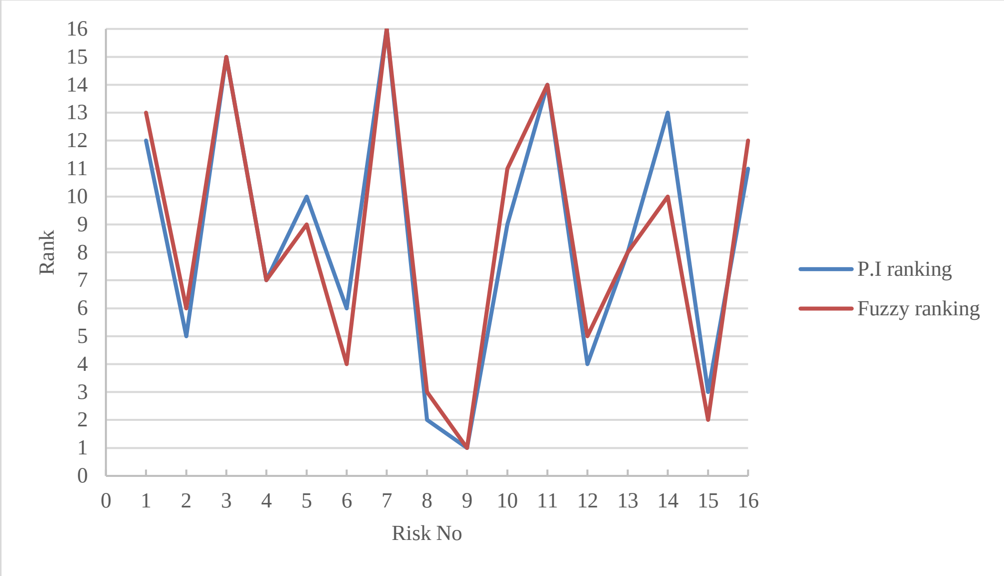


Figure 4-1: Comparison between fuzzy ranking and ($P.I_T$) ranking of time-related construction risks

4.2. Cost-related construction risks of oil and gas projects

Cost-related risk factors of oil and gas projects have been ranked and presented in Table 4-2. According to this table '*Damage to environment*' and '*Waste caused by contractors*' and '*Poor and ineffective construction management by consultant*' have been considered as the most important risk factors that can increase the total project cost while '*Severe temperature and weather conditions during the construction*' and '*Wrong constructability assumptions*' and '*Construction equipment failure and inefficiency*' have been evaluated as the least important risk factors of the list. Based on the information in this table, controlling the '*Damage to environment*' meaningfully can prevent the projects from cost overrun. In Figure 4-2 two diagrams have been presented that illustrate the comparison between the fuzzy ranking and the multiplication of probability by impact ($P.I_C$) ranking for the cost-related construction risk factors.

Table 4-2: Prioritizing the cost-related construction risk factors based on fuzzy analysis and of probability by impact (P.I)

						Risk ranking	
				Cost-related			
No	Risk factor	Probability (P)	Impact (I_C)	$P.I_C$	Fuzzy risk	$P.I_C$	Fuzzy
1	Wrong constructability assumptions	20.00	6.75	1.35	30	16	16
2	Complexity level of construction	45.83	5.88	2.69	44.5	10	8
3	Faulty construction techniques	15.00	14.96	2.24	38.3	13	13
4	Construction equipment failure and inefficiency	46.67	3.71	1.73	37.2	14	14
5	Encountering with an incomplete or a defective construction work	22.50	16.29	3.67	42.8	8	9
6	Mistakes in construction because of contractor default	40.00	15.67	6.27	52.3	5	5
7	Waste caused by contractors	53.33	26.29	14.02	65.3	2	2

8	Poor and ineffective construction management by consultant	55.83	13.17	7.35	55.5	3	3
9	Delays in stage passing approval	50.83	9.54	4.85	50.8	7	6
10	Construction work variations	20.83	15.54	3.24	40.9	9	11
11	Inconsistency of construction conditions with construction plans	15.83	14.42	2.28	38.4	12	12
12	Inconsistency of construction conditions with construction planning	47.50	14.42	6.85	52.9	4	4
13	Need to protect the geological and historical objects during the construction	22.50	24.17	5.44	49.5	6	7
14	Fatalities and weighted injuries of workforce	66.67	3.96	2.64	41.7	11	10
15	Damage to environment	70.83	23.08	16.35	66.8	1	1
16	Severe temperature and weather conditions during the construction	20.83	7.29	1.52	31.4	15	15

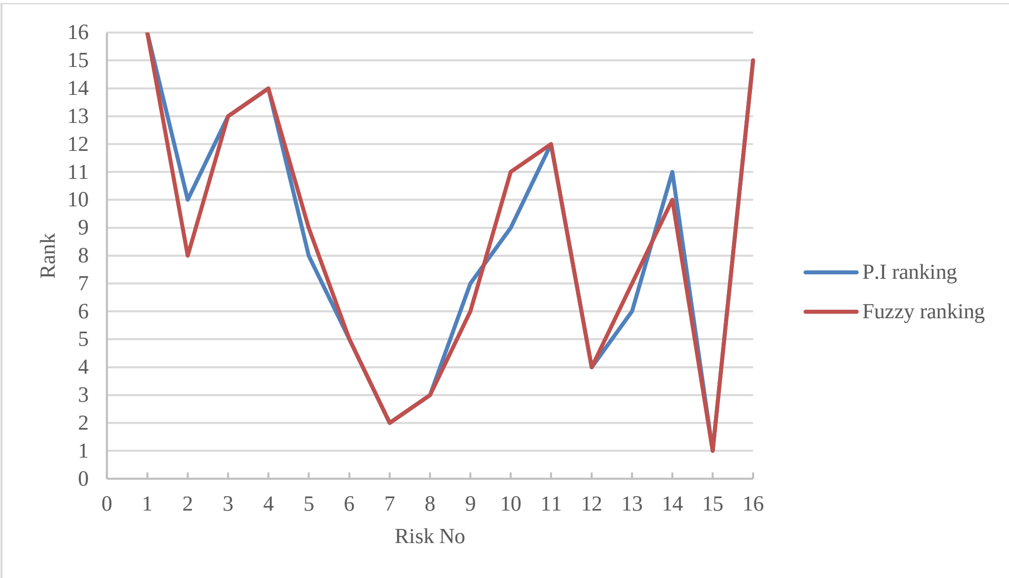


Figure 4-2: Comparison between fuzzy ranking and ($P.I_C$) ranking of cost-related construction risks

4.3. Quality-related construction risks of oil and gas projects

The prioritization of quality-related risk factors of oil and gas projects have been presented in Table 4-3. According to this table '*Poor and ineffective construction management by consultant*' and '*Mistakes in construction because of contractor default*' and '*Damage to environment*' have been considered as the risk factors that can influentially decrease and degrade the construction quality of an oil and gas project while '*Inconsistency of construction conditions with construction plans'* and '*Severe temperature and weather conditions during the construction*' and '*Construction work variations*' have been prioritized as the least important risk factors in this table. Based on the information on this table, the most effective way to have a high quality accomplished project is '*focusing on project management activities by consultant'*. Figure 4-3Figure 4-1 shows two diagrams that illustrate the comparison between the fuzzy ranking and the multiplication of probability by impact ($P.I_Q$) ranking of quality-related construction risk factors.

Table 4-3: Prioritizing the quality-related construction risk factors based on fuzzy analysis and probability by impact ($P.I_Q$)

Quality-related							
No	Risk factor	Probability (P)	Impact (I_Q)	$P.I_Q$	Fuzzy risk	Risk ranking $P.I_Q$	Risk ranking Fuzzy
1	Wrong constructability assumptions	20.00	4.25	0.85	33.8	10	11
2	Complexity level of construction	45.83	1.75	0.80	35.9	11	10
3	Faulty construction techniques	15.00	10.00	1.50	50	4	4
4	Construction equipment failure and inefficiency	46.67	1.83	0.86	36.7	8	8
5	Encountering with an incomplete or a defective construction work	22.50	3.46	0.78	30.2	12	12
6	Mistakes in construction because of contractor default	40.00	6.29	2.52	52.6	2	2
7	Waste caused by contractors	53.33	2.79	1.49	44.8	5	5
8	Poor and ineffective construction management by consultant	55.83	22.75	12.70	81.8	1	1
9	Delays in stage passing approval	50.83	1.71	0.87	37.1	7	7
10	Construction work variations	20.83	1.96	0.41	26.1	15	14
11	Inconsistency of construction conditions with construction plans	15.83	3.08	0.49	24.1	13	16
12	Inconsistency of construction conditions with construction planning	47.50	1.79	0.85	36.7	9	9
13	Need to protect the geological and historical objects during the construction	22.50	1.96	0.44	27.6	14	13
14	Fatalities and weighted injuries of workforce	66.67	1.88	1.25	41.7	6	6
15	Damage to environment	70.83	3.08	2.18	50.9	3	3
16	Severe temperature and weather conditions during the construction	20.83	1.92	0.40	25.9	16	15

Figure 4-3: Comparison between fuzzy ranking and ($P.I_Q$) ranking of quality-related of construction risks

4.4. Scope-related construction risks of oil and gas projects

Sixteen construction risk factors have been sorted from highest priority to lowest priority in Table 4-4 based on performed fuzzy analysis and also the multiplication of their probability by impact on the scope of oil and gas projects. According to this table *'Poor and ineffective construction management by consultant'* and *'Damage to environment'* and *'Faulty construction techniques'* have been ranked as the most serious risk factors that can change the areas of project scope total project cost while *'Wrong constructability assumptions'* and '*Severe temperature and weather conditions during the construction'* and '*Inconsistency of construction conditions with construction plans'* have been prioritized as the least threatening risk factors that may reduce the expected scope of an oil and gas project. Based on the information on this table, eliminating the '*Poor and ineffective construction management by consultant'* risk meaningfully can increase the acceptance chance of the projects by the client. Figure 4-4 shows two diagrams that present the comparison between fuzzy ranking and multiplication of probability by impact ($P.I_S$) ranking of scope-related construction risk factors.

Table 4-4: Prioritizing the scope-related construction risk factors based on fuzzy analysis and probability by impact ($P.I_S$)

			Scope-related				
No	Risk factor	Probability (P)	Impact (I_S)	$P.I_S$	Fuzzy risk	**Risk ranking** $P.I_S$	**Risk ranking** Fuzzy
1	Wrong constructability assumptions	20.00	1.33	0.27	24.8	16	16
2	Complexity level of construction	45.83	1.42	0.65	37.6	11	11
3	Faulty construction techniques	15.00	6.21	0.93	51.6	5	3
4	Construction equipment failure and inefficiency	46.67	1.50	0.70	38.8	8	8
5	Encountering with an incomplete or a defective construction work	22.50	1.46	0.33	28	14	13
6	Mistakes in construction because of contractor default	40.00	3.83	1.53	46.9	2	4
7	Waste caused by contractors	53.33	1.58	0.84	41.8	6	6
8	Poor and ineffective construction management by consultant	55.83	3.63	2.02	55.5	1	1
9	Delays in stage passing approval	50.83	1.38	0.70	38.6	9	9
10	Construction work variations	20.83	4.00	0.83	40.3	7	7
11	Inconsistency of construction conditions with construction plans	15.83	2.17	0.34	26.7	13	14
12	Inconsistency of construction conditions with construction planning	47.50	1.42	0.67	38.2	10	10
13	Need to protect the geological and historical objects during the construction	22.50	1.63	0.37	28.1	12	12
14	Fatalities and weighted injuries of workforce	66.67	1.46	0.97	41.9	4	5
15	Damage to environment	70.83	2.13	1.51	52.6	3	2
16	Severe temperature and weather conditions during the construction	20.83	1.50	0.31	26.1	15	15

Figure 4-4: Comparison between fuzzy ranking and ($P.I_S$) ranking of scope-related construction risks

The overall results of fuzzy and non-fuzzy risk analysis for all construction risk factors have been presented in Table 4-5. This table is a summary of section (4.1) to section (4.4) of this chapter and also benefits a colour scale for a better and easier comparison between all risk factors. The colour scale displays the intensity of risk from green for very low to red for very high risk value. The probabilities of risk factors have been listed in the orange column of this table which is constant for each risk factor. The risk impacts on time, cost, quality and scope of project have been listed in ochre, blue, green and purple colour of this table respectively.

Table 4-5: Final fuzzy and non-fuzzy analysis results of construction risk factors

			Risk impact on project objectives											
			Time			**Cost**			**Quality**			**Scope**		
No	Risk Factor	**Risk Probability (P)**	**Impact (I_T)**	**$P \times I_T$**	**Fuzzy Risk**	**Impact (I_C)**	**$P \times I_C$**	**Fuzzy Risk**	**Impact (I_Q)**	**$P \times I_Q$**	**Fuzzy Risk**	**Impact (I_S)**	**$P \times I_S$**	**Fuzzy Risk**
1	Wrong constructability assumptions	20.00	11.33	2.27	40.00	6.75	1.35	30	4.25	0.85	33.8	1.33	0.27	24.8
2	Complexity level of construction	45.83	10.92	5.00	54.30	5.88	2.69	44.5	1.75	0.80	35.9	1.42	0.65	37.6
3	Faulty construction techniques	15.00	9.96	1.49	38.30	14.96	2.24	38.3	10.00	1.50	50	6.21	0.93	51.6
4	Construction equipment failure and inefficiency	46.67	5.92	2.76	46.70	3.71	1.73	37.2	1.83	0.86	36.7	1.50	0.70	38.8
5	Encountering with an incomplete or a defective construction work	22.50	10.71	2.41	42.80	16.29	3.67	42.8	3.46	0.78	30.2	1.46	0.33	28
6	Mistakes in construction because of contractor default	40.00	12.29	4.92	56.20	15.67	6.27	52.3	6.29	2.52	52.6	3.83	1.53	46.9
7	Waste caused by contractors	53.33	2.71	1.44	36.90	26.29	14.02	65.3	2.79	1.49	44.8	1.58	0.84	41.8
8	Poor and ineffective construction management by consultant	55.83	15.92	8.89	60.60	13.17	7.35	55.5	22.75	12.70	81.8	3.63	2.02	55.5
9	Delays in stage passing approval	50.83	22.00	11.18	64.80	9.54	4.85	50.8	1.71	0.87	37.1	1.38	0.70	38.6
10	Construction work variations	20.83	12.29	2.56	40.90	15.54	3.24	40.9	1.96	0.41	26.1	4.00	0.83	40.3
11	Inconsistency of construction conditions with construction plans	15.83	11.92	1.89	38.60	14.42	2.28	38.4	3.08	0.49	24.1	2.17	0.34	26.7
12	Inconsistency of construction conditions with construction planning	47.50	11.17	5.30	55.20	14.42	6.85	52.9	1.79	0.85	36.7	1.42	0.67	38.2
13	Need to protect the geological and historical objects during the construction	22.50	11.67	2.63	42.80	24.17	5.44	49.5	1.96	0.44	27.6	1.63	0.37	28.1
14	Fatalities and weighted injuries of workforce	66.67	3.33	2.22	41.90	3.96	2.64	41.7	1.88	1.25	41.7	1.46	0.97	41.9
15	Damage to environment	70.83	11.08	7.85	64.30	23.08	16.35	66.8	3.08	2.18	50.9	2.13	1.51	52.6
16	Severe temperature and weather conditions during the construction	20.83	11.38	2.37	40.90	7.29	1.52	31.4	1.92	0.40	25.9	1.50	0.31	26.1

4.5. The effect of construction risk group on each oil and gas project objective

After determining the value and the priority of each risk factors that had been categorized under construction risk group, we need to find quantitative responses to the following questions that in case of not controlling the construction risk:

- How much schedule slippage compared to the initial time estimation of the project is expected?
- How much would be the approximate cost of the completed project compared to the initial budget estimated in the project contract?
- How much quality reduction can be expected?
- How much project scope would be different from what the client expected to be?

To answer these questions, a similar fuzzy analysis like what we did for each risk factor, was performed for the construction risk group. For this purpose, we need to calculate five average values for five risk parameters to obtain the inputs of fuzzy analysis system. These inputs include the average value of all risk factors' probabilities and the average value of each risk impact related to each project objective (I_T, I_C, I_Q, I_S) for all risk factors. Using the average value of each risk parameter is a simple method to consider all the identified risk factors under the construction group and determine the contribution of this major risk group in increasing the total time and cost of the project, reduction the expected quality and change the final defined scope of an oil & gas project.

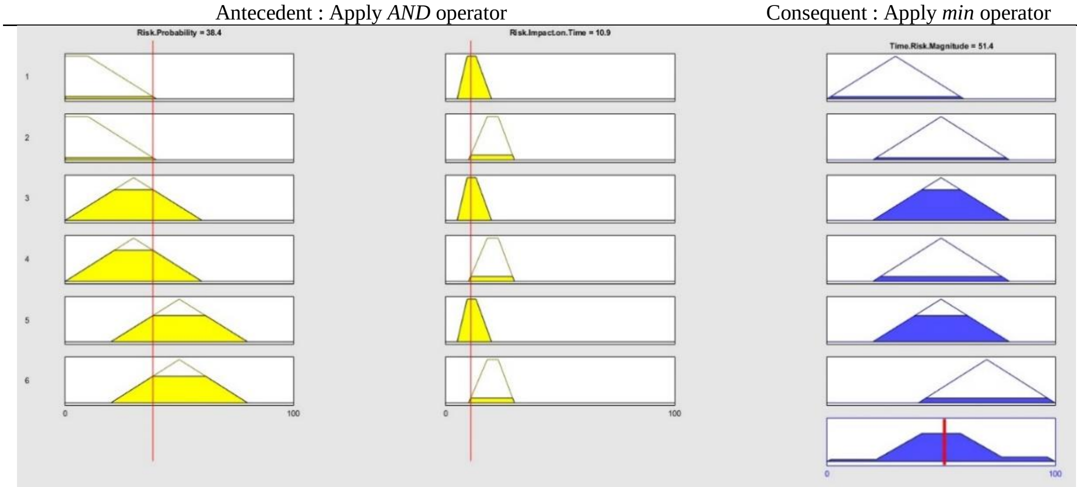
The results of this analysis have been presented in Table 4-6. The graphical display of fuzzy analysis for calculating the construction risk of oil and gas projects' objectives using MATLAB Fuzzy Inference System (FIS) has been illustrated in Figure 4-5, Figure 4-7, Figure 4-9 and Figure 4-11. According to fuzzy analysis values of Table 4-6 the 'Construction risks' group exposes an oil and gas project to a 51.4% risk of schedule slippage, a 44.2% risk of project cost overrun, a 39.4% risk of quality reduction and scope change. So the main project objective that is affected by this group of risk, is project time.

Table 4-6: The effect of construction risk group on objectives of oil & gas projects using fuzzy analysis

		Project Objectives											
		Time-related			Cost-related			Quality-related			Scope-related		
	Average Probability	Average Impact (I_T)	$P.I_T$	Fuzzy Risk	Average Impact (I_C)	$P.I_C$	Fuzzy Risk	Average Impact (I_Q)	$P.I_Q$	Fuzzy Risk	Average Impact (I_S)	$P.I_S$	Fuzzy Risk
Oil & Gas Construction Risks	38.44%	10.91%	4.19%	51.4%	13.45%	5.17%	44.2%	4.41%	1.69%	39.4%	2.29%	0.88%	39.4%

According to the information presented in Table 4-6, Figure 4-6, Figure 4-8, Figure 4-10 and Figure 4-12 illustrate fuzzy functions of time-related, cost-related, quality-related and scope-related construction risk factors respectively, in the form of a 3D (Three-Dimensional) surface using MATLAB software based on the effective rules that map both membership functions of risk probability and risk impact. Given that the input risk probability in all four conditions is the same, these figures show how compaction and magnitude of risk impact can affect the surface of 3D fuzzy functions of risk.

Antecedent : Apply *AND* operator		Consequent : Apply *min* operator



Fuzzification of inputs		Defuzzification (COG) method
Risk Probability=38.44%	Risk Impact=10.91%	Time-related construction risk=51.4%

Figure 4-5: Graphical display of MATLAB Fuzzy Inference System (FIS) for calculating time-related construction risks of oil & gas projects

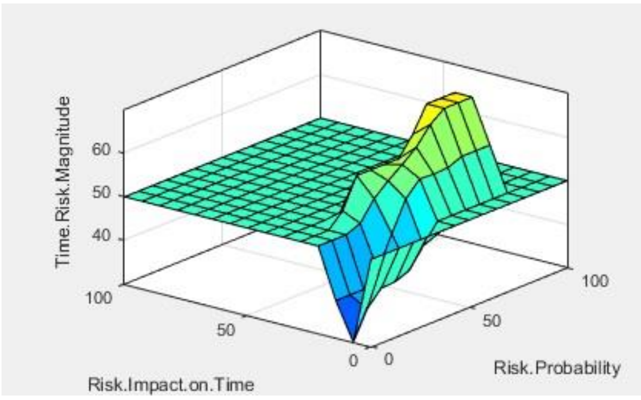
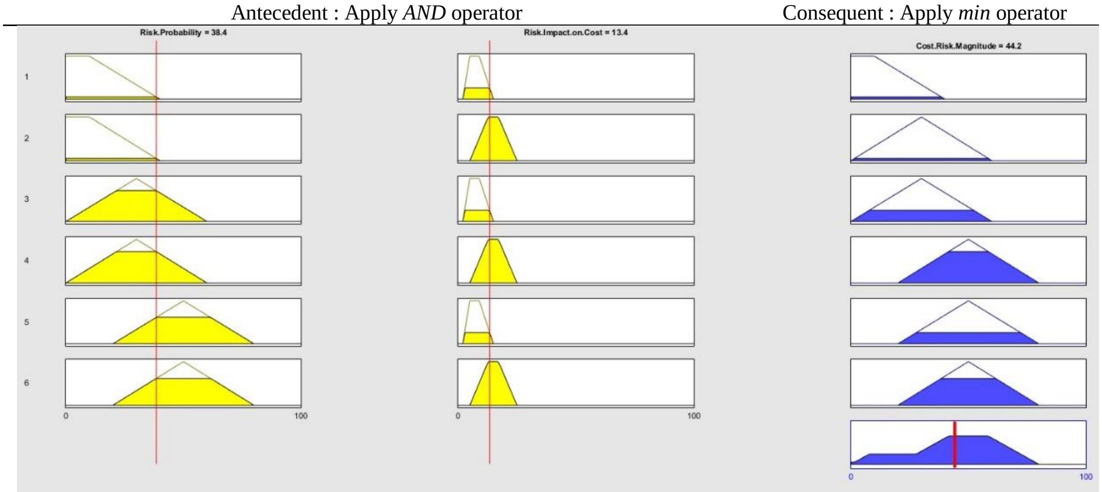


Figure 4-6: 3D fuzzy function of time-related construction risk factors using MATLAB FIS

Antecedent : Apply *AND* operator | Consequent : Apply *min* operator



Fuzzification of inputs | Defuzzification (COG) method

Risk Probability=38.44% | Risk Impact=13.45% | Cost-related construction risk=44.2%

Figure 4-7: Graphical display of MATLAB Fuzzy Inference System (FIS) for calculating cost-related construction risks of oil & gas projects

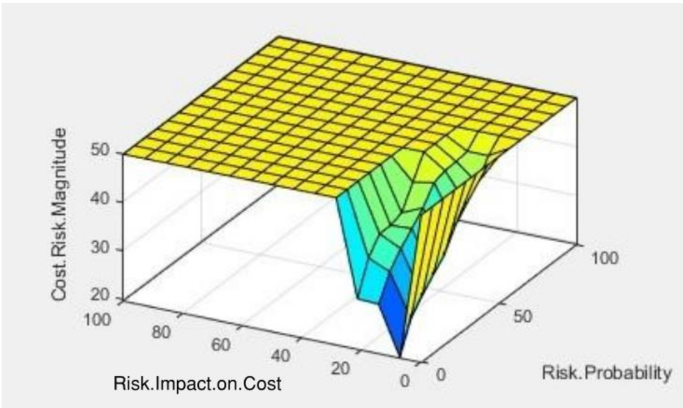
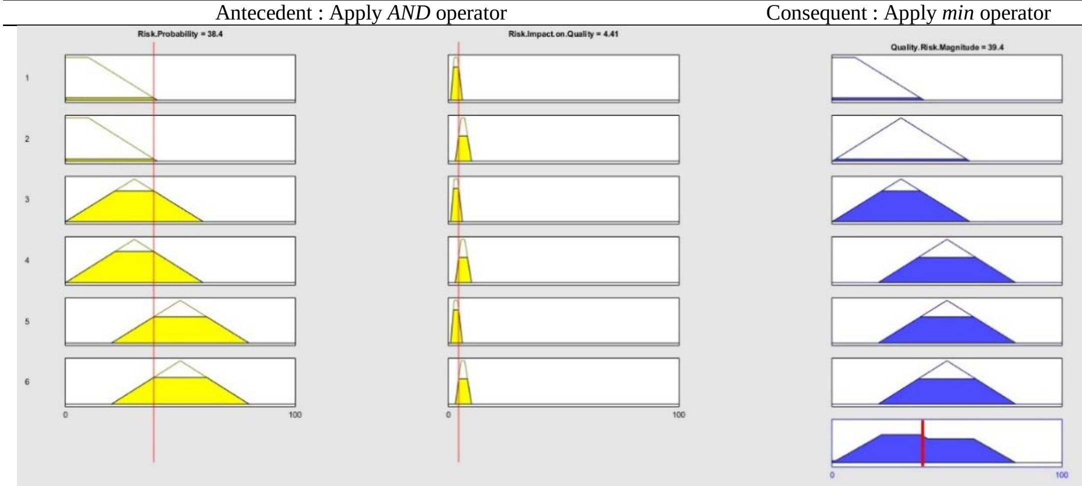


Figure 4-8: 3D fuzzy function of cost-related construction risk factors using MATLAB FIS

Antecedent : Apply *AND* operator | Consequent : Apply *min* operator



Fuzzification of inputs | Defuzzification (COG) method

Risk Probability=38.44% | Risk Impact=4.41% | Quality-related construction risk=39.4%

Figure 4-9: Graphical display of MATLAB Fuzzy Inference System (FIS) for calculating quality-related construction risks of oil & gas projects

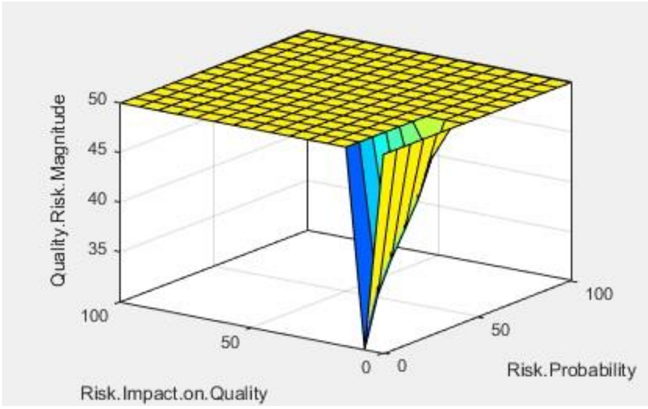
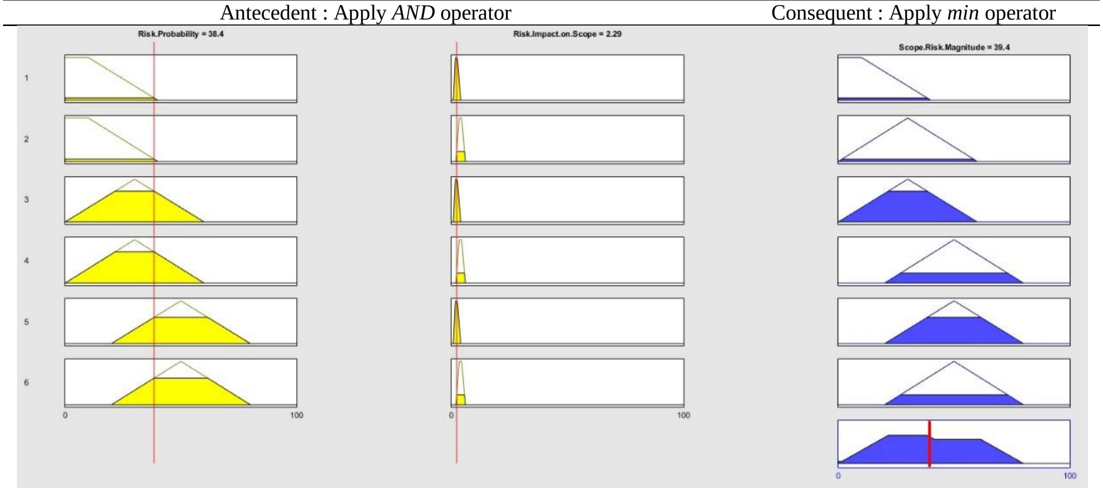


Figure 4-10: 3D fuzzy function of quality-related construction risk factors using MATLAB FIS

Antecedent : Apply *AND* operator Consequent : Apply *min* operator



Fuzzification of inputs Defuzzification (COG) method

Risk Probability=38.44% Risk Impact=2.29 % Scope-related construction risk=39.4%

Figure 4-11: Graphical display of MATLAB Fuzzy Inference System (FIS) for calculating scope-related construction risks of oil & gas projects

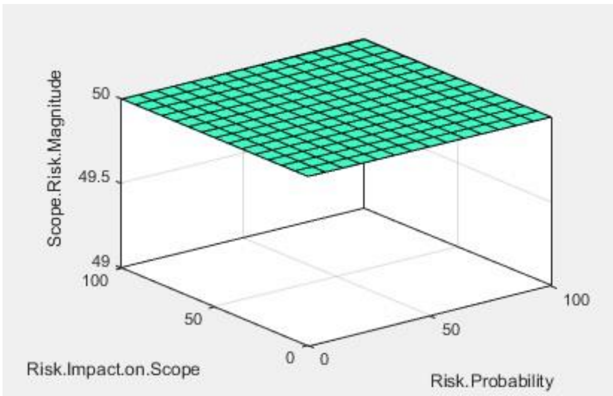


Figure 4-12: 3D fuzzy function of scope-related construction risk factors using MATLAB FIS

4.6. Prioritizing the construction risks based on experts' background

In this section the results of a risk analysis will be presented that shows the priority of construction risk factors in each project objective based on the most prominent experience background of experts. To clarify this issue further, it should be noted that some of the respondents to the survey determined more than one work background in the questionnaire. So for these results the respondents were classified based on their longest work history as a client, a consultant or a contractor. The twenty-four participating experts in this study were classified in three groups of clients consist of four experts; consultants consist of twelve experts and contractor group consist of eight experts.

4.6.1. Ranking time-related construction risks based on experts' background

Table 4-7 shows the ranking of time related-construction risks for each group of clients, consultants and contractors respectively.

Table 4-7: Highest ranked time-related construction risks from the viewpoint of different groups of experts

Rank	Clients	Consultants	Contractors
1	Delays in stage passing approval	Delays in stage passing approval	Delays in stage passing approval
2	Damage to environment	Poor and ineffective construction management by consultant	Damage to environment
3	Poor and ineffective construction management by consultant	Damage to environment	Poor and ineffective construction management by consultant

4.6.2. Ranking cost-related construction risks based on experts' background

Table 4-8 shows the ranking of cost related-construction risks for each group of clients, consultants and contractors respectively.

Table 4-8: Highest ranked cost-related construction risks from the viewpoint of different groups of experts

Rank	Clients	Consultants	Contractors
1	Damage to environment	Waste caused by contractors	Damage to environment
2	Poor and ineffective construction management by consultant	Damage to environment	Inconsistency of construction conditions with construction planning
3	Waste caused by contractors	Mistakes in construction because of contractor default	Delays in stage passing approval

4.6.3. Ranking quality-related construction risks based on experts' background

Table 4-9 shows the ranking of quality-related construction risks for each group of clients, consultants and contractors respectively.

Table 4-9: Highest ranked quality-related construction risks from the viewpoint of different groups of experts

Rank	Clients	Consultants	Contractors
1	Poor and ineffective construction management by consultant	Poor and ineffective construction management by consultant	Poor and ineffective construction management by consultant
2	Faulty construction techniques	Mistakes in construction because of contractor default	Damage to environment
3	Damage to environment	Damage to environment	Faulty construction techniques

4.6.4. Ranking scope-related construction risks based on experts' background

Table 4-10 shows the ranking of scope-related construction risks for each group of clients, consultants and contractors respectively.

Table 4-10: Highest ranked scope-related construction risks from the viewpoint of different groups of experts

Rank	Clients	Consultants	Contractors
1	Poor and ineffective construction management by consultant	Poor and ineffective construction management by consultant	Damage to environment
2	Faulty construction techniques	Mistakes in construction because of contractor default	Faulty construction techniques
3	Damage to environment	Faulty construction techniques	Construction work variations

5. CONCLUSION

Risk is an uncertain situation that if happens, at least one of the project' objectives would be affected so the source of risk is uncertainty and ambiguity that is existed in the projects.

Complexity and integration of economic, political and business relationships and development of multinational corporations in today's world have brought many challenges to the modern management. Among these challenges, risk management is considered as one of the most important ones which is an inseparable part of the body of every modern project management procedure.

This study intended to investigate the risk management in civil and infrastructure projects by focusing on oil and gas projects as one of the most important infrastructure civil projects.

The complexity, variety and huge size of oil and gas projects associated with a significant amount of uncertainties and risk factors. Thus the risk management activities play a vital role in all stages of oil and gas projects from feasibility stage, investment, design, construction to operation and usage stages.

Risk management methods that only rely on certain mathematics or true or false logic and need accurate data for risk analysis are not compatible with the uncertain atmosphere of oil and gas projects as these methods are unable to involve vague and imprecise data. Thus the main purpose of this study was to introduce and develop a fuzzy risk management model based on fuzzy logic, which takes advantage of ambiguous and qualitative judgments and knowledge of experts involved in oil and gas industry.

Fuzzy logic considers a degree of truthfulness and falsehood for propositions and assigns more than one simple binary truth value of 1 (truth) or 0 (false) to the veracity of an element. This attribute provides a more compatible and flexible tool for analysing the uncertain situations like risk exposed activities.

5.1. Challenges faced the research

Conducting this research from the conceptualizing to writing the thesis script was a very complex task which looked like making a puzzle. To tackle a project of this size and complexity we needed to provide a clear image of all required parts and then put all pieces together to get a beautiful picture of them.

Many challenges faced during this research that some of the most significant of them can be listed as follows:

- Various definitions of risk and numerous classifications of risk factors involved in oil and gas industry and projects.
- The classification process of a large number of the identified risk factors in an efficient and convenient way which is more compatible with the goals of the research.
- Lack of direct access to the information resources of oil and gas companies as this project was an external project and was not conducted within the organization.
- Creating and adjusting the survey questionnaire in a way that could extract the experts' judgments in the best way.
- Identification and collecting data from a group of oil and gas experts that could cover a more diverse range of work experience and professional background.
- Providing a clear and perceptible definition of each risk factor in the final list of the construction risk group that prevented the experts from misjudgment or wrong understanding.
- Verifying the reliability and normality of the collected data using the most appropriate statistical tests.
- Proposing a method for constructing the fuzzy membership functions of risk impacts on project objective in a way that could properly reflect the qualitative evaluations.
- Developing an efficient and appropriate model for risk management of oil and gas projects in a way which is capable of applying the concepts of fuzzy logic to provide a more flexible and more dynamic model compared with existing similar models.

5.2. Research outlines and findings

In this work, we investigated the most relevant references and the most recent researches to perform a comprehensive literature review within the determined framework of this study by focusing on the following issues:

- Different definitions and classifications of risk
- Different models, framework and principles of risk management
- Basic concepts and definitions related to fuzzy logic, fuzzy systems and fuzzy management
- Oil and gas industry, its related activities and risks and uncertainties involved in the projects of this industry
- Construction projects and their different phases and elements
- Risk management in the oil and gas projects and using fuzzy approaches for this purpose

The fundamental outcomes of the literature review chapter can be listed as follows:

- Identifying a large variety of risk factors involved in the oil and gas industry and projects, including two hundred and forty-nine (249) risk factors.
- Classification the identified risk factors to seventeen (17) major groups. The identified major risk groups were formed based on their effect on all the stages of oil and gas projects (Upstream, midstream and downstream). For example, all of these seventeen major groups of risk can affect the construction of oil and gas exploration and production platform, transportation pipelines or an oil and gas refinery.

Risks can affect the expected scope, cost, quality and accomplishment time of oil & gas projects in various stages of exploration, excavation and production, transportation, refining and marketing. Regarding the large amount of risk factors and along the major concern of this study, the 'Construction Risks' group was selected for further analysis using the proposed fuzzy risk management model presented in the 'Methodology' chapter. This model was formed based on fuzzy rule base or fuzzy inference system and was used to perform fuzzy analysis of the sixteen risk factors of 'Construction Risks' group in four identified project objectives including: Time, Cost, Quality and Scope.

For collecting the required information around the linguistic terms of risk parameters and risk factors a questionnaire was prepared based on the most convenient features and scales. This questionnaire was sent to the identified experts involved in the oil and gas who had relevant work experience as a client, a consultant or a contractor in this industry. Then, before any further analysis the reliability and normality of the collected data were verified using the relevant statistical tests.

The information from the twenty-four collected questionnaires was used to construct five fuzzy membership functions of linguistic terms of risk impact (VL, L, M, H, VH) on four project objectives including time, cost, quality and scope. For this purpose, *480* ($24\times5\times4$) different evaluations were used. Moreover, the crisp input values of risk probability and risk impact of each risk factor on each project objectives were estimated through *1920* ($24\times5\times16$) single evaluations.

As a result of this section and according the convergence of membership functions of risk impacts we can realize how qualitative assessment of scope change and quality reduction of oil and gas projects differ from qualitative evaluation of schedule slippage or cost increase as more compacted MFs result in more noticeable impacts.

After providing all the required materials, fuzzy analysis of risk factors was performed by proposing a fuzzy assessment model using the MATLAB fuzzy tool box. The results of risk analysis were presented in the fourth chapter of this script. These results can be listed as follows:

1. Determining the value of each construction risk factor related to each project objective (time risk, cost risk, quality risk and scope risk).
2. Ranking the construction risk factors related to each project objective based on fuzzy analysis.
3. Comparison between fuzzy ranking and probability-impact (P.I) ranking, which shows how ambiguous data an affect the total ranking of risks.
4. Determining the total value of 'Construction Risks' group and how this group of risks can affect the project objectives. It can be found that the 'construction risks' group threatens the time of the project more than other project objectives.
5. Determining the most and the least important risk factors, according to the most significant background of experts.

The results of this study can benefit the managers in oil & gas companies or government or researchers in the following ways:

- Awareness of a huge number of risk factors and a more detailed risk classification in risk assessment of oil and gas projects.
- Helping managers to perform a better project planning to complete a project within a specific time, with pre-defined allocated budget that provides expected quality and scope by considering the numerical values of each project objective risk.
- Customizing the flexible risk assessment model helps managers to update it for a particular project or condition.
- Providing the highest possible exploitation of experts' qualitative judgments.
- The results of this study can be used in multi attribute decision making models which are project oriented like models based on simple additive weighting methods, analytical hierarchy process (AHP) or fuzzy multi attribute decision making (FMADM).

During the recent years, many huge oil and gas companies all around the world have been dealing with several financial, legal and development issues. Many employees of these companies have been laid off and lots of development projects have been cancelled or shut down temporarily. It may seem very simplistic but after reviewing and interpreting a large number of papers and article in this area, in the author's opinion, a large portion of current issues in this industry are due to this fact that despite of the existence of large risk management units in these companies, they have failed to apply functional and reliable risk management approaches that could deal with real world risks and opportunities. Many of these approaches need to be redefined or revised because of the following issues:

1. Lack of a precise and integrated definition of risk, its different types and boundaries (e.g. Risk, hazard and opportunities).
2. Lack of a clear definition of risk effectiveness levels and cause and effect relations
3. Lack of a proper classification of risk factors (objective-oriented, project-oriented, external or internal, etc.).
4. Not considering the risk factors as dynamic phenomena with mutual interactions
5. Lack of improper hierarchy of risks.
6. Incorrect perception of real source of risks.
7. Wrong interpretation of subjective perceptions of risk magnitude, probability and impacts on different project objectives.
8. Lack of adequate or reliable data and information for estimating the risk likelihoods and consequences.
9. Defective definition of a project' objectives (e.g. Time, cost, quality or scope).
10. Wrong estimations about a project' objectives (e.g. Unrealistic schedule or cost) or incorrect perception of a project' scope.

5.3. Recommendations for future research

Following subjects are recommended for further investigations and research:

1. Investigating each of other identified groups of risk that can affect the objectives of an oil and gas project.
2. Using Fuzzy Decision Making Models (FDMM) instead of Fuzzy Inference System for risk management of oil and gas projects.
3. Using fuzzy risk management for a more detailed hierarchy of risk factors.
4. Investigating the simultaneous interactions and combination of different risk factors.
5. Conducting risk management approaches using fuzzy logic by focusing on oil and gas challenges (e.g. Technical, Human resource or Managerial).
6. Conducting risk management based on other definitions of risks or a combination of different definitions (e.g. hazard or opportunities with positive consequences).
7. Conducting any research to investigate and rank the major failure reasons of risk management approaches taken by oil and gas companies.
8. Investigating the experts' interpretations of subjective concepts (e.g. very low, low, moderate, high very high) to define new fuzzy membership functions for risk magnitude and risk probability.

9. Updating fuzzy membership functions of risk consequences on project objectives.
10. Using other kinds of fuzzy membership functions rather than triangular or trapezoidal membership functions for risk likelihood, risk impact and risk magnitude
11. Using other kind of fuzzy inference systems such as Sugeno instead of a Mamdani inference system.
12. Investigating the risk management of oil and gas projects with considering the interaction between the environment and the project (for example risks that are imposed to the environment because of the construction of an oil and gas project).

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APENDICES

APPENDIX A- Research Participation Request

Survey Name: Construction Risks Assessment of Oil & Gas Projects

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Dear Expert,

I am a Ph.D. Student of Civil Engineering faculty of Curtin University, conducting a research study focusing on identifying, evaluating and analysing the most effective risk parameters during the construction of oil & gas projects (extraction platforms, refineries, transport pipelines, etc.) by developing a model based on Fuzzy logic. This study investigates one category of risks containing 16 risks out of 17 categories of risks containing 249 identified risks affecting oil & gas projects and industries.

Unlike the classic logic, fuzzy logic assigns more than a simple binary truth value of 1 (True) or 0 (False) to the veracity of an element. With fuzzy logic, propositions can be represented with degrees of truthfulness and falsehood so it is more compatible with the uncertainty atmosphere of risks. Fuzzy risk management model considers vague data and experts' feelings, knowledge and judgement expressed by linguistic variables in the modelling which leads to more accurate and flexible model for risk management. The outcome of this study will be helping the managers in companies to make quick and accurate strategic decisions with minimal risk and maximum profitability.

Because of your expertise and knowledge, you have been identified as a key person to be a respondent in my survey. I know you are very busy, but your judgment is very important to me and will be kept strictly confidential. All survey data is compiled into a fuzzy model database and then a report of results is generated after analysis.

To complete the survey online, simply copy the entire URL into your browser to access the survey. If you don't like to take the online survey, please fill up the risk assessment table provided in word format and then email it back to me. Thank you in advance for your participation in this project. If you have any questions, please do not hesitate to contact me.

By Best Regards

Amin Amini

Faculty of Science and Engineering, Curtin University, Kent St, Bentley WA 6102
Mobile: (+61)426631369 - Email: amin.amini@postgrad.curtin.edu.au
Survey Link: https://eSurv.org?u=Construction_risk_assessment_of_oil_and_gas_projects

EXPERTS' BACKGORUND

Experts' Background

In this section please specify your work experience or expertise background.

Your work experience as a "Client":

☐ 0-5 Years

☐ 5-10 Years

☐ More than 10 Years

Your work experience as a "Consultant":

☐ 0-5 Years

☐ 5-10 Years

☐ More than 10 Years

Your work experience as a "Contractor or Subcontractor":

☐ 0-5 Years

☐ 5-10 Years

☐ More than 10 Years

Other (Please mention in the comment box):

RISK IMPACT ASSESSMENT

Risk Impact on Project Cost

Cost of project:

All costs specific to a project incurred through start-up of a facility, but prior to the operation of the facility. So total project cost includes total estimated cost and other project costs.

In this section please give your definition of linguistic terms of risk impact on the **"Total Project Cost"** by specifying a range using the scrolls.

What percentage of cost increase do you consider as "Very Low" impact of risk on the total project cost?

0 % 10 %-90 % 100 %

What percentage of cost increase do you consider as "Low" impact of risk on the total project cost?

0 % 10 %-90 % 100 %

What percentage of cost increase do you consider as "Moderate" impact of risk on the total project cost?

0 % 10 %-90 % 100 %

What percentage of cost increase do you consider as "High" impact of risk on the total project cost?

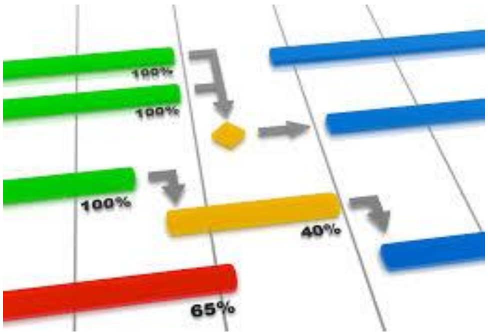
0 % 10 %-90 % 100 %

What percentage of cost increase do you consider as "Very High" impact of risk on the total project cost?

0 % 10 %-90 % 100 %

RISK IMPACT ASSESSMENT

Risk Impact on Project Time



Time of project:

The schedule of a project determines the total project time through listing planned dates for performing activities and meeting identified milestones in the project plan. The schedule of a project is created through analysing activity sequences, activity durations with planned start and expected finish dates and resource requirements.

In this section please give your definition of linguistic term of risk impact on the **"Total Project Time"** by specifying a range using the scrolls.

What percentage of schedule slippage do you consider as "Very Low" impact of risk on the total project time?

0 % 10 %-90 % 100 %

What percentage of schedule slippage do you consider as "Low" impact of risk on the total project time?

0 % 10 %-90 % 100 %

What percentage of schedule slippage do you consider as "Moderate" impact of risk on the total project time?

0 % 10 %-90 % 100 %

What percentage of schedule slippage do you consider as "High" impact of risk on the total project time?

0 % 10 %-90 % 100 %

What percentage of schedule slippage do you consider as "Very High" impact of risk on the total project time?

0 % 10 %-90 % 100 %

RISK IMPACT ASSESSMENT

Risk Impact on Project Quality

Quality of project:

Quality of a project is defined as the totality of characteristics of an entity that bear on its ability to satisfy stated or implied needs. Stated and implied needs are the inputs to developing project requirements. Quality of a project should satisfy the needs for which it was taken.

In this section please give your definition of linguistic terms of risk impact on the **"Project Quality"** by specifying a range using the scrolls.

What percentage of quality reduction do you consider as "Very Low" impact of risk on the expected project quality?

0 % 10 %-90 % 100 %

What percentage of quality reduction do you consider as "Low" impact of risk on the expected project quality?

0 % 10 %-90 % 100 %

What percentage of quality reduction do you consider as "Moderate" impact of risk on the expected project quality?

0 % 10 %-90 % 100 %

What percentage of quality reduction do you consider as "High" impact of risk on the expected project quality?

0 % 10 %-90 % 100 %

What percentage of quality reduction do you consider as "Very High" impact of risk on the expected project quality?

0 % 10 %-90 % 100 %

RISK IMPACT ASSESSMENT

Risk Impact on Project Scope

Scope of project:

Specific project goals, deliverables, tasks, costs and deadlines are determined and documented as a part of project planning called project scope .in other word the project scope defines the project boundaries. PMBOK defines scope as “the sum of products and services to be provided as a project”. Defining the project scope is one of the most essential and critical steps of the project planning that determines what is supposed to be delivered at the end of the project to the client.

In this section please give your definition of linguistic terms of risk impact on the **"Project Scope"** by specifying a range using the scrolls.

What percentage of scope change do you consider as "Very Low" impact of risk on the defined project scope?

0 % 10 %-90 % 100 %

What percentage of scope change do you consider as "Low" impact of risk on the defined project scope?

0 % 10 %-90 % 100 %

What percentage of scope change do you consider as "Moderate" impact of risk on the defined project scope?

0 % 10 %-90 % 100 %

What percentage of scope change do you consider as "High" impact of risk on the defined project scope?

0 % 10 %-90 % 100 %

What percentage of scope change do you consider as "Very High" impact of risk on the defined project scope?

0 % 10 %-90 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 1: Wrong constructability assumption

Modern construction management approaches define constructability term as "the effective and timely integration of construction knowledge into the conceptual planning, design, construction, and field operations of a project to achieve the overall project objectives in the best possible time and accuracy at the most cost-effective levels". Difficult design documents and wrong interpretation may result in a wrong constructability assumption that can affect the goals, performance, quality and ease of construction a project.

The probability of occurrence of " Wrong constructability assumption" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of " Wrong constructability assumption" risk on increasing the cost of an oil & gas project is:

0 %　　50 %　　100 %

The impact of " Wrong constructability assumption" risk on schedule slippage of an oil & gas project is:

0 %　　50 %　　100 %

The impact of " Wrong constructability assumption" risk on quality reduction of an oil & gas project is:

0 %　　50 %　　100 %

The impact of " Wrong constructability assumption" risk on scope change of an oil & gas project is:

0 %　　50 %　　100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 2: Complexity Level of Construction

Increasing the size and complexity level of a project can expose its construction to significant uncertainties and make it difficult to implement, inspect and managed. Oil and gas construction projects are inherently huge, complex and dynamic, so in this case the risk factor is unknown or unpredicted probable event due to the complexity level of construction that may occur and have negative impacts on the construction process.

The probability of occurrence of "complexity level of construction" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "complexity level of construction" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "complexity level of construction" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "complexity level of construction" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "complexity level of construction" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 3: Faulty Construction Techniques

Choosing and using any kind of imperfect, false, inaccurate, unreliable or malfunctioning construction method has serious consequences on project objectives.

The probability of occurrence of "faulty construction techniques" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "faulty construction techniques" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "faulty construction techniques" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "faulty construction techniques" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "faulty construction techniques" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 4: Construction Equipment Failure and Inefficiency

Old or even new construction equipment can fail or be inefficient, which may be as a result of defective design or defective manufacturing or poor maintenance and repair. Corruption, overuse or inappropriate training can also cause failure and inefficiency of equipment. In construction projects failure of motorized equipment like cranes, lifts, forklifts, bulldozers, loaders, trucks, excavators or failure of hydraulic lines, brake lines, cables, bolts, pumps, pressure tanks and compressed air lines are considered as common examples of equipment failure.

The probability of occurrence of "construction equipment failure and inefficiency" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "construction equipment failure and inefficiency" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "construction equipment failure and inefficiency" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "construction equipment failure and inefficiency" risk on quality reduction of an oil & gas project is:

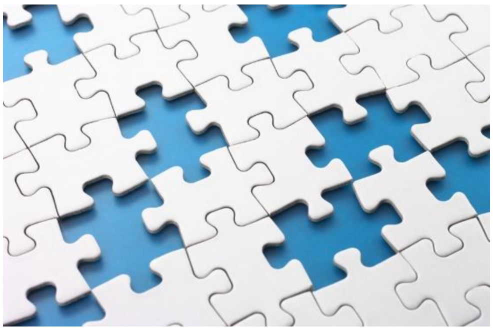
0 % 50 % 100 %

The impact of "construction equipment failure and inefficiency" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.



Risk Factor 5: Encountering with defective or incomplete construction work

Sometimes a construction work activity cannot be completed or is completed defectively because of reasons such as inadequate financial, technical or logistic supports or even legal conflicts. This may lead to dismiss the current contractor by the owner and transfer the job to another contractor. So the new contractor team members encounter with an incomplete or defective work that may have consequences for project objectives.

The probability of occurrence of "Encountering with defective or incomplete construction work" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Encountering with defective or incomplete construction work" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Encountering with defective or incomplete construction work" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Encountering with defective or incomplete construction work" risk on quality reduction of an oil & gas project is:

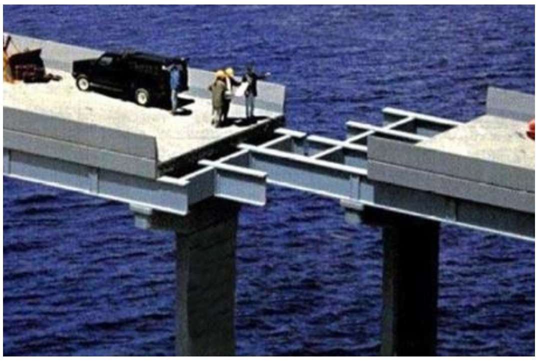
0 % 50 % 100 %

The impact of "Encountering with defective or incomplete construction work" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.



Risk Factor 6: Mistakes in construction because of contractor default

Failure to perform specific characteristics of a construction work indicated in contractor's obligations because of delinquency, negligence, insufficiency or error of the contractor.

The probability of occurrence of "mistakes in construction because of contractor default" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "mistakes in construction because of contractor default" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "mistakes in construction because of contractor default" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "mistakes in construction because of contractor default" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "mistakes in construction because of contractor default" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 7: Waste caused by contractors

In general, any direct or indirect loss produced by contractors' activity that does not add any value to the product and has negative impacts on time, cost, resources, and other objectives of a project is called waste. Inefficient work practices and processes, waiting periods for materials, repairs, equipment, instructions and resources, poor performance, wastage of materials because of too much inventory on site, unnecessary material handling, nonstandard specifications, damages and loss of materials because of improper storage of materials are kinds of waste caused by contractors and subcontractors.

The probability of occurrence of "Waste caused by contractors" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Waste caused by contractors" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Waste caused by contractors" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Waste caused by contractors" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Waste caused by contractors" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 8: Poor and ineffective construction management by consultant

Ineffective supervision on contractors and subcontractors' work, inadequate quality control, ineffective coordination between client, contractors and consultant head office, supervising by not an appropriately licenced person, not checking the contractors' licence to make sure that the work is carrying out by a qualified team or person, inappropriate supervision on fixing the defective or nonstandard work by contractors, non-permanent presence of site supervisor or irregular inspection by site supervisor, improper supervision on health and safety regulations, etc. can raise many issues, lead the work does not meet the standards and encounter the project objectives with serious dangers.

The probability of occurrence of "Poor and ineffective construction management by consultant" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Poor and ineffective construction management by consultant" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Poor and ineffective construction management by consultant" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Poor and ineffective construction management by consultant" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Poor and ineffective construction management by consultant" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 9: Delays in stage passing approval

Disapproval of job by client or consultant because of low construction quality, failure to meet performance criteria, commissioning tests failure, failure to properly correct the defective work by contractors, disagreements and conflicts between consultant and contractors about statements, job terms and conditions, etc., and failure to complete the extra items are some of reasons that can cause delays in approval of contractors' work and passing the stage.

The probability of occurrence of "Delays in stage passing approval" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Delays in stage passing approval" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Delays in stage passing approval" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Delays in stage passing approval" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Delays in stage passing approval" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 10: Construction variations

Variations in schedule, scope and specifications of construction activities when the project is in the construction phase due to extra demands by the owner, new required obligations and standards, design reviews, new information, missing data, inability to build as specified and procurement or budget restrictions.

The probability of occurrence of "Construction variations" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Construction variations" risk on increasing the cost of an oil & gas project is:

0 %　　50 %　　100 %

The impact of "Construction variations" risk on schedule slippage of an oil & gas project is:

0 %　　50 %　　100 %

The impact of "Construction variations" risk on quality reduction of an oil & gas project is:

0 %　　50 %　　100 %

The impact of "Construction variations" risk on scope change of an oil & gas project is:

0 %　　50 %　　100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 11: Inconsistency of construction conditions with construction plans

Any unexpected inconsistency between construction conditions and construction specifications identified in the construction plans due to wrong implementation or faulty interpretation of construction siting, direction, level, dimension, form, etc.

The probability of occurrence of "Inconsistency of construction conditions with construction plans" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Inconsistency of construction conditions with construction plans" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction plans" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction plans" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction plans" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 12: Inconsistency of construction conditions with construction planning

Any unexpected inconsistency of construction conditions with planning due to missing or faulty information about the construction site conditions, inadmissible land use, inability to install the required equipment or using the power supplies, inability to get required permissions, etc. are in this major group.

The probability of occurrence of "Inconsistency of construction conditions with construction planning" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Inconsistency of construction conditions with construction planning" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction planning" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction planning" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Inconsistency of construction conditions with construction planning" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 13: Need to protect the geological and historical objects during the construction

Sometimes because of inadequate investigations, inaccurate or lack of data about an undiscovered location it is required to provide protection for historical or geological objects during the construction phase. This factor can cause delays in completion of the project, cost overrun or even change the scope of the project. In another form, it is possible that oil and gas projects take place in areas inhabited or used by indigenous people. In this case unplanned land use during the construction or development projects may be able to seriously affect the indigenous people, their heritage and culture that requires its special protection needs.

The probability of occurrence of "Need to protect the geological and historical objects during the construction" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Need to protect the geological and historical objects during the construction" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Need to protect the geological and historical objects during the construction" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Need to protect the geological and historical objects during the construction" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Need to protect the geological and historical objects during the construction" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 14: Fatalities and weighted injuries of workforce

This item is a criterion to measure the workforce safety. Most of fatalities and injuries of work force during the construction caused by industrial accidents or failure to follow safety procedures. Fire, explosion, improper use of equipment, equipment failure, vehicle accidents, fatigue, failure of individual workers to follow safety procedures, lack of safety knowledge of hazards present, failure to use PPE, inadequate workplace layout and many other factors can cause serious weighted injuries or fatalities of workforce.

The probability of occurrence of "Fatalities and weighted injuries of workforce" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Fatalities and weighted injuries of workforce" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Fatalities and weighted injuries of workforce" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Fatalities and weighted injuries of workforce" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Fatalities and weighted injuries of workforce" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.

Risk Factor 15: Damage to environment

This category includes negative and destructive short term or long term impacts of oil and gas construction projects on the natural environment including water, soil and air. Seas, rivers, oceans, forests, fertile lands, air and all marine and terrestrial ecosystems can be affected by realising high quantity of exhausted gases and particular matters, deforestation, chemical influences, spills and blowouts, etc. due to construction of oil and gas projects such as exploration and production platforms, pipelines, refineries, etc.

The probability of occurrence of "Damage to environment" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Damage to environment" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Damage to environment" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Damage to environment" risk on quality reduction of an oil & gas project is:

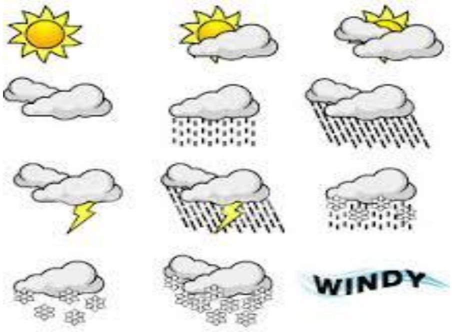
0 % 50 % 100 %

The impact of "Damage to environment" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

RISK FACTOR ASSESSMENT

In this section, please determine the probability of occurrence and the impact of each identified construction risk of oil & gas projects using the scroll.



Risk Factor 16: Severe temperature and weather conditions during the construction

Serious injuries to the workers and operators or heavy damages to the construction equipment due to very low or very high weather temperature, heavy wind, dust or fog, heavy snow, rain and hail.

The probability of occurrence of "Severe temperature and weather conditions during the construction" risk in an oil & gas project is:

☐Very Low
☐ Low
☐ Moderate
☐ High
☐ Very High

The impact of "Severe temperature and weather conditions during the construction" risk on increasing the cost of an oil & gas project is:

0 % 50 % 100 %

The impact of "Severe temperature and weather conditions during the construction" risk on schedule slippage of an oil & gas project is:

0 % 50 % 100 %

The impact of "Severe temperature and weather conditions during the construction" risk on quality reduction of an oil & gas project is:

0 % 50 % 100 %

The impact of "Severe temperature and weather conditions during the construction" risk on scope change of an oil & gas project is:

0 % 50 % 100 %

APPENDIX B-Ranking construction risks of oil & gas projects based on experts' background

Table App.B-1: Prioritizing the time-related construction risk factors for group of clients

Time-related							
No	Risk Factor	Probability (P)	Impact (I)	P.I	Fuzzy Risk	Risk Ranking	
						P.I	Fuzzy
1	Wrong constructability assumptions	15	11.25	1.69	38.30	12	10
2	Complexity level of construction	30	5.75	1.73	34.80	11	14
3	Faulty construction techniques	15	12.00	1.80	38.30	8	7
4	Construction equipment failure and inefficiency	30	6.75	2.03	35.60	7	13
5	Encountering with an incomplete or a defective construction work	30	10.00	3.00	43.60	6	6
6	Mistakes in construction because of contractor default	30	13.25	3.98	50.00	4	4
7	Waste caused by contractors	50	1.25	0.63	34.80	16	16
8	Poor and ineffective construction management by consultant	70	10.75	7.53	63.80	3	3
9	Delays in stage passing approval	50	21.00	10.50	63.90	1	1
10	Construction work variations	15	11.25	1.69	38.30	13	11
11	Inconsistency of construction conditions with construction plans	15	11.75	1.76	38.30	9	8
12	Inconsistency of construction conditions with construction planning	30	11.50	3.45	47.60	5	5
13	Need to protect the geological and historical objects during the construction	15	10.50	1.58	38.30	14	12
14	Fatalities and weighted injuries of workforce	50	2.00	1.00	34.80	15	15
15	Damage to environment	70	11.00	7.70	63.90	2	2
16	Severe temperature and weather conditions during the construction	15	11.75	1.76	38.30	10	9

Table App.B-2: Prioritizing the time-related construction risk factors for group of consultants

Time-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking P.I**	**Risk Ranking Fuzzy**
1	Wrong constructability assumptions	15	11.83	1.78	38.30	11	12
2	Complexity level of construction	50	11.92	5.96	56.40	5	5
3	Faulty construction techniques	15	9.75	1.46	38.20	16	16
4	Construction equipment failure and inefficiency	50	5.25	2.63	45.00	8	8
5	Encountering with an incomplete or a defective construction work	15	10.42	1.56	38.30	15	15
6	Mistakes in construction because of contractor default	50	13.25	6.63	57.10	4	4
7	Waste caused by contractors	70	2.83	1.98	43.60	9	9
8	Poor and ineffective construction management by consultant	50	21.25	10.63	64.00	2	2
9	Delays in stage passing approval	50	22.17	11.08	64.60	1	1
10	Construction work variations	15	12.67	1.90	38.30	10	11
11	Inconsistency of construction conditions with construction plans	15	11.50	1.73	38.30	12	13
12	Inconsistency of construction conditions with construction planning	50	11.42	5.71	56.40	6	6
13	Need to protect the geological and historical objects during the construction	30	11.75	3.53	48.20	7	7
14	Fatalities and weighted injuries of workforce	70	2.33	1.63	43.60	13	10
15	Damage to environment	70	10.75	7.53	63.80	3	3
16	Severe temperature and weather conditions during the construction	15	10.83	1.63	38.30	14	14

Table App.B-3: Prioritizing the time-related construction risk factors for group of contractors

Time-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	30	10.63	3.19	45.50	11	10
2	Complexity level of construction	47.5	12.00	5.70	55.20	4	5
3	Faulty construction techniques	15	9.25	1.39	37.50	15	15
4	Construction equipment failure and inefficiency	50	6.50	3.25	50.00	10	8
5	Encountering with an incomplete or a defective construction work	30	11.50	3.45	47.60	9	11
6	Mistakes in construction because of contractor default	30	10.38	3.11	44.80	12	12
7	Waste caused by contractors	30	3.25	0.98	30.40	16	16
8	Poor and ineffective construction management by consultant	57.5	10.50	6.04	59.20	3	3
9	Delays in stage passing approval	52.5	22.25	11.68	65.80	1	1
10	Construction work variations	32.5	12.25	3.98	50.40	6	7
11	Inconsistency of construction conditions with construction plans	17.5	12.63	2.21	39.20	13	13
12	Inconsistency of construction conditions with construction planning	52.5	10.63	5.58	57.40	5	4
13	Need to protect the geological and historical objects during the construction	15	12.13	1.82	38.30	14	14
14	Fatalities and weighted injuries of workforce	70	5.50	3.85	52.70	8	6
15	Damage to environment	72.5	11.63	8.43	65.50	2	2
16	Severe temperature and weather conditions during the construction	32.5	12.00	3.90	49.90	7	9

Table App.B-4: Prioritizing the cost-related construction risk factors for group of clients

Cost-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	15	7.50	1.13	29.70	13	13
2	Complexity level of construction	30	2.00	0.60	20.20	16	16
3	Faulty construction techniques	15	18.00	2.70	38.30	10	10
4	Construction equipment failure and inefficiency	30	2.50	0.75	24.70	15	15
5	Encountering with an incomplete or a defective construction work	30	18.25	5.48	50.00	4	4
6	Mistakes in construction because of contractor default	30	17.50	5.25	49.80	5	6
7	Waste caused by contractors	50	25.25	12.63	63.60	3	3
8	Poor and ineffective construction management by consultant	70	18.25	12.78	65.10	2	2
9	Delays in stage passing approval	50	6.00	3.00	46.50	8	8
10	Construction work variations	15	18.50	2.78	38.30	9	9
11	Inconsistency of construction conditions with construction plans	15	15.00	2.25	38.30	11	11
12	Inconsistency of construction conditions with construction planning	30	16.75	5.03	48.30	6	7
13	Need to protect the geological and historical objects during the construction	15	25.50	3.83	50.00	7	5
14	Fatalities and weighted injuries of workforce	50	3.50	1.75	37.30	12	12
15	Damage to environment	70	47.50	33.25	86.30	1	1
16	Severe temperature and weather conditions during the construction	15	6.75	1.01	28.10	14	14

Table App B-5: Prioritizing the cost-related construction risk factors for group of consultants

Cost-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking P.I**	**Risk Ranking Fuzzy**
1	Wrong constructability assumptions	15	7.42	1.11	29.50	16	16
2	Complexity level of construction	50	6.83	3.42	48.50	8	8
3	Faulty construction techniques	15	15.08	2.26	38.30	11	12
4	Construction equipment failure and inefficiency	50	3.00	1.50	34.90	14	14
5	Encountering with an incomplete or a defective construction work	15	15.58	2.34	38.30	9	10
6	Mistakes in construction because of contractor default	50	15.08	7.54	56.40	3	3
7	Waste caused by contractors	70	27.67	19.37	71.60	1	1
8	Poor and ineffective construction management by consultant	50	14.83	7.42	55.70	5	5
9	Delays in stage passing approval	50	7.25	3.63	49.40	7	7
10	Construction work variations	15	15.33	2.30	38.30	10	11
11	Inconsistency of construction conditions with construction plans	15	13.92	2.09	37.80	12	13
12	Inconsistency of construction conditions with construction planning	50	13.08	6.54	50.20	6	6
13	Need to protect the geological and historical objects during the construction	30	24.83	7.45	55.80	4	4
14	Fatalities and weighted injuries of workforce	70	2.33	1.63	43.60	13	9
15	Damage to environment	70	15.33	10.73	63.70	2	2
16	Severe temperature and weather conditions during the construction	15	8.42	1.26	31.30	15	15

Table App.B-6: Prioritizing the cost-related construction risk factors for group of contractors

Cost-related							
No	Risk Factor	Probability (P)	Impact (I)	P.I	Fuzzy Risk	Risk Ranking	
						P.I	Fuzzy
1	Wrong constructability assumptions	30	5.38	1.61	34.80	16	16
2	Complexity level of construction	47.5	6.38	3.03	46.40	11	8
3	Faulty construction techniques	15	13.25	1.99	37.00	14	14
4	Construction equipment failure and inefficiency	50	5.38	2.69	44.80	12	10
5	Encountering with an incomplete or a defective construction work	30	16.38	4.91	47.50	5	7
6	Mistakes in construction because of contractor default	30	15.63	4.69	45.50	6	9
7	Waste caused by contractors	30	24.75	7.43	55.60	4	4
8	Poor and ineffective construction management by consultant	57.5	8.13	4.67	55.50	7	5
9	Delays in stage passing approval	52.5	14.75	7.74	56.40	3	3
10	Construction work variations	32.5	14.38	4.67	44.50	8	11
11	Inconsistency of construction conditions with construction plans	17.5	14.88	2.60	39.10	13	13
12	Inconsistency of construction conditions with construction planning	52.5	15.25	8.01	57.40	2	2
13	Need to protect the geological and historical objects during the construction	15	22.50	3.38	43.70	10	12
14	Fatalities and weighted injuries of workforce	70	6.63	4.64	54.50	9	6
15	Damage to environment	72.5	22.50	16.31	67.10	1	1
16	Severe temperature and weather conditions during the construction	32.5	5.88	1.91	36.40	15	15

Table App.B-7: Prioritizing the quality-related construction risk factors for group of clients

		Quality-related					
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	15	2.50	0.38	23.10	13	13
2	Complexity level of construction	30	1.50	0.45	29.00	11	11
3	Faulty construction techniques	15	12.75	1.91	58.80	2	2
4	Construction equipment failure and inefficiency	30	1.75	0.53	30.90	10	9
5	Encountering with an incomplete or a defective construction work	30	2.75	0.83	34.90	7	8
6	Mistakes in construction because of contractor default	30	6.00	1.80	43.60	3	4
7	Waste caused by contractors	50	1.75	0.88	37.30	5	5
8	Poor and ineffective construction management by consultant	70	13.75	9.63	79.10	1	1
9	Delays in stage passing approval	50	1.75	0.88	37.30	6	6
10	Construction work variations	15	2.75	0.41	23.10	12	15
11	Inconsistency of construction conditions with construction plans	15	2.25	0.34	23.10	14	14
12	Inconsistency of construction conditions with construction planning	30	1.75	0.53	30.70	9	10
13	Need to protect the geological and historical objects during the construction	15	2.00	0.30	24.10	15	12
14	Fatalities and weighted injuries of workforce	50	1.50	0.75	35.30	8	7
15	Damage to environment	70	2.50	1.75	44.10	4	3
16	Severe temperature and weather conditions during the construction	15	1.25	0.19	19.20	16	16

Table App.B-8: Prioritizing the quality-related construction risk factors for group of consultants

Quality-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	15	3.67	0.55	29.20	12	13
2	Complexity level of construction	50	1.83	0.92	37.90	8	8
3	Faulty construction techniques	15	9.42	1.41	45.70	5	5
4	Construction equipment failure and inefficiency	50	1.83	0.92	37.90	9	9
5	Encountering with an incomplete or a defective construction work	15	3.92	0.59	30.80	11	12
6	Mistakes in construction because of contractor default	50	6.83	3.42	56.40	2	2
7	Waste caused by contractors	70	2.75	1.93	46.60	4	4
8	Poor and ineffective construction management by consultant	50	35.42	17.71	79.50	1	1
9	Delays in stage passing approval	50	1.92	0.96	38.50	7	7
10	Construction work variations	15	1.92	0.29	24.60	15	15
11	Inconsistency of construction conditions with construction plans	15	3.50	0.53	28.00	13	14
12	Inconsistency of construction conditions with construction planning	50	1.67	0.83	36.70	10	10
13	Need to protect the geological and historical objects during the construction	30	1.75	0.53	30.90	14	11
14	Fatalities and weighted injuries of workforce	70	1.92	1.34	42.90	6	6
15	Damage to environment	70	3.42	2.39	53.90	3	3
16	Severe temperature and weather conditions during the construction	15	1.92	0.29	24.60	16	16

Table App.B-9: Prioritizing the quality-related construction risk factors for group of contractors

Quality-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	30	6.00	1.80	43.60	3	4
2	Complexity level of construction	47.5	1.75	0.83	36.60	11	9
3	Faulty construction techniques	15	9.50	1.43	46.20	6	3
4	Construction equipment failure and inefficiency	50	1.88	0.94	38.20	9	8
5	Encountering with an incomplete or a defective construction work	30	3.13	0.94	34.90	10	12
6	Mistakes in construction because of contractor default	30	5.63	1.69	43.10	4	6
7	Waste caused by contractors	30	3.38	1.01	34.90	8	11
8	Poor and ineffective construction management by consultant	57.5	8.25	4.74	60.80	1	1
9	Delays in stage passing approval	52.5	1.50	0.79	36.50	12	10
10	Construction work variations	32.5	1.63	0.53	31.20	14	14
11	Inconsistency of construction conditions with construction plans	17.5	2.88	0.50	24.20	15	15
12	Inconsistency of construction conditions with construction planning	52.5	2.00	1.05	39.60	7	7
13	Need to protect the geological and historical objects during the construction	15	2.00	0.30	24.10	16	16
14	Fatalities and weighted injuries of workforce	70	2.25	1.58	43.60	5	5
15	Damage to environment	72.5	2.88	2.08	48.20	2	2
16	Severe temperature and weather conditions during the construction	32.5	2.25	0.73	34.90	13	13

Table App.B-10: Prioritizing the scope-related construction risk factors for group of clients

Scope-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	15	1.25	0.19	23.60	16	13
2	Complexity level of construction	30	1.00	0.30	23.80	13	12
3	Faulty construction techniques	15	7.00	1.05	56.10	4	2
4	Construction equipment failure and inefficiency	30	1.50	0.45	33.80	9	9
5	Encountering with an incomplete or a defective construction work	30	1.25	0.38	31.10	11	11
6	Mistakes in construction because of contractor default	30	4.25	1.28	46.90	3	4
7	Waste caused by contractors	50	1.50	0.75	40.10	5	5
8	Poor and ineffective construction management by consultant	70	5.25	3.68	64.80	1	1
9	Delays in stage passing approval	50	1.25	0.63	36.50	7	7
10	Construction work variations	15	3.75	0.56	37.90	8	6
11	Inconsistency of construction conditions with construction plans	15	2.00	0.30	23.50	12	14
12	Inconsistency of construction conditions with construction planning	30	1.50	0.45	33.80	10	10
13	Need to protect the geological and historical objects during the construction	15	1.50	0.23	23.50	14	15
14	Fatalities and weighted injuries of workforce	50	1.25	0.63	36.50	6	8
15	Damage to environment	70	2.00	1.40	50.40	2	3
16	Severe temperature and weather conditions during the construction	15	1.50	0.23	23.50	15	16

Table App.B-11: Prioritizing the scope-related construction risk factors for group of consultants

Scope-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking P.I**	**Risk Ranking Fuzzy**
1	Wrong constructability assumptions	15	1.25	0.19	23.60	16	15
2	Complexity level of construction	50	1.58	0.79	41.00	7	7
3	Faulty construction techniques	15	6.00	0.90	50.00	6	3
4	Construction equipment failure and inefficiency	50	1.58	0.79	41.00	8	8
5	Encountering with an incomplete or a defective construction work	15	1.33	0.20	24.80	15	14
6	Mistakes in construction because of contractor default	50	3.50	1.75	50.00	2	2
7	Waste caused by contractors	70	1.58	1.11	43.60	4	5
8	Poor and ineffective construction management by consultant	50	4.08	2.04	56.40	1	1
9	Delays in stage passing approval	50	1.33	0.67	37.80	10	11
10	Construction work variations	15	3.75	0.56	37.90	11	9
11	Inconsistency of construction conditions with construction plans	15	2.25	0.34	27.80	13	13
12	Inconsistency of construction conditions with construction planning	50	1.33	0.67	37.80	9	10
13	Need to protect the geological and historical objects during the construction	30	1.67	0.50	34.90	12	12
14	Fatalities and weighted injuries of workforce	70	1.50	1.05	43.40	5	6
15	Damage to environment	70	1.92	1.34	48.10	3	4
16	Severe temperature and weather conditions during the construction	15	1.58	0.24	23.10	14	16

Table App.B-12: Prioritizing the scope-related construction risk factors for group of contractors

Scope-related							
No	**Risk Factor**	**Probability (P)**	**Impact (I)**	**P.I**	**Fuzzy Risk**	**Risk Ranking**	
						P.I	**Fuzzy**
1	Wrong constructability assumptions	30	1.50	0.45	33.80	13	14
2	Complexity level of construction	47.5	1.38	0.65	37.80	10	10
3	Faulty construction techniques	15	6.13	0.92	51.00	6	2
4	Construction equipment failure and inefficiency	50	1.38	0.69	38.50	9	9
5	Encountering with an incomplete or a defective construction work	30	1.75	0.53	34.90	11	11
6	Mistakes in construction because of contractor default	30	4.13	1.24	45.40	3	5
7	Waste caused by contractors	30	1.63	0.49	34.80	12	12
8	Poor and ineffective construction management by consultant	57.5	2.13	1.22	50.60	4	4
9	Delays in stage passing approval	52.5	1.50	0.79	40.80	8	8
10	Construction work variations	32.5	4.50	1.46	50.70	2	3
11	Inconsistency of construction conditions with construction plans	17.5	2.13	0.37	27.00	15	15
12	Inconsistency of construction conditions with construction planning	52.5	1.50	0.79	40.80	7	7
13	Need to protect the geological and historical objects during the construction	15	1.63	0.24	23.10	16	16
14	Fatalities and weighted injuries of workforce	70	1.50	1.05	43.40	5	6
15	Damage to environment	72.5	11.63	1.81	57.00	1	1
16	Severe temperature and weather conditions during the construction	32.5	12.00	0.45	33.90	14	13

PUBLICATIONS

Paper 1: "*Identifying and evaluating the effective parameters in prioritization of urban roadway bridges for maintenance operations*. Australian Journal of Civil Engineering, Vol 14, (1) Pages 23-34."

	conception and design	**acquisition of data & method**	**data conditioning & manipulation**	**analysis & statistical method**	**interpretation & discussion**	**Final Approval**
Amin Amini	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed.						
Dr.Navid Nikraz	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed.						
Ali Fathizadeh	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed.						

Paper 2: "*Proposing Two Defuzzification Methods based on Output Fuzzy Set Weights*. International Journal of Intelligent Systems and Applications, (2016), Vol 8, (2), Page 1."

	conception and design	**acquisition of data & method**	**data conditioning & manipulation**	**analysis & statistical method**	**interpretation & discussion**	**Final Approval**
Amin Amini	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed.						
Dr.Navid Nikraz	x	x	x	x	x	x
I acknowledge that these represent my contribution to the above research output. Signed.						