

# **Modelling the effects of risk factors on project cost and time**

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A Dissertation Submitted to  
The School of Mechanical and Industrial Engineering

Presented in Fulfilment of the Requirements for the Degree of Doctor of  
Philosophy in Industrial Engineering

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Addis Ababa, Ethiopia

April, 2017

## Abstract

A significant number of projects fail to achieve their intended goals. The main reason for the failure is due to the associate risks with every project. Among different sectors, the construction industry is usually prone to risk. This is because of the involvement of many stakeholders, complexity, dynamic nature of business, environment and process. Although road construction projects play a significant role in Ethiopian economy, different studies conducted on Ethiopian road construction revealed a significant failure on time and cost of projects. The survey in this industry shows that there is no systematic risk management. In addition, most of the research works on risk assessment are limited to risk ranking. Furthermore, there is no suitable tool or theory for assessing the compounded risk factors on the project objective without considering the interdependencies of risk factor among each other.

Thus, the objective of this research is to develop the interrelationship and examine the impact of individual risk factors on project cost and time. Moreover, it is aimed at studying the aggregated impact of risk factors. The research uses questionnaires to examine the risk magnitude by ranking 51 risk factors obtained from comprehensive literature review and expert interview against the probability of occurrence and impact on time and cost. Pairwise relationship matrix is developed for the experts in construction industries to identify the interrelationship between risk factors. The interrelationship between risk factors are developed by using Interpretative Structural Modelling (ISM) technique. On the other hand, the individual risk factors are ranked using fuzzy expert system to examine experts' judgement due to unavailability of data. The results of the risk ranking revealed that contractual claim and right of way risk factors are found to have high magnitude on both cost and time of the project. Finally, System Dynamics is used to model the aggregation of risk factors on project cost and time. The unintended change in a single risk factor is evaluated on the whole system of the project execution and ultimately on project cost and time. The relationship between risk factors project costs and time were developed. The sensitivity analyses on the change in aggregate risk factors on project cost and time are also deeply examined.

**Keywords:** Risk, Project, Fuzzy Expert System, System Dynamics, Interpretative Structural Modelling.

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Project Cost and Time in Ethiopia**

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**Author's Declaration**

I hereby declare that this dissertation has been composed solely by myself and that it has not been, and will not be, submitted in whole or in part to another University for the award of any other degree.

Ermias Tesfaye

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**Supervisor's Declaration**

I hereby declare that this dissertation is done under my supervision, and that it has not been, will not be, submitted in whole or in part to another University for the award of any other degree.

Prof. Daniel Kitaw,

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# Contents

Abstract .....	I
Acronyms .....	XIII
Acknowledgements .....	XIV
Chapter One Introduction to Research Project.....	1
1.1. Background of the research .....	1
1.2. Research problem .....	3
Research Questions .....	5
1.3. Research Objectives.....	5
1.3.1. General Objective .....	5
1.3.2. Specific Objective.....	6
1.4. Justification of the research.....	6
1.5. Methodology .....	7
1.6. Outline of the research.....	8
1.7. Delimitation of scope and key assumptions.....	9
Chapter Two Literature review into Project risks, cost and time overrun .....	11
2.1. Introduction.....	11
2.1.1. Definition of Risks.....	11
2.1.2. Risk and Uncertainty .....	11
2.2. Risk Management .....	12
2.2.1. Risk Identification.....	15
2.2.2. Risk Classification.....	17
2.2.3. Risk Assessment.....	23
2.2.4. Risk Ranking .....	25
2.2.5. Risk Mapping .....	27
2.2.6. Chronological Development of Risk Management since 1995.....	28

2.2.7.	Analysis of Literatures on Risk Management .....	34
2.2.8.	Construction Project Risk Management in Ethiopia.....	42
2.3.	Literature summary .....	42
2.4.	Conclusion .....	43
Chapter Three Research Design and Methodology .....		44
3.1.	Introduction.....	44
3.2.	Research Design .....	44
3.3.	Data collection procedure .....	45
3.3.1.	Literature Review.....	45
3.3.2.	Primary Data.....	46
3.3.3.	Secondary Data .....	48
3.4.	Target population .....	48
3.5.	Method of Data Analysis .....	50
3.5.1.	Interrelationship between risk factors .....	50
3.5.2.	Fuzzy Expert System .....	51
3.5.3.	System Dynamics .....	55
3.6.	Model verification.....	57
3.7.	Research steps .....	58
3.8.	Ethical considerations .....	59
3.9.	Conclusion .....	60
Chapter Four Data Analysis and Presentation .....		61
4.1.	Introduction.....	61
4.2.	Risk Identification.....	61
4.3.	Identification of the interrelationship between risk factors .....	63
4.4.	Analysis of Risk Factors Using Fuzzy Expert System .....	79
4.5.	Conclusion .....	85

Chapter Five Results and Discussion .....	86
5.1. Introduction.....	86
5.2. Interrelationship between risk factors .....	86
5.3. Risk Ranking.....	90
5.3.1. Risks affecting project duration.....	90
5.3.2. Risks affecting Project Costs.....	95
5.4. Conclusion .....	101
Chapter Six System Dynamics Model development.....	102
6.1. Introduction.....	102
6.2. Problem Articulation.....	103
6.2.1. Key Variables .....	105
6.3. Formulation of dynamic behaviours .....	108
6.3.1. Model Boundary .....	108
6.4. A simulation model formulation .....	112
6.5. Causal loop diagrams.....	112
6.6. Model Description.....	116
6.6.1. Scope Growth Causal Loop Model .....	116
6.6.2. Productivity Causal Loop Model.....	119
6.7. Stocks and Flows.....	120
6.8. Mathematical Formulation .....	124
6.9. Conclusion .....	130
Chapter Seven Results and Testing of Models .....	131
7.1. Introduction.....	131
7.2. Simulation run and results .....	131
7.2.1. Effects of Design change on work addition, project cost and time.....	131
7.2.2. Effects of Government Intervention on project time and cost.....	135

7.2.3.	Effects of Inadequate site information on project time and cost.....	137
7.2.4.	Effects of poor quality of design on project time and cost .....	139
7.2.5.	Effects of delay in contractors' payment certification by consultant on project cost and time .....	141
7.2.6.	Effects of Improper construction method on project cost and time.....	144
7.3.	Sensitivity analysis .....	147
7.3.1.	Environmental related Risks .....	147
7.3.2.	Stakeholder related risk factors.....	149
7.3.3.	Project Site related risk factors.....	150
7.3.4.	Economic related risk factors.....	152
7.3.5.	Contractor related risk factors.....	153
7.4.	Conclusion .....	155
Chapter Eight conclusions and recommendations .....		156
8.1.	Conclusion .....	156
8.2.	Recommendations and Future Study .....	158
References.....		159
APPENDIX I – Questionnaire.....		178
APPENDIX II – Normalized membership values of risk factors and its impact on time and cost .....		184

## List of Figures

Figure 2-1 Number of Publication in each continent.....	35
Figure 2-2 classification of risk factors .....	35
Figure 3-1 Triangular Fuzzy Number.....	54
Figure 4-1 Approximation of Triangular Membership Function .....	81
Figure 4-2 Best Fit Triangular Membership Function for Inadequate Site Investigation....	83
Figure 5-1 Relationship diagram of risk factors under Scope growth .....	88
Figure 5-2 Relationship diagram of risk factors under Productivity .....	89
Figure 5-3 the individual risk magnitude on project duration.....	94
Figure 5-4 the frequencies of risk factors and the risk rank for project duration .....	95
Figure 5-5 the frequency of risk factors in each rank for project costs .....	99
Figure 5-6 Risk magnitudes affecting project costs.....	100
Figure 6-1 Construction project subsystem diagram.....	112
Figure 6-2 Closed Loop diagram for Scope growth related risks .....	114
Figure 6-3 Causal Loop diagram for Productivity Related Risks.....	115
Figure 6-4 Reinforcing loop of Scope growth, additional work and work completed.....	117
Figure 6-5 Reinforcing loop of Scope growth, additional work, contract modification and client related risk factors .....	117
Figure 6-6 Reinforcing loop of Scope growth, additional work, Client management ability and client related risk factors .....	118
Figure 6-7 Reinforcing loop of Scope growth, additional work, Client management ability, inappropriate intervention by client and client related risk factors.....	118
Figure 6-8 Reinforcing loop of error, work completed and fraction completed .....	119
Figure 6-9 Reinforcing loop of productivity, work completed, fraction completed, perceived progress, completion time, schedule pressure and inappropriate intervention of clients ...	120
Figure 6-10 The Basic Model of Project management.....	121
Figure 6-11 Creating the relationship for the work progress.....	122
Figure 6-12 Additional Work Stock and Flow Model.....	122
Figure 6-13 Stock and Flow model for Project cost.....	123
Figure 6-14 Stock and Flow Model for Project Duration .....	123
Figure 6-15 The overall SD model for Time and Cost Overrun of a project.....	129

Figure 7-1 Simulation result of delay in design work by varying the need to change the design by the client risk factor with 5 and 10% .....	132
Figure 7-2 Simulation result of Additional Work by varying the need to change the design by the client risk factor with 5 and 10% .....	133
Figure 7-3 Simulation result of Project Cost by varying the need to change the design by the client risk factor with 5 and 10% .....	134
Figure 7-4 Simulation result of Project Duration by varying the need to change the design by the client risk factor with 5 and 10% .....	134
Figure 7-5 Simulation result of Additional work by varying the government intervention risk factor with 5 and 10%.....	135
Figure 7-6 Simulation result of Project cost by varying government intervention risk factor with 5 and 10% .....	136
Figure 7-7 Simulation result of Project duration by varying government intervention risk factor with 5 and 10%.....	136
Figure 7-8 Simulation result of Additional Work by varying Inadequate site information risk factor with 5 and 10%.....	137
Figure 7-9 Simulation result of Project cost by varying Inadequate site information risk factor with 5 and 10% .....	138
Figure 7-10 Simulation result of Project duration by varying Inadequate site information risk factor with 5 and 10%.....	139
Figure 7-11 Simulation result of Additional Work by varying Poor quality of design risk factor with 5, 7.5 and 10% .....	140
Figure 7-12 Simulation result of Project cost by varying Poor quality of design risk factor with 5, 7.5 and 10% .....	140
Figure 7-13 Simulation result of Project time by varying Poor quality of design risk factor with 5, 7.5 and 10% .....	141
Figure 7-14 Simulation result of project progress by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%.....	142
Figure 7-15 Simulation result of project duration by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%.....	142
Figure 7-16 Simulation result of project cost by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%.....	143

Figure 7-17 Simulation result of project progress by varying improper construction method risk factor with 5 and 10% .....	144
Figure 7-18 The change in the risk magnitude of schedule pressure due to the change in the improper construction methods.....	145
Figure 7-19 Simulation result of project duration by varying improper construction methods risk factor with 5 and 10% .....	146
Figure 7-20 Simulation result of project cost by varying improper construction methods risk factor with 5 and 10%.....	146
Figure 7-21 Sensitivity graph for project cost due to Environmental related risk factors ..	148
Figure 7-22 Sensitivity graph for project duration due to Environmental related risk factors .....	148
Figure 7-23 Sensitivity graph for project cost due to stakeholder related risk factors .....	149
Figure 7-24 Sensitivity graph for project duration due to stakeholder related risk factors	150
Figure 7-25 Sensitivity graph for project cost due to Project Site related risk factors.....	151
Figure 7-26 Sensitivity graph for project duration due to Project Site related risk factors	151
Figure 7-27 Sensitivity graph for project cost due to Economic related risk factors .....	152
Figure 7-28 Sensitivity graph for project time due to Economic related risk factors .....	153
Figure 7-29 Sensitivity graph for project cost due to Contractor related risk factors .....	154
Figure 7-30 Sensitivity graph for project time due to Contractor related risk factors.....	154

## List of Tables

Table 2-1 classification of risk factors.....	19
Table 2-2 Classifications of Risk Factors from Developed Countries Perspective.....	36
Table 2-3 Classifications of Risk Factors from Developing Countries Perspective .....	37
Table 2-4 Summary of Reviewed Studies on Risk analysis tools .....	40
Table 3-1 Respondents of Questionnaire based on company type.....	49
Table 3-2 Respondents' position.....	50
Table 3-3 Respondents work experience .....	50
Table 3-4 Education level of the Respondent.....	50
Table 4-1 Identified risk factors .....	62
Table 4-2 Structural self-interaction matrix (SSIM) of Risk factors related to productivity	65
Table 4-3 Structural self-interaction matrix (SSIM) of Risk factors related to scope growth .....	66
Table 4-4 Membership values for Probability of occurrence of Risk Factor ( $R_3$ ).....	80
Table 4-5 Membership values for Impact of Risk Factor ( $R_3$ ) on time and cost .....	80
Table 4-6 Normalized Membership value of Risk Factor ( $R_3$ ) occurrence .....	81
Table 4-7 Normalized Membership value of Risk Factor ( $R_3$ ) Impact on Time and Cost .....	81
Table 4-8 Values used for Error Calculation .....	82
Table 5-1 The risk magnitude and rank on project duration .....	91
Table 5-2 The risk magnitude and rank on project Cost .....	97
Table 6-1 Key variables used in SD simulation.....	105
Table 6-2 Model boundary of productivity subsystem .....	109
Table 6-3 Model boundary for Scope growth subsystem .....	110
Table 6-4 Model boundary for project execution subsystem.....	111
Table 6-5 The variable and types of loops in Scope growth-related causal loop diagram ...	113
Table 6-6 The variable and types of loops in productivity related causal loop diagram .....	116
Table 6-7 Mathematical formulae for each variable used for SD Model.....	124
Table A-1 Normalized membership values for risk factors affecting project duration.....	184
Table A-2 Normalized membership values for risk factors affecting project duration.....	186

## Acronyms

- ERA – Ethiopian Road Authority
- AACRA – Addis Ababa City Road Authority
- TFN – Triangular Fuzzy Number
- SD – System Dynamics
- ISM – Interpretative Structural Modelling
- AfDB – African Developmental Bank
- BOT – Build-Operate-Transfer
- AHP – Analytical Heirarchy Process
- PPP – Public Private Partnership
- RBS – Risk Breakdown Structure
- SEM – Strutural Equation Modelling
- CoST – Construction Sector Initiative
- GC – General Contractors
- SSIM – Structural Self-Interacting Matrix
- MF – Membership Function
- CLD – Closed Loop Diagram

## Acknowledgements

First and foremost, I would like to thank Almighty God for all of the good things including the ability and opportunity to finish my PhD.

I would like to express my deepest gratitude to my supervisor, Prof. Daniel Kitaw, Professor of Industrial Engineering, for his unreserved guidance, patience, support and commitment. I have learnt a lot from him not only from courses and research but in various contexts both academically and in real life. This PhD study would never have been possible without his encouragement from the very beginning.

I would like to also extend my appreciation to Dr. Birhanu Beshah (Associate Professor) and Dr.-Ir. Eshetie Berhan (Associate Professor) for their continuous advice, support and encouragement. This dissertation would not have happened without their valuable contributions. I am also grateful to Editor Berhanu Tibebu Zewolde, part-time lecturer at the Institute of Language Studies of Addis Ababa University (AAU) and Journalism Graduate of Columbia University, N.Y., for his advice on academic and scholarly writing.

Many thanks also go to Ato Tsega Soboka and Yinges Tafere from Ethiopian Road Authority (ERA) Training Directorate, and to all Regional Directorate Directors for their positive response and participation, ERA Highway research team leader Ato Alemayehu Ayele for providing me the current research documents regarding ERA construction projects, and also to all Local Contractors and consultants working with ERA and AACRA for their quick and positive replies in connection with data collection. My appreciation also goes to Ato Tesfaye from Construction Sector Transparency Initiative (CoST) Ethiopia for providing me with valuable information for this research.

My special thanks go to Prof. Carlo Rafele for all the support and guidance during my study by giving me the necessary courses and closely follow up my work during my stay in Italy.

I am also indebted to the DIGEP research group of Politecnico Di Torino particularly Dr.-Ing. Giulio Mangano, Dr.-Ing. Alberto De Marco and Dr.-Ing. Anna Cagliano for their help in shaping my dissertation. Moreover, my gratitude goes to Politecnico Di Torino for the opportunity I have been offered to stay three months in the university.

In particular, I would like to thank the School of Mechanical and Industrial Engineering for giving me the opportunity and providing me different support during the entire period of my PhD study. In this connection, I would like to express appreciation goes to Ato Getasew Ashagrie, Dean of the school for his unreserved support and cooperation during the study.

My colleagues and friends in AAIT, especially Ameha Mulugeta, Kassu Jilcha, Yared Lemma, Yitagesu Yilma, Fitsum Getachew, Dr. Gulelat Gatew, Dr. Kassahun Yimer, Milka Hagos, all members of Industrial Engineering chair and the School of Mechanical and Industrial Engineering have played their part with their valuable comments and suggestions for the development of this dissertation and I would like to thank them all. My thanks are also due to my students Kidist Girma and Tesfaye Gashaw for their contribution to this research.

I am also deeply indebted to Dr. Esayas Gebreyouhannes and Dr. Dereje Hailemariam for the support and cooperation during the last phase of my study.

The corner stones of all my endeavours are my family members. I am extremely grateful to my father, Tesfaye Mengistu, and my mother, Mebrat Shiferaw, who brought me up teaching me to study hard and to give priority to the pursuit for knowledge. My sister Frehiwot Tesfaye, and my brothers Alemayehu Tesfaye, Abiy Abegaz and Biruk Adenew deserves utmost thanks for their unreserved encouragement and support at all times.

Finally, my absolute and unqualified thanks go to my wife, Christina Abebe without whose sacrifices both in time and effort this dissertation could not have been accomplished. Last but not certainly the least, I want to mention my son, Beaman Ermias, for the endless joy he brought to our lives.

Ermias Tesfaye  
April 2017  
Addis Ababa

*Dedication*

*I dedicate this work to my mother Mebrat Shiferaw*

*Dear Mother, This was your dream!*

*I wish that you were here and see what I have accomplished.*

*I pay special tribute to you for all the things you gave me*

# Chapter One Introduction to Research Project

## 1.1. Background of the research

Today, all over the world, there are a number of developmental projects that have either been completed or are actually in progress with substantial amounts of investments. The level of investments and their anticipated returns vary from one country to another and from continent to continent. Though many of regions around the world are experiencing slow economic growth, Africa is evolving as an emerging market for world business and opportunities for investors. Six of the ten fastest growing economies in the world are found in this region today. Accordingly, Africa has begun to attract one of the highest levels of investment for infrastructural development as it is an essential factor to realize its fullest potential. This has provided the continent with the driving force to embark upon, and to be actively engaged in, implementing and managing infrastructural development projects.

A huge amount of infrastructural project is required to meet the demand and attract more investments. According to the African Developmental Bank (AfDB), the region requires US \$93 billion in basic infrastructure investment every year (Scott, 2013). Currently, the top sectors in African infrastructure development (rated by investment value) are: Energy and Power (36%), Transport (25%), Mining, Real Estate and Water, followed by Oil and Gas, indicating that there is a solid step being taken forward in these sectors (Deloitte, 2013). Based on the number of projects under way within the region, 38% of the projects are located in Southern Africa, 29% are in East Africa, while 21% are in West Africa (Deloitte, 2013).

From among the countries of East Africa, Ethiopia possesses one of the six fast-growing economies of the African region. Currently, the country is investing a significant amount of resources for infrastructural projects. Some of these projects are part of the energy, road and transport, building, telecommunication, water and many other sectors. Therefore, the success of these projects is of crucial significance for the development of the country.

Currently, the construction sector plays a vital role in leading the way towards modernization and industrialization in Ethiopia. After the launch of Road Sector Development Program (RSDP), a number of road projects were under construction by international and local contractors. However, it was noted that many of the completed road projects had a significant time-loss and cost overrun which negatively affected the development of the program.

Significant number of the construction projects undertaken in Ethiopia went beyond the expected time for completion and also are required additional budget more than what was initially envisaged for the projects. This problem, in turn, caused difficulties in financing upcoming projects, timely utilization of the facility by the general public, the stakeholders 'positive involvement in the construction process, etc.

The factors that obstruct the success of construction projects were identified by different researchers in Ethiopia. NEGA (2008) showed that rate of cost overrun ranged from 0% to 126% of the contract amount for individual projects alone. TURKEY (2011) presented in his study that 80% of road projects under study suffered cost overrun. Abubeker (2015) study revealed that 100% of ten road projects investigated in the research suffered time and cost overrun; that time overruns ranged from 25% to 264.38% of the contract time and that the cost overrun ranged from 4.11% to 135.06% of the contract amount. The study conducted by the Ethiopian Road Authority revealed that among 56 projects in the period 2006-2013, a total of 14.3% had encountered cost overrun only; 19.6% time overrun only and 66% had faced both cost and time overrun (Tafere, 2015). The working papers of Construction Transparency Initiative (CoST) discovered that road projects had been challenged by cost and time overrun, lack of transparency, prolonged procurement, design modification and limited capability of contractors.

Though Ethiopia is investing substantially in infrastructural projects, a significant number of these project failed to hit their targets. The causes for such failures were explained in terms of project delay, cost overruns and poor quality of construction materials. One of the causes for the failure of these projects is the risk associated with the projects. The presence of risks and uncertainties is inherent in project development and implementation playing a significant role in precipitating failure that is intrinsic in all stages of the project.

The standard books of risk management express risk in more or less similar ways. The Australia/New Zealand risk management standards explain risk as 'the chance of something happening that will have an impact on objectives; which may have a positive or negative impact' (Keey, 1998) whereas the British standard (IEC) and (PMI, 2008) defined risk as a 'combination of the probability or frequency of occurrence of a defined threat or opportunity and the magnitude of the consequences of the occurrence'. Based on the above definitions,

the occurrence of unknown events which have a negative impact (delay of project/increased cost) on the project are risks.

But risks are mostly dependent on the type of the project. Project delays and cost overrun in the construction industry are common and are taken as a global phenomenon (Mahamid, 2014, Sambasivan and Soon, 2007a). As a result, construction is a risk-prone industry with delays in project completion, resulting in cost overrun and failing to meet quality standards.

Hence, this dissertation is aimed at modelling the effect of the risk factors on the project objectives, particularly on project time and costs by developing the interrelationship of road construction project risks, quantifying their effects, and analysing the impact of these risks on project objectives particularly time and costs in a systematic way.

## **1.2. Research problem**

Every project has a unique feature. This is because of the social, technical, economic, geographic and many other factors that influence it in one way or another (Karlsson, 2011). Thus, the construction projects of Ethiopia could be said to be different from those of other countries or regions in business development, cultural, work practice, and specific problems that are experienced in other countries due to the difference in economy, social, culture and geography. Therefore, analysing critical causes for negative consequences in construction projects in the country's context is essential, rather than depending on risk factors that shape other countries' experience.

Some of the reasons for the construction industries being regarded as risk-prone are the nature of construction business activities, processes, environment, organization and involvement of many contracting parties such as owners, designers, contractors, sub-contractors, suppliers, etc. (PMI, 2004). The unique feature of the construction industry that triggers the risks are long-period, complicated processes, hostile environment, divergent interests of the project stakeholders, financial intensity and dynamic organization structures (Flanagan, 1993). Because of their complexity and dynamic nature of their composition, construction projects are exposed to effects of numerous factors leading to uncertainty in the timing and sequence of project activities (Chan et al., 2004).

The pressure on project delay and cost, the need for improved performance in the construction industry and the increasing contractual obligations lead to the necessity of a more effective risk management approach. Improving the risk management process is, therefore, a key challenge in construction projects (Taillandier et al., 2015). Thus, Risk analysis and management are an important part of the decision-making process in the construction industry.

In the construction context, risk management is an organized way of identifying, analysing and dealing with risks for the successful realization of project objectives. This industry has given due attention to risk management strategies and techniques for achieving the project objective through dealing with the potential risks (Zou et al., 2007b). However, most of such projects lack systematic risk management techniques such as proper identification of risks and their likelihood as well as impact on cost and time that are not analysed before the execution of the project to control the effect of project risks on project performance. Hence, a need to assess and analyse the associated risk and its impact on construction project is crucial to deliver the project on time with the allocated budget and the desired quality.

Risk analysis or management in the construction industry involves identifying risk events that could potentially affect a project and its delivery, quantifying those risks, and developing strategies to enhance project success.

As most of the construction risks are dynamic in nature, the unsystematic and arbitrary risk management can threaten the success of the project throughout the project lifetime (Nieto-Morote and Ruz-Vila, 2011). Thus, the effect of project risks has to be analysed to enhance the overall project performances. This shows that project risk management is essential to construction activities in minimizing losses and enhancing profitability (Khodeir and Mohamed, 2015), due to the fact that there is a direct relationship between effective risk management and project success (Issa, 2013). Risk analysis helps project managers gain an overall and comprehensive understanding of the risk level of the project, and determine the most important risks influencing the project performance.

With regard to the increasingly complex dynamics of construction projects, the tendency is to use risk quantification and modelling methods to aid managers' control the uncertainties of construction projects.

The delay and cost overrun of these road construction projects are caused by different risk factors during the project lifecycle. But experts in the field claimed that there is no systematic way of managing risks. Risk management in the Ethiopian construction industry is conducted mostly in terms of individual intuition, judgment, and field experiences gained from previous projects. It is hardly possible to manage risk just by Intuition and/or experience gained from other projects. To comprehensively understand risk factors and propose strategies for their management, it is imperative to understand their nature, source and degree of impact. Therefore, categorizing and prioritizing risks based on their association with the stakeholders, significance to the various objectives of the project and degree of impact were found to be of primary importance. Thus, this dissertation has found it essential to focus on risk quantification and analysis in construction projects based on a methodical approach by identifying key risk factors in the Ethiopian context.

However, various researchers and experts witnessed that these risk factors have an interdependent character in which they relied on one another. Although the above-mentioned studies had highlighted the importance of risk interdependency and contributed to the structuring of cause-and-effect relations among risk-related factors through various techniques, mostly they failed to cover interactions among risk paths and demonstrated an overall risk map structure of the generated risk paths.

## **Research Questions**

1. What are the different risk factors associated with road construction projects?
2. What is the interdependence that exists among different risk factors?
3. Which risk factors are vital on the cost overrun of the road construction projects?
4. Which risk factors are vital on the time overrun of the road construction projects?
5. What is the relationship between the risk factors with the time and cost overrun of the Road Construction Project?

## **1.3. Research Objectives**

### **1.3.1. General Objective**

The purpose of this research is to establish the nature and extent of cost and time overrun of the road construction project and to develop a model for determining the effects of exogenous on endogenous risks and ultimately on the two project objectives (i.e. time and cost).

Moreover, this research aims at developing the model that establishes relationship between different risk factors and the percentage of time and cost overrun as a measurement of the performance of road construction projects.

### **1.3.2. Specific Objective**

The specific objectives of this dissertation are:

1. Identifying the different risks associated with road construction projects
2. Identifying and analysing the interdependence between risk factors
3. Analysing and prioritizing the vital risks affecting project cost
4. Analysing and prioritizing the vital risks affecting the project duration
5. Developing a model the depict the relationship between the individual risk factors and project objectives (time and cost).

## **1.4. Justification of the research**

Construction projects involves a large number of tasks and activities which all have some associated risks. These risks have complex structures arising from (1) multiple interdependent of risks affecting their overall impact internally through various cause-and-effect feedback loops which results in the nature of the risks to be highly dynamic; and (2) the existence of external interactions between different risks (APM, 2004) that may have cascaded effect on the overall impact of a risk due to the indirect and secondary effects caused by the other risks(Nasirzadeh et al., 2008c).

Though different research works have used several quantitative risk management techniques, the dynamism of the risk factors cannot be easily considered by conventional approaches.

Little considerations are given to the unique characteristics of the risks outlined in the previous research indicated above. Enormous risk factors are considered in different research works; however, it is limited to the geographic scope and types of project with the organizational and cross-cultural perspective.

Not much research appears to exist that that tries to related the relationship between different risk factors with the project objectives in road construction. To date, no satisfactory theory or tool for assessing the cascaded effects of construction risk on project objectives has

been developed or proposed. To comprehensively understand a risk, it is helpful to identify its causes as well as its effects. Several methods and approaches for risk analysis had been proposed but they still concentrate on a single risk in order to simplify the problem. Many of these methodologies independently evaluate the characteristics of risks, and focus on analysis of individual risks failing to consider the interactions of different risks. Risk factors have interdependencies to each other and difficult to anticipate and control the interrelationship between different risks (Fang and Marle, 2012, Fang and Marle, 2013). However, no suitable methods are proposed and developed to study the relationship and the multivariate effects of the relationship on the project objective so far.

## 1.5. Methodology

Due to the lack of systematic risk management practice in road construction project of Ethiopia, this research adopts expert opinions in the field as the foundation to the methodology and is an important approach for presenting information (Lindley and Singpurwalla, 1986, Singpurwalla, 1988). Moreover, the use of the historical data is augmented as a support to reconcile the different causes of cost and time overrun of road construction projects in Ethiopia.

Table 1.1 An outline of the stages of the research to be followed designed to provide answers to the research questions.

Stage	Research Procedure
1	Literature survey and review to determine the research focus
2.	Establish data sources of road construction projects
3.	Determine the risk factors affecting road construction objectives using expert opinion
4.	Use experts' opinion and Interpretative Structural Modelling (ISM) to determine the interrelationship between different risk factors
5.	Use Fuzzy expert system to quantitatively analyse the qualitative feedback of the experts
6.	Undertake the research analysis, model risk factors as a percentage of project cost and time overrun using system dynamics. Establish the relationship

between key risk factors with the project objectives particularly with time and cost overrun

## 1.6. Outline of the research

This dissertation is organized into seven chapters as follows:

- Chapter one – Background
- Chapter two – Literature review on construction project risks and its impact on cost and time overrun of the project
- Chapter three – research design and methodology
- Chapter four – data analysis and presentation
- Chapter five – Result and discussion of the interrelationship between different risk factors and the risk rank
- Chapter Six – System Dynamics model development
- Chapter Seven – Result and testing of system dynamics models
- Chapter Eight – conclusion and recommendations

*Chapter one* begins with the background phase of the research by providing the problem statement, stating the research problem and purpose, the objective of the research, an overview on the methodology and the scope of the research.

*Chapter two* is a literature review from professional journals, books, internet searches. This chapter essentially provides a review of the current state of the art in construction project risk management, different causes and effects of risks, development trends of risk analysis techniques and its limitation is assessed.

*Chapter three* discusses the research methodology necessary to achieve the research objectives. The research method adopted is that of analysing the data collection obtained from experts in different road construction projects.

*Chapter four* contains the data collection and analysis techniques using different tools and techniques such as Interpretative Structural Modelling to develop the interrelationship between risk factors and Fuzzy Expert System to rank the magnitude or risk factors

*Chapter five* discusses the results of chapter five

*Chapter six* is the development of the model for representing the risk factors and the project execution processes using system dynamics

*Chapter seven* is the result and discussion on the effect of exogenous risk factors on the project cost and time. Moreover, this chapter illustrates the sensitivity analysis of project cost and time subjected to aggregation of risk factors.

*Chapter Eight* is the conclusion and recommendations that are derived from the research and how the research objectives align with the findings. Both specific and general recommendations are provided, as well as recommendations for future research.

## **1.7. Delimitation of scope and key assumptions**

This dissertation focuses on developing methods for managing risks of road construction projects in Ethiopia. Other infrastructure and building projects are not included. This study uses the data mostly obtained from the Ethiopian Road Authority (ERA) and the Addis Ababa City Road Authority (AACRA). It emphasizes on modelling cost and time overrun of projects due to risks. In addition, it focuses only on road projects due to the fact that huge amounts of finance from the Ethiopian economy is allocated to this sector with substantial loss incurred as a result of mismanagement of various risk factors.

However, the data available for analysis is limited to clients, contractors, designers and consultants in road construction. Since the research is highly dependent on experts' opinions and secondary sources, some elements of subjectivity may appear to limit the reliability of the findings. Nevertheless, the quantitative aspect of the study has been handled in a scientific way to balance opinions with objective facts.

Cost growth, cost change and cost overrun are considered to have the same meaning for the purpose of this research. The same approach applies to time extension, duration change and time overrun. The two groups of words and phrases can be defined as the difference between the achieved project objectives and the planned objectives at the time when the decision was taken to design and build a particular project.

The definition adopted for a client or project owner is an organization which has vested interest in something is built or delivered under some form of contract-agreement. ERA and AACRA are the two client/owners and organizations for which the road construction projects

are constructed anywhere across the region and within Addis Ababa respectively. It should be noted that some historic project data utilized in this research may be additionally influenced by long-term economic conditions and contracting climates that may vary from time to time.

# Chapter Two Literature review into Project risks, cost and time overrun

## 2.1. Introduction

A deviation of project objectives particularly related to cost and time overrun occurs as a result of risks linked with project activities. Systematic analysis of the causes for the deviation from the plan in construction projects is essential for the improvement of the project outcome. As part of this process, this chapter provides a literature review on project risks and the corresponding effect on project objectives.

The chapter deals with the basic definition of risks, followed by differentiating risks and uncertainty. The review then discusses phases of project risk management mainly risk identification, classification and assessment particularly in the construction sector. It then analyses the trends of risk management research in chronological order. As the risk factors are unique for specific geography, risk management researches are categorized based on the geographical perspective are presented. Finally, the review investigates the tools and techniques used in risk analysis and summarizes the gaps identified in the literature review.

### 2.1.1. Definition of Risks

Risk is defined by different authors in different ways. According to the definition of Adedokun et al. (2013), risk should consider both the positive and negative effects of a project objective. Risk is closely connected to uncertainty and is a commonly used term in all kinds of contexts, but is often related to the negative outcome of a certain event. Risk is also defined by Sarkar and Panchal (2015), as a measure of the probability, severity and the exposure to all hazards of an activity. Project risk is also defined as effect of uncertainties on project objectives: cost, time and project performance (Wang et al., 2004b).

### 2.1.2. Risk and Uncertainty

Risk and uncertainty is used interchangeably in most of the project management literature. However, researchers and authors require that there is need to differentiate these two concepts. Hillson (2004 ) described the logical difference between risk and uncertainty. Risk can be said to be aleatoric meaning dice, whereas uncertainty is described as epistemic meaning knowledge. This indicates that a risk is an event where the set of possible outcomes

is known, and the probability of obtaining each outcome can be measured or estimated, but the precise outcome in any particular instance is not known in advance. Thus, according to the author “risk” is an unknown event drawn from a known set of possible outcomes whereas, “uncertainty” is an unknown event from an unknown set of possible outcomes. The relationship between risk and uncertainty, and the distinction between aleatoric and epistemic, are captured in the following couplet: Risk is measurable uncertainty; uncertainty is unmeasurable risk. Likewise, ISO Guide73:2009 (2009) distinguished risk and uncertainty in the same manner as Hillson (2004 ) did. Similarly, Besner and Hobbs (2012) have reviewed the difference between these two concepts. Furthermore, the term “uncertainty” emphasizes actions taken with incomplete knowledge about projects that do not yet physically exist (Walker et al., 2003) and Fijnvandraat and Bouwman (2010) describe uncertainty as “any deviation from the ideal of completely deterministic knowledge of the relevant system”.

Meanwhile, Sicotte and Bourgault (2008) expressed risk as an identifiable event that will have negative consequences while uncertainty as the source of risk. Likewise, Perminova et al. (2007) define uncertainty and risk in the same way like that of Sicotte and Bourgault (2008) but with the additional context of risk as an event having either negative or positive impact. Chapman and Ward (2003) have encouraged and largely influenced the use of the uncertainty concept over risk partly as risk is captured in the viewpoint of negative perceptions which will overlook the practitioners from dealing with opportunities.

Drouin et al. (2012) revealed the relationship between risk and uncertainty and concluded that an increase in uncertainty will induce an increase in risk of project failure, and risk management can help avoid such an outcome. Risk management is the most important skill/competence required for projects with high uncertainty. Risk management is thus generally perceived as a way of reducing uncertainty and its consequences which, in turn, will improve the chances of success.

## **2.2. Risk Management**

Every human endeavour involves risk; the success or failure of any venture depends crucially on how to deal with it. Risks have an stochastic nature (Hamzaoui et al., 2015). Science and engineering increasingly make progress by major projects many of whom are in high risk category. For years, the engineering and construction industry has had a very poor reputation

for coping with risk, with many major projects failing to meet deadlines, cost targets, and specifications (Dey and Ogunlana, 2004).

The construction industry in particular is prone to risks. This is due to the fact that the construction projects originate in complex and dynamic environments which results in high risk and uncertainty (Zhen-Yu and Lin-Ling, 2008, Adedokun et al., 2013, Hamzaoui et al., 2015).

Risk and uncertainty are inherent in all construction work no matter what the size of the project (Jha and Devaya, 2008, Carr and Tah, 2001). Some of the major causes of risk are size, complexity, speed of construction, location of the project, the technology being used, and familiarity with the work. Moreover, the difference in the interest due to the construction process involves various kinds of people with various ideas, experience and skills results in difficulty of coordinating project goals (Dey and Ogunlana, 2004).

In addition to the organizational and technical complexities, project managers have to consider a growing number of parameters (e.g. environmental, social, and safety and security) and a growing number of stakeholders, both inside and outside the project. The complexity of a project results in a network of interdependent risks (Fang and Marle, 2012), Thus. the outcome of such phenomena will be hard to anticipate and hard to keep under control (Fang and Marle, 2013, Huang et al., 2013, Hamzaoui et al., 2015). These risks have a direct influence on project success.

Many projects tend to exhibit cost overruns and schedule delays. Project risks primarily comprise schedule and cost uncertainties. These risks would result in huge time and cost overrun which would ultimately reduce the probability of a successful completion of the project within stipulated time and cost frame (Sarkar, 2012).

Therefore, several research works have been conducted to investigate the cost and time overrun of the construction project. Researchers, such as Arditi et al. (1985) analysed cost overruns in Turkish public projects, Chan and Kumaraswamy (1997) and Chapman (1997) examined delays in Hong Kong and Saudi Arabia construction projects respectively. Then, Floricel and Miller (2001) discussed how to design project structures in a proactive manner to govern “turbulences” triggered by unanticipated real dangers.

The research on risk and risk assessment in construction projects is vast because construction risk factor research has been (and continues to be) of interest to both academics and practitioners. The area of risk management has received significant recognition in the field of project management in recent years while the financial and economic crisis is evident globally (MEZHER and TAWIL, 1998).

While the financial and economic crisis is present at the global level and the competition in the market is more and more aggressive, the interest in risk management increases (Kendrick, 2015). Effective risk management enables the project to strive for reduced costs, improve the interactions with the stakeholders and provide a solid basis for decision-making in projects, bringing important benefits such as: reduced costs, increased engagement with stakeholders and improved change management (Bodea and Purnus, 2012).

Project risk management primarily deals with cost and schedule uncertainties (Sarkar and Panchal, 2015). It is crucial to the success of projects. Unexpected conditions or planning errors may lead to delays, over-costs and other failures, which can undermine the successful realization of the project (Fang and Marle, 2013).

Project risk management aims at identifying and assessing risks in order to manage them effectively (Rasool et al., 2012a). It is a dynamic process along the project life whose usual stages are risk identification, risk analysis (qualitative or quantitative), response planning and risk mitigation (Wang et al., 2004b, Huang et al., 2013). The importance of using a rigorous approach along all these stages has been pointed out by many authors and synthetic guidelines which usually provide a general perspective on stakes, tools and methods used in research and practice of project risk management (Wang et al., 2004b).

The dynamic nature of project risks is one of the main difficulties of risk management. The risk management process consists of three typical phases: (1) identification; (2) analysis; and (3) treatment (Jha and Devaya, 2008, Bing et al., 1999). The aim is to be able, during the project processing, to update at each new event and situation (addition of information and/or change of objectives), the risk representation and assessment (Hamzaoui et al., 2015). Hertz and Thomas (1983) proposed a step-wise procedure of risk identification, measurement, evaluation, and re-evaluation. Hayes et al. (1987), Flanagan and Norman (1993), Raftery

(2003) proposed frameworks for risk management comprising risk identification, analysis, response planning, continuous monitoring, and action planning.

Peterson et al. (2005) worked on risk and uncertainty identification, risk and uncertainty analysis and decision analysis, which, according to them, are all integral to any responsible and respectable risk management process.

Different institution and associations such as the European community, Association of Project Managers, Project Management Institute, International Competence Baseline, Standards Australia/Standards New Zealand and Guidance on Project Management have all contributed for the development of project risk management techniques by setting guidelines and developing risk management methodologies (Carter et al., 1996, Chapman, 1997, PMI, 2008, Association, 2006, Cooper, 2004, Stellingwerf and Zandhuis, 2013)

The need for risk identification and assessments are agreed upon by all risk management frameworks to ensure effective implementation of the subsequent phases (Bu-Qammaz et al., 2009).

### **2.2.1. Risk Identification**

The first process in the iterative Project Risk Management process aims at identifying all the knowable risks to project objectives (PMI, 2008a). Hence, risk identification is the first step of risk management process in which potential risks associated with a construction project are identified (Zou et al., 2007a).

Risk identification is an organized and ongoing process of understanding, identifying and classifying potential risks associated with a project (Bajaj et al., 1997, Rasool et al., 2012a). The uniqueness of the project feature and sector has resulted in the risk factors to be industry-specific. Therefore, it is difficult to generalize the risk factors identified for one industry to others (Ameyaw and Chan, 2015).

Due to the high subjectivity and lack of exact procedures to be used, risk identification is found to be a challenging task. It mainly relies on the intuition and experience of experts (Bajaj et al., 1997). However, trend analysis from historical data may not be dependable because it also depends on environmental factors. In such situations, the experts judgement

in forecasting risk has a significant role to play than relying only on historical data (Al-Tabtabai, 2000).

Most of the research works on risk identification focus on risk factors taking into account the specific sectors or country of the project. There are several tools and techniques for identifying the risks associated with construction projects through the literature review, interviews conducted with experts, assumptions and constraints analysis, brainstorming, cause-and-effect diagram, checklists, case studies, surveys, expert judgement, Delphi technique, document review, fault tree analysis, influence diagram, post project reviews and others (Effah Ameyaw and Chan, 2013).

To thoroughly understand a risk, it is important to study the cause-and-effect of the risks (Fang and Marle, 2013). Construction projects have managerial and technical complexities linked with many uncertainties. These uncertain events can influence the project objective. One of the reasons for the complexity of a construction project is the involvement of different stakeholders. The high number of stakeholders and, therefore, of interfaces is a significant factor in risk. Furthermore, organizational factors and human decision processes have a major impact on risks (Wang et al., 2004b).

The construction process can be influenced by changing variables and unpredictable factors that could result from different sources (Arain and Pheng, 2007). Each decision within the process can affect the whole project, a specific task, a stakeholder, etc. The results of decision can have a major impact on the project objectives positively or negatively, and on its environment (injured people or fatalities, environmental damage, political consequences, etc.) (Wang et al., 2004b, Fang and Marle, 2013).

Some of the variables and factors have interactions with each other. The main difficulty is to identify and evaluate these interactions. It requires a consideration of the dynamic aspect of the project, as most of the interactions are due to the looping of the cause/consequence processes. Moreover, it is important to take into account the dynamic responses from the different stakeholders on risks (Wang et al., 2004b).

Risks can be identified based on analogy (Smith et al., 2002), on heuristics (Chapman, 2001) or analytically. The resulting project risk list serves as an input for studying risk interactions in order to build the project risk network (Fang and Marle, 2013).

### **2.2.2. Risk Classification**

Risk classification is the process of structuring the key elements to examine risks systematically, in each area of the project to be assessed (F.Cooper et al., 2005). The primary inputs for risk classification is risk identification.

As an integrative part of risk identification, risk classification attempts to structure the diverse risks affecting a construction project. There are many different risk sources in the construction projects and some approaches have been suggested in the literature for classifying them. Some classifications focus on the nature of the risks and their magnitude (Chapman and Ward, 1997), while others use a hierarchical structure of risks (Tah and Carr, 2000b) to classify risks according to their origin and to the location of the risk impact in the project.

Different literatures recommend several approaches for classifying risks. Chapman and Ward (1997) classified risks according to their nature and magnitude, making the difference between primary and secondary risks. It is also usual to categorize risks into dynamic/static, corporate/individual, internal/external, positive/negative, acceptable/unacceptable and insurable/non-insurable (Baloi and Price, 2003). However, the fact is that a standard or consensus on how to classify risk does not currently exist (Rasool et al., 2012b).

Khodeir and Mohamed (2015) categorized risks into internal and external risks and identified 63 risk factors in construction projects in Egypt. The authors Irimia-Diéguez et al. (2014) classified risks into nine groups: design risks, legal and/or political risks, contractual risks, construction risks, operation and maintenance risks, labour risks, clients/users/society risks, financial and/or economic risks and force majeure. Wang et al. (2004a) studied international construction projects in developing countries and identified 28 critical risks and then categorized them into three hierarchy levels (Country, Market and Project). Zou et al. (2007a) grouped the 25 major project risks in China into six: risk related to clients, contractors, designers, suppliers, government agencies and external issues.

A detailed literature review was carried out to gather causes of risks and risk factors in construction projects in this study. Table 2-1 lists the causes of risk factors.

Table 2-1 classification of risk factors

Author	Classification of risk factors
<u>Beidleman et al. (1990)</u>	Technology risk, credit risk, bid risk. Completion risk, cost overrun risk, performance risk, political risk. performance risk, cost overrun risk, liability risk, equity resale risk, off take risk
<u>Bing et al. (1999)</u>	<i>Internal</i> (Partner's parent company in financial problems, Disagreement on accounting of profits and Loss, Employees from each partner distrust each other, Policy changes in your partner's parent, company toward ICJV Partner's lack of management competence and resourcefulness, Over interference by parent company of either partner, Disagreement on allocation of staff positions in ICJV, Disagreement on allocation of works, Technology transfer dispute) <i>Project Specific</i> (Cash flow problems of client, Poor project relationship, Incompetence of subcontractors/suppliers, Excessive demands and variation by client, Disagree some conditions of contract) <i>External</i> (Inconsistency in policies, laws, and regulations, Economy fluctuation, Exchange rate, Force majeure and social disorder, Inflation, Restrictions on fund repatriation, Import restriction, Security problems, Language barrier, Different social, culture, and religious, Pollution)
Dey and Ogunlana (2004); Grimsey and Lewis (2002)	completion delay, cost overrun, <i>force majeure</i> , political risk, infrastructure risk raw material supply, market, performance/technical, operation/maintenance, foreign exchange, other contingencies
<u>Gimpelevich (2011)</u>	General inflation General inflation, Market vacancy, starting occupancy and stabilization period, Market rent, Rent escalation, Hard (construction) cost inflation, Direct capitalization rate, Construction period duration (TS-TC), Actual rate of return on invested equity

<u>Jha and Devaya (2008)</u>	Poor government responsiveness, Weak legal system, Political instability, Cultural differences, Force majeure, Poor financial capability of the local partner, Foreign exchange risk (forex), Inaccurate assessment of market demand, Low project team cohesion, Ambiguous project scope definition, Poor cost management and control, Poor project management, Poor productivity and quality, Weak safety ethos
<u>Ke et al. (2011b)</u>	Corruption, Government's intervention, Expropriation and nationalization, Government's reliability, Third-party reliability, Public/political opposition, Immature juristic system, Change in law, Interest rate, Foreign exchange and convertibility, Inflation, Poor political decision making, Land acquisition, Approval and permit, Improper contracts, Financial risk Poor financial market or unavailability of financial instrument, Construction/operation changes, Construction completion, Delay in supply Subcontractors and suppliers, Technology risk, Ground/weather conditions, Operation cost overrun, Competition (exclusive right), Market demand, Tariff change, Payment risk, Supporting utilities risk, Residual assets risk, Uncompetitive tender, Consortium inability, Force majeure, Organization and coordination risk, Tax regulation changes, Environmental protection, Private investor change, Subjective evaluation, Insufficient financial audit
<u>Koushki et al. (2005)</u>	changing orders, owners' financial constraints, and owners' lack of experience
<u>MEZHER and TAWIL (1998)</u>	financial issues; contractors regarded contractual relationships, project management issues
<u>Palomo et al. (2007)</u>	acts of nature, physical risks, financial and economic risks, political and environmental risks, design risks, and job-site-related risks
<u>Sachs et al. (2007)</u>	political risks (Currency Inconvertibility and Transfer Restriction, Expropriation, Breach of Contract, Legal, Regulatory, Bureaucratic Risks, Non-Governmental Action Risks) <i>Project-related risks:</i> cost and time overruns, poor contract management, contractual disputes, delays of tendering and selection procedures, poor communication between project parties,

	<p><i>Government-related risks:</i> inadequate approved project budgets, delays in obtaining permissions, changes in Government regulations and laws, lack of project controls, administrative interference.</p> <p><i>Client-related risks:</i> inadequate project budgets, poor project brief, variations in project specifications, delays in the settlement of contractor's claims, lack of project control.</p> <p><i>Design-related risks:</i> inadequate soil investigation, delays in design, ambiguities and inconsistencies in design and design changes.</p> <p><i>Contractor-related risks:</i> inadequate estimates, financial difficulties, lack of experience, poor management, difficult in controlling nominated subcontractors.</p> <p><i>Consultant-related risks:</i> lack of experience, performance delays, poor communication with other project parties.</p> <p><i>Market-related risks:</i> increase in wages, shortages of technical personnel, materials inflation, shortage of materials, shortage of equipment required.</p>
<p>Tah et al. (1993); Zhen-Yu and Lin-Ling (2008) and Zhen-Yu and Lin-Ling (2008)</p>	<p>Internal (Local) Labour, Plant, Material, Subcontractor, Site Risks, bidding mistake)</p> <p>Internal (Global) Performance, Contractual, Location, Financial Risk</p> <p>External (Inflation, Exchange Rate, Technological, Major Client Induced changes, Politics the delay of design, the interference by the third parties)</p>
<p><u>Wang et al. (2004b)</u></p>	<p>Approval and permit, Change in law, Justice reinforcement, Government influence on disputes, Corruption, Expropriation, Quota allocation, Political instability, Government policies, Cultural differences, Environmental protection, Public image, Force majeure</p> <p>Human resource, Local partner's creditworthiness, Corporate fraud, Termination of joint venture (JV), Foreign exchange and convertibility, Inflation and interest rates, Market demand, Competition</p>

	<p>Cost overrun, Improper design, Low construction productivity, Site safety, Improper quality control, Improper project management, Intellectual property protection</p> <p>increase of material prices, an accident during the construction, a decision-maker change of mind.</p> <p>Interactions,</p>
Woodward (1992)	<p><i>Political:</i> government, technology.</p> <p><i>Legal:</i> framework, type of agreement.</p> <p><i>Commercial:</i> market, input, currency</p> <p><i>Environment:</i> impact, ecological.</p> <p><i>Technical:</i> physical conditions, construction, design, technology.</p> <p><i>Operational:</i> operation, maintenance, training.</p> <p><i>Financial:</i> form of financing, evaluation, ownership, return, currency.</p> <p><i>Revenue:</i> demand, toll/tariff, development</p>
<u>Zhen-Yu and Lin-Ling</u> (2008)	<p>The natural factors (earthquake, fires, flood, typhoon, hurricane, torrential rain, torrent, debris flow, extraordinary climate, geologic structure and force major else.</p> <p>The human-induced factors (political risk, economic risk, financial risk, technical risk, material risk and so on.)</p>

### **2.2.3. Risk Assessment**

Risk assessment is a complex subject shrouded in vagueness and uncertainty (Carr and Tah, 2001). As an intermediate process between risk identification and risk response, risk analysis incorporates uncertainty in a qualitative and quantitative manner to evaluate the potential impact of risks.

Risk assessment is the evaluation of how identified risk factors can affect the success of a project and its outcomes by determining their significance (i.e. probability and consequence) (Ameyaw and Chan, 2015). Then the secret for a good risk management lies in the ability to analyse the risk qualitatively and quantitatively. Risk assessment is considered as being critical for an effective project risk management (Bodea and Purnus, 2012).

Risk assessment is an indispensable activity for project management, even more for complex projects dealing with large stakes and involving interdependent tasks and organizations (Kloss-Grote and Moss, 2008). In risk management process, risk analysis has a central place. Thus, to have an efficient risk management, it is necessary to have an efficient risk analysis (Wang et al., 2004b).

For effective risk assessment, proper investigation and identification of the sources of risks need to be carried out by the risk management team. These risks can be assessed or measured in terms of likelihood, impact and consequences. The most appropriate way of dealing with the project risk is treating it as a function of likelihood and impact (Fang and Marle, 2013, Sarkar, 2012, Marle, 2014, Adedokun et al., 2013). Many of these methods independently evaluate the characteristics of risks and focus on the analysis of individual risks. Risks are usually listed and ranked by one or more parameters.

Several models are prevalent in risk quantification and assessment, such as fuzzy logic, hidden Markov and decision tree models, and artificial neural and Bayesian networks, explicitly consider the underlying cause-and-effect relationships and recognize the unknown complexity. With appropriate risk identification and risk control in place, operational risk can be significantly mitigated, despite the lack of consensus concerning which quantitative models should be used (Kailan Shang, November 2013).

Each of the above tools has its strengths and weaknesses. Understanding the strengths and weaknesses is indispensable for their appropriate applications to risk management. Enhanced understanding of risk analysis tools and techniques will provide the industry with improved risk management support (Dey and Ogunlana, 2004).

Generally, risk analysis can be categorized into qualitative and quantitative depending on the data used.

### ***A. Qualitative Risk analysis***

In qualitative analysis, risks are subjectively estimated and ranked in a descriptive manner (Adedokun et al., 2013). Qualitative risk analysis is described as the process of prioritizing risks for subsequent further analysis or action by assessing and combining their probability and impact. Qualitative estimation can be used for the following purposes:

- as an initial screening activity to identify risks which require more detailed estimation;
- when it provides sufficient information for decision-making; or
- where available data or resources are insufficient for a quantitative estimation.

Qualitative risk analysis is a rapid and cost-effective means of establishing priorities for risk response planning, and it lays the foundation for quantitative risk analysis.

The main qualitative risk analysis techniques are checklists, assumptions analysis, data precision ranking, probability and impact description, probability-impact risk rating tables, cause-and-effect diagrams or fishbone diagrams, flowcharts, influence diagrams, and event and fault trees.

In the absence of easy-to-use tools and techniques for project risk quantification, most of the project team applies exclusively to risk qualitative analysis (Bodea and Purnus, 2012).

### ***B. Quantitative analysis***

The project quantitative risk analysis is considered as the hardest part of the risk management, because it is based on advanced statistics and mathematical methods. A lot of deterministic and probabilistic methods were developed over time and made available, especially through software implementation. Quantitative risk and uncertainty analysis can

consist of deterministic methods such as decision-trees or risk matrices and stochastic methods like Monte Carlo simulation (Sarkar, 2012).

But these methods are usually not properly applied, or not applied at all. The main reasons for this are lack of expertise, difficulties in collecting historical data, complexity of risk quantification methods and also the need to considerable computation effort. Only for a few project types, such as research and development projects and public and military capital Investments in projects is the risk quantification is regularly performed (Bodea and Purnus, 2012).

The quantitative analysis of the identified risks for a complex infrastructure project can be most effectively carried out by expected value method (EVM), decision-tree analysis (DTA), interpretative structural modelling (ISM), and integrated ISM and fuzzy approach. (Sarkar and Panchal, 2015).

#### **2.2.4. Risk Ranking**

Several research works have been conducted in different countries to rank and prioritize risk factors. This is an essential practice for the users, particularly the risk/project managers in construction projects to focus on few vital projects. The results of some of research works on the risk ranking activity is summarized below:

For example, the most significant factors causing delays on building construction projects in Uganda were identified as delay in assessing changes in the scope of work by the consultant, financial indiscipline or dishonesty by the contractor, inadequate contractor's experience, design errors by designers, and inadequate site investigation by the consultant (Muhwezi et al., 2014).

Pourrostan and Ismail (2012) identified ten most important causes of delay in Iranian construction projects. The factors are delay in progress payments by client, change orders by client during construction, poor site management, slow decision-making process by client, financial difficulties by contractor, procrastination in reviewing and approving design documents by client, problems with subcontractors, ineffective planning and scheduling of project by contractor, mistakes and discrepancies in design documents and influence of bad weather.

Top factors identified as causing delay of building construction projects in Malaysia were: financial difficulties and economic problems; lack of supervision; delay in making decisions and giving instructions, lack of materials on the market, poor site management, materials shortages on site, construction mistakes and defective work, delay in delivery of materials to site, slowness in making decisions, lack of consultant's experience and incomplete documents (Alaghbari et al., 2007a).

Delay causes in Egyptian construction projects were identified under owner, consultant, contractor, material, labour and equipment, project and external categories. The authors identified top ten causes of delay as Finance and payments of completed work by owner, variation orders/changes of scope by owner during construction, effects of subsurface conditions (e.g., soil, high water table, etc.), low productivity level of labours, ineffective planning and scheduling of project, difficulties in financing project by contractor, type of project bidding and award (negotiation, lowest bidder), shortage of construction materials in market, late in revising and approving design documents by owner and unqualified workforce (Marzouk and El-Rasas, 2014).

The study conducted on Malaysia construction projects (Sambasivan and Soon, 2007a) identified ten most important causes of delay from 28 different causes. Ten most important causes were: contractor's improper planning, contractor's poor site management, inadequate contractor experience, inadequate client's finance and payments for completed work, problems with subcontractors, shortage in material, labour supply, equipment availability and failure, lack of communication between parties, and mistakes during the construction stage.

Financial difficulties faced by the contractor and too many change orders by the owner are the leading causes of construction delay in Jordan construction projects. Severe weather conditions and changes in government regulations and laws ranked among the least important causes (Sweis et al., 2008).

(Hwang et al., 2013) identified the risk factors impacting the schedule performance of public housing projects in Singapore, and found the following factors as most influential: effective site management; coordination among various parties; and availability of labourers.

A survey on evaluation of the impact of risk on project cost overrun in the Nigerian construction industry was conducted based on physical, environmental, design, logistics, financial, legal, political and construction operation risk factors. The main risk factors identified were finance and political influence(Dada and Jagboro, 2007b).

A survey on Palestine road construction project indicated that the top risks affecting time overrun are: financial status of the contractors, payment delays by the owner, the political situation and segmentation of the West Bank, poor communication between construction parties, lack of equipment efficiency and high competition in bids (Mahamid, 2013).

Based on the overall perceived importance of factors surveyed, the authors (Jarkas and Haupt, 2015a) identified ten prominent construction risk factors namely slow decision-making process by client, delay in payment process by client, frequent change orders by client, errors and omissions in design drawings, unavailability or shortage in specified materials, contractor's financial difficulties, clarity of drawings and technical specifications, shortage in technical staff and skilled labour, late delivery of materials and delay in consultant's response to requests for information.

### **2.2.5. Risk Mapping**

Within the literature, several risk identification and assessment methods have been proposed to facilitate project risk management. In majority of the proposed methods, risk checklists and risk breakdown structures are introduced to identify potential risks of a project, which in turn lead to risks to be assessed individually. On the other hand, "generally risks affect, magnify or diminish each other and have mutual influence on a project" Ren (1994). Several researchers such as Kim et al. (2009), Ashley and Bonner (1987), Dikmen et al. (2007) emphasized the vital role of consideration of independency among risk-related factors and claimed that rather than individual risk factors, risks should be assessed with the consideration of their interdependencies, to achieve better simulation of project conditions. Within this context, authors have made some encouraging efforts for demonstration of risk interdependencies using influence diagrams, flow charts, cause-effect diagrams, risk paths and risk maps (Yildiz et al., 2012).

Chapman (2001) proposed studying risk relationships by classifying them as, dependent risks in series and independent risks in parallel and suggested precedence, influence diagrams,

knowledge maps or flow charts to represent these relationships. The study of Chapman (2001) is one of the important contributions examining cause-effect relations among risks, risk paths generated from these relationships and graphical representation of these paths. Additionally, Han et al. (2008) analysed the causality between risk variables, sorted them as risk sources (causes) and events with respect to their hierarchical order and constructed series of risk paths from its source to event, to incorporate a scenario-based risk checklist. Ashley and Bonner (1987) utilized influence diagrams to represent interrelationships between macro risks (political source variables) and micro risks (project consequence variables) and their either direct or indirect effect on project cash flow variables (cost of labour, material, overhead costs and project revenues). Akinci and Fischer (1998) used knowledge maps for demonstration of relationships among uncontrollable risk factors (i.e. economic factors, political risk factors, client related factors and subcontractor related factors) and cost overrun variables (i.e. unit cost, estimated quantity, and final unit cost). To assess the cost overrun risk rating of an international construction project, Dikmen et al. (2007) incorporated influence diagramming and fuzzy risk rating approach for risk identification and risk assessment purposes. Authors used influence diagrams for representation of hierarchical order and interactions of major sources of country and project risks that relates cost overrun (Yildiz et al., 2012).

#### **2.2.6. Chronological Development of Risk Management since 1995**

The presence of risks and uncertainties inherent in project development and implementation plays significant role in such a failure intrinsic in all stages of project (Nasirzadeh et al., 2008a). Because of complexity and dynamic nature of construction projects, they are exposed to effects of plentiful factors leading to uncertainty in the timing and sequence of project activities (Chan et al., 2004). Project delays and cost overrun in the construction industry are common and taken as a global phenomenon (Mahamid, 2014, Sambasivan and Soon, 2007b). As a result, construction is a risk-prone industry with delays in project completion, cost overrun and failing to meet quality standards.

The pressure on project delay and cost, the need for improved performance in the construction industry and the increasing contractual obligations lead to the necessity of a more effective risk management approach. Improving the risk management process is therefore a key

challenge in construction projects (Taillandier et al., 2015). Thus, Risk analysis and management are an important part of the decision-making process in construction industry.

Risk analysis has been known for more than two millennia since 3200 B.C. Despite the fact that concept of risk analysis in construction is evident since the 1960s, it became a well-established project management functions since 1980s. During the 1990's different techniques and theories were developed to account for unique nature of construction project risks.

#### **A. From the year 1995 – 1999**

Researches indicate that the development trends of risk analysis have gained a momentum during the 1990s from the search results from 1995 – 2000 only three articles are obtained. Among these Mack (1995) has used a fuzzy set theory to analyse uncertainties project conducted in Hong Kong. The research by Edwards and Bowen (1998) is on the literature review of the future research directions of risk analysis. No tools and techniques have been used except using literature review to identify the research gaps. Ahmed et al. (1999) has used mean scoring of the parameters obtained from questionnaire to assess the risk allocation practices of contractors in Hong Kong.

#### **B. From the year 2000 – 2005**

During this period, most of the research has used the statistics and fuzzy set to analyse the risks on construction project. Most of the researches are in Europe and Asia with the only exception of one research from Australia. Tah and Carr (2000a) has used a hierarchical risk breakdown structure and fuzzy risk assessment model to illustrate the existing knowledge of risk management procedurally based on the UK context. Mills (2001) has conducted a research in Australia to highlight the effectiveness of systematic risk management and highlight the dangers associated with using incomplete assumptions in risk analysis models. Carr and Tah (2001) has used a case study to assess the construction project risks in London. He has used fuzzy risk analysis model as a tool.

Motiar Rahman and Kumaraswamy (2002) has used a questionnaire survey to assess the risk management practices of construction industry in Hong Kong. He used arithmetic mean as a tool to analyse the data obtained from the survey. The result of the research is only

contextualizing the existing knowledge to the Hong Kong construction industry to assess the perceptions of the present and preferred risk allocation in construction contracts.

Thomas et al. (2003) has used BOT road Projects to analyse the risk perceptions and managements in India. The perception was evaluated by literature review, unstructured interview and discussions with stakeholders of the project and questionnaire survey for their research methodology and used regression analysis. Likewise, San Santoso et al. (2003) the same methodology to assess the risks associated with high rise building construction in Jakarta and analyse it through mean value, correlation matrix and Bartlett's test. Though the authors addressed the risk impact in relation to the country's specific context on the basis of statistical analysis, it fails to meet the uncertainties of the sector raised by the respondents. On the other hand, Hillson (2003) has used Risk Breakdown Structure (RBS) to manage risks in United Kingdom but there is no significant finding from the research.

Odeck (2004) has used Norwegian Public Road Administration (NPRA) database to assess the cost overruns in road construction project. He used statistical relationship between the actual and estimated costs of the road construction to identify the causes and size of cost overrun for the projects. Dey and Ogunlana (2004) has analysed the content and context of BOT projects for the selection and application of risk management tools and techniques in Build-Operate-Transfer projects. They reviewed literature and analysed various kinds of risk analysis and tools and techniques to structure the existing findings and developed a model for selecting risk management tools and techniques. A risk management framework for construction projects was developed by Wang et al. (2004b) particularly for developing countries. The research has used literature review, international survey, interviews and discussions and analysed it through statistical analysis, mean criticality and standard deviation to develop the model. The model has enabled to better categorize risks and represent the influence relationship among risks at different hierarchy levels as well as revealing the mitigating sequence (priority of risks).

In 2005, the financial risks of Build-Operate-Transfer projects has been assessed by Xenidis and Angelides (2005) through literature review, expert evaluation and questionnaire to identify 27 financial risks of BOT projects. The research facilitates the risk analysis process that is being conducted by risk managers prior to bidding for a BOT project and during the negotiation period.

### ***C. From the year 2006-2010***

During this period, more than 32 researches have been conducted on risk analysis throughout the world. However, most of these researches are from Asia which accounts more than 50 percent. A significant number of researches are from Africa and Europe.

Different authors have attempted to identify the risk factors and the corresponding impacts on the projects through statistical analysis for data obtained from questionnaire, interview and literature review and tried to conceptualize the existing knowledges of risks to the specific country (Dada and Jagboro, 2007a, Van Thuyet et al., 2007, Zou et al., 2007b, Sachs et al., 2007, Alaghbari et al., 2007b, Ibrahim et al., 2006, Andi, 2006, Al Zubaidi and Al Otaibi, 2008, Manelele and Muya, 2008, Hlaing et al., 2008, Enshassi et al., 2009, Kaliba et al., 2009, Bryde and Volm, 2009, Panthi et al., 2009, Zou and Zhang, 2009, Kululanga and Kuotcha, 2010, Khoshgoftar et al., 2010, Deng and Zhou, 2010).

A research conducted by Adams (2006) has used expert opinions through the support of elicitation model to investigate construction contract risks and validated the application of Bayesian Method in Mississippi. Thomas et al. (2006) has used literature review, interviews and case studies to assess and model the critical risks of BOT Road projects in India. He used a fuzzy-fault tree to reduce the variability among the experts in the probability estimation of complex risk events. Meeampol and Ogunlan (2006) has tried to contextualize the existing knowledge of risk analysis using descriptive and inferential analysis to Thailand Construction projects to assess the project success factors in relation to project performances though literature review and questionnaire survey.

Hassanein and Afify (2007) has reviewed the tender documents of power station projects in Egypt to contextualize the existing knowledge of risk management in Egypt. They investigate contractor's perceptions of construction risks and their attitudes towards risk identification and management and identified significant risks relevant to the case projects. Dikmen et al. (2007) has used fuzzy risk assessment together with influence diagram to rate cost overrun risks in international construction projects in Turkey. Expert opinions are used to collect data through brainstorming session. Zeng et al. (2007) studied the application of a fuzzy based decision making methodology to construction risk assessment in UK using experts on real case data. They proposed a risk assessment model based on fuzzy reasoning and modified AHP method to deal with the drawback of the AHP method that it can only deal with definite

scales and deal with qualitative and quantitative data and information. Moreover, this research has also addressed the issue of uncertainties and subjectivities arising in the factor comparison.

Adams (2008) validated the application of Bayesian method on the analysis of payment delays in international contracts with the support of elicitation model in Ghana. Nasirzadeh et al. (2008c) addressed the issues of the dynamic behaviour and uncertain nature of construction risks by integration system dynamics and fuzzy logic modelling. Jha and Devaya (2008) introduces a new approach based on structural analysis tools, Interpretative Structural Modelling (ISM) and Matrix Cross-Reference Multiplication Applied to Classification (MICMAC) to the study of international construction risks. Zayed et al. (2008) has identified the sources of risk and prioritize it using AHP techniques in Chinese highway projects.

Perera et al. (2009) has studied risk management practices in Sri Lanka through multiple case studies, semi-structured interviews and documentary evidences to identify risk responsibilities of contractual parties to improve their risk handling strategies. Kim et al. (2009) incorporates uncertainties through their conditional probabilities through Bayesian Belief Network based models for quantifying schedule risk in construction projects.

Makui et al. (2010) has used Fuzzy group TOPSIS for project risk identification and analysis based on group decision making. Zavadskas et al. (2010) adopts multi-attribute decision making methods to assess risks in Lithuania construction projects. Al-Humaidi and Hadipriono Tan (2010) modelled the likelihood for the delays of construction projects using rotational fuzzy fault tree model. Dikmen et al. (2010) integrates Analytical Network Process (ANP) with Delphi method to evaluate the interrelations among the model parameters and the relative importance weights of risks in construction firms. Kumaraswamy et al. (2010) illustrates the factors influencing the lack of coherence in risk management practices within a Public Private Partnership (PPP) projects using Integrated Risk Management System (IRMS) model.

#### ***D. From the year 2011 – 2015***

During this period, most of the researches has used fuzzy expert system as a tool for analysing construction project risks (Nieto-Morote and Ruz-Vila, 2011, KarimiAzari et al.,

2011, Lin and Jianping, 2011, Fouladgar et al., 2012, Xu et al., 2012, Yazdani-Chamzini et al., 2013, Polat and Neval Bingol, 2013, Ravanshadnia and Rajaie, 2013, Kuo and Lu, 2013, Perera et al., 2014). Another research method used for risk analysis during this period is the use of questionnaires, literature review, interviews and experts opinion to identify risks the quantification of data's are interpreted using statistical means (Mahamid, 2011a, Banaitienė et al., 2011, Mousavi et al., 2011, Ke et al., 2011a, Doloi, 2012a, Doloi et al., 2012, Famakin et al., 2012, Chileshe and Boadua Yirenkyi-Fianko, 2012, Adedokun et al., 2013, Špačková et al., 2013, Chileshe and John Kikwasi, 2014, Jarkas and Haupt, 2015b, Rostami et al., 2015, Lundin et al., 2015, Ameyaw and Chan, 2015, Shehu et al., 2015)

KarimiAzari et al. (2011) focuses on risk assessment model selection technique using fuzzy TOPSIS. The research suggested the superiority of the Nominal Group Technique (NGT) for the identification of decision criteria. However, it does not clearly state the advantage of this group management technique over the others. Lin et al. (2011) evaluated the impact of risk factors using AHP.

Drouin et al. (2012) attempts to illustrate the problem of dealing with ill-defined and uncertain projects with the existing risk management practices. Rasool et al. (2012a) integrates Risk Breakdown Structure (RBS) with Multi-criteria decision method to validate RBS as a tool for evaluating risks in France construction projects. Xu et al. (2012) developed a risk evaluation model using VBA, to efficiently address most risky areas in a PPP project with reduced human and mathematical errors.

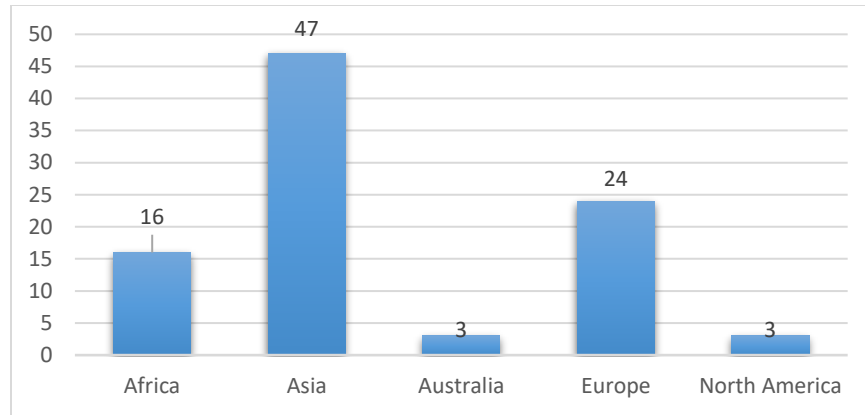
Yazdani-Chamzini et al. (2013) adopted the ELECTRE method to analyse risk in multiple criteria rather from likelihood and consequence only by integrating AHP-ELECTRE under a fuzzy environment. Polat and Neval Bingol (2013) presented two tools that can be used in international projects for cost contingency estimation in bid price and compares the modelling mechanisms and the performance of these approaches. Ravanshadnia and Rajaie (2013) setups a fuzzy TOPSIS framework to evaluate and prioritize bidding opportunities. Kuo and Lu (2013) introduces the concept of Fuzzy Multiple Criteria Decision Making (FMCDM) and employs Consistent Fuzzy Preference Relations (CFPR) to enhance and simplify the operations of the conventional AHP because of its difficulty and inefficiency when huge number of pair-wise criteria comparison is required.

Yildiz et al. (2014) attempts to explore the process of assignment of risk ratings by the decision makers and question how the reliability of the risk assessment process using risk mapping tools. Budi et al. (2014) provides an emphatically validated instrument to assess organizational Project Risk Management (PRM) Maturity Level through a post hoc analysis, simple averaging and factor score methods in Indonesia. Nasirzadeh et al. (2014) integrates fuzzy system dynamics based approach to address the issues of quantitative risk allocation process with complex inter-related influencing factors as well as the contractor's defensive strategies in Iran. Taylan et al. (2014) integrates fuzzy AHP and fuzzy TOPSIS model to assess the overall risks of construction project throughout its life time.

Salah and Moselhi (2015) developed a framework lies on the newly developed fuzzy-set based model for estimating, allocating, depleting and managing contingency fund over the lifecycle of construction projects. Hamzaoui et al. (2015) used tailor made RBS model for managing construction project risks of railway projects in Algeria. Hossen et al. (2015) incorporates AHP- RII methodology to assess delay risk in terms of severity and frequency of occurrences, and to analyse the risk perception of different parties in the Nuclear Power Plant projects of Turkey. Iqbal et al. (2015) highlights different significant risks, ultimate responsibility, and risk management techniques practices on the countries context. However, the problem related to construction projects were addressed, it falls to strengthen the reliability and validity of the measurement.

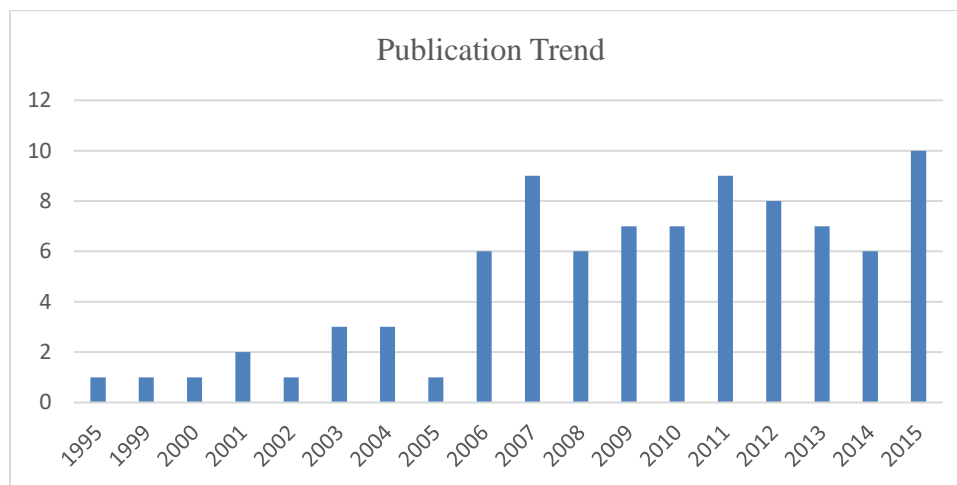
### **2.2.7. Analysis of Literatures on Risk Management**

Though the topics of Construction project risk is a paramount factor for successful completion of project, the attention given to it varies from continent to continent. Among the reviewed researches, 50% (47) researches were published in Asia, 25% (24) from Europe, 17% (16) researches from Africa and the rest is from North America and Australia. However, the dispersion of these researches are limited to specific countries as shown in Figure 2-1. One can easily understand that there is a limited research in the area of construction project risks in Australia and North America.



*Figure 2-1 Number of Publication in each continent*

On the other hand, the trends of publication is increasing from time to time for the past two decades. Figure 2-2 revealed that the top publication year for the topic construction project assessment is in 2015 where the number of publication during this year is only up to August 2015.



*Figure 2-2 classification of risk factors*

Different researchers have identified many different risk factors which are specific and contextual to the culture, geography, economy, type of project and many other determinant issues. More than 126 risk factors have been identified from different researches. Table 2-2 and 2-3 shows Identified Risk Factor in Developing and Developed World Trend. However, the classification of the risk factors in developed and developing world are similar, this might be due to the adoption of the risk factors form previously published journals.

*Table 2-2 Classifications of Risk Factors from Developed Countries Perspective*

<b>No.</b>	<b>Author</b>	<b>Country</b>	<b>Classification of Risk Factors</b>
1	(Hlaing et al., 2008)	Singapore	Client-generated risks, Contractor-generated risks, Project specific risks, Procurement specific risks, Subcontractor/supplier generated risks, External risks
2	(Mills, 2001)	Australia	Planning risks, Design and construction risks, Site-related risks, Market risks
3	(Kumaraswamy et al., 2010)	Germany	Sites risks, Demand risks, Subsoil risks, Building structure risks, Tendering and awarding risks, Complaint and protest risks, Design risks, Contractual risks, Approval risks, Input risks, Interference risks, Management risks, Technical implementation risks, Technology risks, Operation risks, Risk arising for change in service standard, Maintenance risks, Vandalism risks, Financial risks, Inflation risks, Tax risks, Income risks, Risk of the principal and contractors insolvency, Risks of changes in laws/standards
4	(Ahmed et al., 1999)	Hong Kong	Force majeure, Exploitation risks Contractor, Owner, Both owner and contractor, other
5	(Dikmen et al., 2007)	Turkey	Technical risk, Managerial risk, Productivity risk, Design risk, Payment risk, Client risk, Subcontractor risk, Construction risk, Project risk
6	(Doloi, 2012b)	Australia	Planning and design, Communication site conditions, Market dynamics, Construction risk, Policy, legislation and regulation

7	(Mehdizadeh Rasool, June 2012)	France	Political, Design change, Financial (internal and external resources), Unexpected weather, Natural constraints of site, Time management, Economic, Natural hazards, Defective design, Quality management, Poor communication
8	(J. H. M. Tah, 2000)	London	Internal risks, External risks
9	(Yelin Xu, 2012)	China	Macroeconomic risk, Construction and operation risk, Government maturity risk, Market environment risk, Economic viability risk
10	(Patrick. X.W. Zou, 2009)	Australia	Cost related risks, Time related risks, Quality related risks, Environment related risks, Safety related risks
11	(Vaughan and Vaughan, 2007)		static or dynamic, fundamental or particular, government source or private source, speculative or pure, financial or non-financial, measurable or immeasurable

*Table 2-3 Classifications of Risk Factors from Developing Countries Perspective*

No.	Author	Developing Countries Risks	Classification of Risk Factors
1.	(Wa'el Alaghbari Mohd., 2007)	Malaysia	contractor's factor, owner's factor, consultant's factor
2.	(Mahamid, 2011b)	West Bank	risk factor under logic and environment, risk factor under managerial and risk factor under consultant group
3.	(Joshua O Dada, 2007)	Nigeria	factors related to procurement method
4.	(Adnan Enshassi, 2009a)	Gaza Strip	external factors, factors related to material, contractor's responsibilities, labour and equipment, owner's responsibilities,

			consultant's responsibilities, professional management, factors related to execution, government relations, contractual relationship, design and documentation and project
5.	(O.A. Adedokun, 2013)	Nigeria	internal (controllable) and external (uncontrollable)
6.	(I. Mañelele, 2008)	Zambia	project initiation risks, community contribution and participation risks, budget and financial risks, skilled labour risks, materials procurement risks, technical supervision and quality control risks
7.	(Charles Teye Amoatey, 2015)	Ghana	financial, resource, technical, economic, environmental, operational, government and political, relationship, security/safety and legal
8.	(Abdulaziz M. Jarkas, 2015)	Qatar	client, contractor, consultant and exogenous
9.	(Wa'el Alaghbari Mohd., 2007)	Malaysia	contractor's responsibility, consultant's responsibilities, owner's responsibilities and external factors
10.	(A D Ibrahim, 2006)	Nigeria	exogenous risk factors and endogenous risk factors
11.	(Yao-Chen Kuo, 2013)	Taipei	engineering design, construction management, construction safety-related, natural hazard and social and economic
12.	(Laila Mohamed Khodeir, 2015)	Egypt	external, internal and external/internal
13.	(Fethi HamzaoFranck Taillandier, 2015)	Algeria	project stakeholders, management and external risks
14.	(Shahid IQBAL, 2015)	Pakistan	client's responsibility, contractor's responsibility, shared responsibility and undecided responsibility

- |            |                         |              |   |
|------------|-------------------------|--------------|---|
| <b>15.</b> | (KAMALESH PANTHI, 2009) | Taiwan       | construction related, financial and economic, performance related, contractual and legal, physical, and political and social  |
| <b>16.</b> | (HEMANTA DOLOI, 2012)   | India        | contractor's inefficiency, lack of commitment, improper planning and client's influence   |
| <b>17.</b> | (Sid Ghosh, 2004)       | Thailand     | financial and economic risk, contractual and legal risk, subcontractors related risk, operational risk, safety and social risk, design risk, force majeure risk, physical risk and delay risk |
| <b>18.</b> | (Tarek Zayed, 2008)     | China        | political, financial, cultural, market, technology, contract and legal issues, resources, design, quality, construction and others  |
| <b>19.</b> | (S.M. Mousavi, 2011)    | Iran         | engineering, procurement, construction and management   |
| <b>20.</b> | (Yao-Chen Kuo, 2013)    | Sri Lanka    | technical and contractual risks, economic, financial and political risks, managerial risks and external and site condition risks  |
| <b>21.</b> | (Adnan Enshassi, 2009b) | Gaza Strip   | cost, time, quality, productivity, client satisfaction, regular and community satisfaction, people, health and safety, innovation and learning and environment factors                        |
| <b>22.</b> | (Alhomidan, June 2013)  | Saudi Arabia | managerial, consultant, financial and external group  |

Apart from identifying the constructs that make up risk management processes, the literature shows a variety of tools that are employed for measuring risk management processes based on both qualitative and quantitative approaches with varying degrees of complexity (Koh et al., 2007). There are several risk measuring tools implemented on construction projects risk assessment which differ according to the nature of risks, the sector specific environment in which they are being implemented and at the same time the availability of dates and knowledge of the risk analyst.

As shown in Table 2-4, out of the 36 risk assessment methods identified, about 35.1 percent of the papers adopted descriptive and inferential analysis, 8.5 percent fuzzy set theory, 7.44 percent Bayesian Belief Network, 6.38 percent descriptive and inferential analysis with RII, 3.19 percent Fuzzy TOPSIS, 2.13 percent shared by AHP Pair wise comparison, Fuzzy fault tree, AHP-ELECTRE method, RBS Model respectively, percent respectively, the remaining 37.26 percent are equality distributed among other methods specified in the table. Even though the most commonly used method among researchers is the descriptive and inferential analysis it does not necessarily indicate its strength. This is because it lacks to address the uncertainty and biasness associated with the involvement of experts and project analyst. This large usage could possibly be due its simplistic nature for implementation.

Fuzzy logic models are more convenient for incorporating different expert opinions and more adapted to cases with insufficient and imprecise data. They provide a framework in which experts' input and experience data can jointly assess the uncertainty and identify major issues. Using approximation and making inferences from ambiguous knowledge and data, fuzzy logic models may be used for modelling risks that are not fully understood (Kailan Shang, November 2013).

*Table 2-4 Summary of Reviewed Studies on Risk analysis tools*

No.	Risk Analysis Methodology	No. of publication
1.	Descriptive and Inferential Analysis	33
2.	AHP Pair wise comparison	2
3.	Different probabilistic models	1
4.	Fuzzy-TOPSIS	3

5.	Non-parametric Jackknife technique	1
6.	Fuzzy fault tree	2
7.	Fuzzy rating with influence diagram	1
8.	Fuzzy set theory	8
9.	Modified AHP with fuzzy approach	1
10.	Fuzzy analytical network	1
11.	Bayesian Belief network	7
12.	Relative importance index (RII)	1
13.	Fuzzy system dynamics approach	1
14.	AHP-ELECTRE method	2
15.	Structural equation modelling (SEM)	1
16.	Descriptive and Inferential Analysis with RII	6
17.	AHP Pair wise comparison with RII	2
18.	AHP Pair wise comparison with Fuzzy-TOPSIS and RII	1
19.	Descriptive and Inferential Analysis with Fuzzy Set Theory	1
20.	Significance index score	1
21.	AHP Pair wise comparison with Monte carol simulation	1
22.	Descriptive and Inferential Analysis with Structural equation modelling (SEM)	1
23.	Descriptive and Inferential Analysis with Fuzzy Set Theory and RII	1
24.	RBS Model	2
25.	RBS with fuzzy model	1
26.	QSR software application	1
27.	TOPSIS Grey	1
28.	Interpretative structural modelling (ISM) technique and Impact Matrix Cross-Reference Multiplication Applied to a Classification (MICMAC)	1
29.	Simulation Techniques	2
30.	Decision Tree Analysis	1
31.	Artificial Neural Network	1
32.	Influence Diagram	1

33. Eigen Structure Analysis	1
34. Linear Programming	1
35. GARCH and ICSS Model	1
36. Simulated Annealing and Building Information Modelling	1
TOTAL	94

### **2.2.8. Construction Project Risk Management in Ethiopia**

To the best of the author’s knowledge from the online databases used for this research, international publications related to construction risk management on Ethiopian context have not been found. However, there are academic papers published in university level to address some of the issues faced by the construction sectors.

Review of the academic papers reveals the risk assessment method is solely based on descriptive statistics. While this technique provides general information on the risk assessment, it does not address the subjective nature of the expert’s opinion and the uncertainty of the construction activities.

The ongoing price escalation and its unpredictability affect project costs, borrowers’ affordability, monthly loan repayment, building finishing time, and occupancy rate are the main causes for the construction project risks in Ethiopia(NEGA, 2008, Addis, 2014, Abubeker, 2015, Abrham, 2004, Getachew, 2009, Tafere, 2015).

### **2.3. Literature summary**

Enormous risk factors are considered in different researches, however, these risk factors are limited to the geographic scope and types of project with the organizational and cross-cultural perspectives.

- Though various researches have been conducted for decades, construction risk modelling is a developing and ongoing process.
- To date no satisfactory theory or tool for assessing the compounded effects of construction risk on project objectives has been developed or proposed. To comprehensively understand a risk, it is helpful to identify its causes as well as its effects. Several methods include this principle, but they still concentrate on a single risk in order to simplify the problem. Many of these methodologies independently evaluate

the characteristics of risks, and focus on analysis of individual risks and failed to consider the interactions of different risks.

- The majority of existing risk assessment contributions have only delivered risk ratings.
- Risk factors have interdependencies to each other and difficult to anticipate and control the interrelationship between different risks. However, no suitable methods are proposed and developed so far.

## **2.4. Conclusion**

This chapter presented a review of construction project risk assessment literatures published over the last two decades. It assesses the risk management lifecycles in construction project. Moreover, it focuses on the development of risk assessment techniques and tools. It also aimed to assess the contribution of different researches on the various techniques, theories and aggregation rules. From the chronological study of the research, it was found out that the research tools used from simple statistical tools to fuzzy expert system and the aggregation of this tool with AHP, TOPIS and System Dynamics to accommodate the dynamic nature or risks. However, it was discovered that the dominant researches have used statistical analysis to contextualize the construction risks based on the geography or type of project under consideration.

The review had confirmed what was previously mentioned that the literature lacks a comprehensive risk assessment framework which takes into account the different types of impact of the risk on different project objectives simultaneously.

## **Chapter Three Research Design and Methodology**

### **3.1. Introduction**

This chapter tries to present the research design and methodology used in this dissertation. It begins with the general approaches and steps of the research framework. Both qualitative and quantitative approaches will be used for the data obtained from different sources.

### **3.2. Research Design**

This research is designed mainly to address the research questions posed in the first chapter under section 1.2 of the dissertation.

Road construction project risk identification is the first task of the research. The identification process was performed primarily through a comprehensive review of literature on road construction projects, factors that influence construction project delay and cost overrun, and studies on construction project risks encountered in Ethiopia. The literature review identified various risks under internal and external risk categories comprising client, consultant and contractor related risk factors under internal risks, and political, economic, social, contractual and legal and force majeure risks under external factors. These risks were reviewed by road construction industry experts to ensure accuracy and completeness. This was achieved by conducting discussions with experts including highway Engineers, senior surveyors and project managers with more than five years of experience working in road construction projects.

Moreover, there is an interrelationship between risk factors. Therefore, it is necessary to study the impact of each risk on the other risk factors and ultimately the cascaded effects of risks on the project objectives.

Hence, this study tries to model the multifaceted risk factors on the project objectives for the construction industries particularly engaged in road construction project. Both internal and external risk factors; which affects the project objectives were used for model development.

On the other hand, different risk factors have different impact on the project objective. The purified and filtered risk factors by the experts are used for developing the questionnaire. The questionnaire is then used as an instrument for collecting the data related to the impact of each risk factors on the project objectives. The experts in different areas of the sector are

used for the survey and the result enables the researcher to prioritize the risk factors based on the impact on the project objective. The fuzzy expert system is used as a tool for analysing the risk magnitude and risk ranking.

Thus, experts in the field of road construction projects are used to judge the probability of occurrence of risk factors and the corresponding impact on time and cost of the project subjectively. These are used as an input for the fuzzy expert system to begin the analysis. It is used to identify the weighted alpha of each risk factors and based on the results obtained from Fuzzy arithmetic analysis. This analysis has been used to identify the magnitude and critical risk factors. The results of the fuzzy expert system are further used as an input for system dynamics model.

### **3.3. Data collection procedure**

To achieve the research objectives, different approaches are used for the research methodology. Both qualitative and quantitative data are either collected or simulated depending on the type and availability of data. The data are collected from clients (Addis Ababa City Road Authority and Ethiopian Road Authority), consultants and Contractors working on road construction projects. The target population of the survey are General Contractors (GC 1), Category 1 Highway and Bridge consultants and clients of Addis Ababa City Road Authority and Ethiopian Road Authority.

Different data collection approaches used in this dissertation are described below.

#### **3.3.1. Literature Review**

This Literature review revealed the results of an extensive study of the literature on construction project risk modelling and assessment. The study focuses on construction project risks such as highway, road and building constructions. The target literature sources are limited to peer reviewed academic journals, published in English. Papers published on construction risk assessment for the past two decades have been reviewed. Relevant research papers are identified and gathered first, using keyword searching on several online databases, including Emerald Database, Science Direct, Taylor and Francis, Springer Link, Google Scholar, ProQuest, ABI/Inform, IEEE, IgentaConnect and Web of Science. For this purpose, keywords used include “Risks in construction projects”, Risk quantification in construction projects” Risk analysis in construction projects”, “Risk quantification and

analysis in construction” and “modelling project risks”. However, different combinations of them were used to validate the extensiveness of the search results.

The search targeted the past two decades of available articles in the databases in order to review the development of risk modelling and assessment.

As a result of the search, more than 208 journal articles have been found. However, through systematic refinement, only 93 papers were found to be more relevant. Consequently, these articles were reviewed and essential information was captured. This information includes authors’ name, year of publication, paper title, journal title, country of origin, research method, data analysis method, sector, purpose and research goals; etc.

Thus, different techniques, efforts and models for analysing project risks are captured through systematic analysis of the literature review. On the other hand, different risk factors registered by previous researchers were assessed and collected which will later be used for examining the critical risk factors.

### **3.3.2. Primary Data**

#### ***A. Interview***

The primary data are collected using a questionnaire and interviews of the experts in in road construction who are facing the challenges of risks in their works frequently. Initially, identification of risk factors is conducted using semi-structured interviews of the experts to purify the relevant risk factors which were identified in the literature. The interviews mainly focus on the identification of risk factors and their relationship and influences of risk factors on each other.

A total of 51 risk factors were identified as the relevant risk factors affecting the project objectives in Ethiopia through interviews with the experts. Six experts from various facets of the industry (such as construction, consulting companies and two road authorities) were interviewed. The experts were chosen based on their willingness to participate and their experience.

Moreover, the same technique is used to identify the interrelationship between the risk factors. The matrix containing all the risk factors are provided to the experts to identify the

interrelationship of the risks. These are used to develop the influence diagram and initial causal loop diagram of system dynamics.

Expert opinion from different stakeholders of the project are used to develop causal loop diagram and verify the logic of system dynamics. Furthermore, the logic of the causal loop diagram was verified by experts.

### ***B. Questionnaire***

The identified risk factors are employed for the preparation of questionnaires to rank the weight of the risk factors and rate the effects of each risk factor on the project cost and time. The likelihood and impact on project cost and time of project risk factors are determined from clients', consultants' and contractors' perspective using the questionnaire. The questionnaire comprises general information of respondent, risk management practice and project objectives of the company and project risk factors of road construction projects under internal (client-related, consultant-related, contractor-related) and external risk factors category. The questionnaire used for this survey is attached in appendix I.

The questionnaire comprises general information of respondent, risk management practice and project objectives of the company and project risk factors of road construction projects under internal (client-related, consultant-related, contractor-related) and external risk factors category. The data were collected from different stakeholders of the project particularly from consultants, contractors and project owners. Questionnaires were used to identify the risk magnitudes in terms of risk probability, consequences and allocation of risks based on the lists of risk factors identified from the literature.

From the collected data, the respondents' perception of project performance for Road construction Project and the level of impact of risk factors on project cost and time are calculated using preliminary risk analysis. The respondents were asked to rate the likelihood of risk factors using Likert Scale, where 5=Almost Certain; 4= Likely; 3= Possible; 2 = Unlikely; 1 = Rare and level of risk factors impact on project cost and time from very low to very high, where 5 =Very High; 4 = High; 3= Moderate; 2 = Low; 1 =Very Low.

Before the questionnaires were distributed to each respondent, a quick briefing was made to elaborate the context of the questionnaire regarding the objective of the thesis and some

references attached to the questionnaire to explain some technical terms and also the linguistic definition of each Likert Scale.

### **3.3.3. Secondary Data**

Apart from the literature review, various secondary data that are relevant to the study were collected from different offices and organizations. The sources of secondary data are:

- The reports and studies obtained from the Ethiopian Road Authority and the Addis Ababa City Road Authority to collect data about the registered risk factors, to detect the most frequent risk factors, evaluate the risk management practices of the organization, and assess the risk events of selected projects.
- The reports of Construction Sector Transparency Initiatives working under the Federal Ethics and Anti-corruption Commission of Ethiopia to collect data on the project performance and identify risk factors.
- Reports generated from ERAMS software (a tool used by Ethiopian Road Authority for the performance measure of contractors in road construction project). However, the limitation of this report is that it contains risks related to clients which is used to request additional budget and time for the contractors.

The variables to be measured are the occurrences of different risk factors (obtained from various literatures and refined by experts in the field), and the impact of these risk factors on project objectives mainly time and cost of the project.

## **3.4. Target population**

This research uses purposive sampling to examine the risks involved in road construction project. This is due to the fact that valuable information can only be captured from contractors and consultants who have participated in road construction project of AACRA and ERA.

The target population of the survey is GC 1 (General contractors), Category 1 Highway and Bridge consultants and Clients-Addis Ababa City Road Authority and Ethiopian Road Authority (AACRA) and the Ethiopian Road Authority (ERA).

The ranking and prioritization of the major risk factors were carried out from the perspective of the clients (AACRA and ERA), consultants and contractors.

Eighteen questionnaires are distributed to the clients (AACRA and ERA) working at different levels of the organization. Mainly the directors, project managers, department managers for Engineering and Construction, deputy directors, contract administration department heads, planning and contract managers and engineering operations managers, highway engineers and office engineers are used for the survey. Among these, 10 questionnaires are filled and returned to the researcher.

On the other hand, 22 consultants involved and working on road construction projects are used for the survey at different levels mainly as a design head, resident/site engineering and highway engineers are used for the survey and 12 questionnaires are returned.

Furthermore, 34 questionnaires are distributed for contractors who have been involved or are currently working on road construction projects. Nineteen respondents have filled and returned the questionnaire.

*Table 3-1 Respondents of Questionnaire based on company type*

<b>Company</b>	<b>Questionnaire Distributed</b>	<b>Returned</b>	<b>Return Rate</b>
Client	18	10	55.56%
Consultant	22	12	54.55%
Contractor	34	19	55.88%
<b>Total</b>	<b>74</b>	<b>41</b>	<b>55.41%</b>

The respondents are from different departments and positions within the sector. The positions are clustered into four groups. The first group is project manager and design engineer. The second group is resident, site and construction engineer. Highway engineer and office engineer are grouped into third and fourth groups respectively.

Fourteen respondents (amid are found to have 7 clients, 2 consultants and 5 contractors) are working as project manager or design head. Whereas, 4 consultants and 8 contractors working as resident/site engineers have participated in the survey. Further, a total of 9 highway engineers from different sectors (1 client, 6 consultants and 2 contractors) are chosen as respondents. The office engineers responded for the survey are 2 from clients and 3 from contractors.

The work experiences of the respondent are assessed based on five categories; 43.90% (18) of the respondents have less than five years' experience. Respondents between 5 and 9 years' experiences are 34.15% (14). As shown in Table 3-3, 9.76% (4) respondents are between 9 and 12 years' experience. The remaining 12.19% of the respondents have more than 12 years' experience.

*Table 3-2 Respondents' position*

<b>Respondent's Position</b>	<b>Client</b>	<b>Consultant</b>	<b>Contractor</b>	<b>Total</b>	<b>Percentage</b>
Project Manager/Design Engineer	7	2	5	14	34.15%
Resident/site/construction Engineer	0	4	8	12	29.27%
Highway Engineer	1	6	2	9	21.95%
Office Engineer	2	0	4	6	14.64%

*Table 3-3 Respondents work experience*

<b>Experience of Respondent</b>	<b>Client</b>	<b>Consultant</b>	<b>Contractor</b>	<b>Total</b>	<b>Percentage</b>
Less than 5 years	4	4	10	18	43.90%
5-9 years	2	6	6	14	34.15%
9-12 years	1	1	2	4	9.76%
Greater than 12 years	3	1	1	5	12.19%

The educational background of the respondents is indicated in Table 3-4. The majority of the respondents, 85.37% have the educational level of BSc degrees. The rest of the respondents have MSc degrees.

*Table 3-4 Education level of the Respondent*

<b>Education</b>	<b>Client</b>	<b>Consultant</b>	<b>Contractor</b>	<b>Total</b>	<b>Percentage</b>
BSc degree	9	9	17	35	85.37%
MSc	1	3	2	6	14.63%

### **3.5. Method of Data Analysis**

#### **3.5.1. Interrelationship between risk factors**

Various research works suggest that the need to consider the dependency between risk factors (Yang, 2007, Ranasinghe and Russell, 1992, Touran and Suphot, 1997, Touran and Lopez, 2006). When dependent risk factors are used to determine the final project cost and time overrun, inaccurate correlations can occur due to the collinearity of variables. However,

the finding of comprehensive literature review revealed that there is no research conducted to determine the interrelationship between different risk factors in construction projects.

Interpretative Structural Modelling (ISM) is a structural analysis tool used to identify and summarize relationship between different variables (risk factors). It is used to structure a set of different directly and indirectly related elements into a comprehensive systematic model (Jha and Devaya, 2008). Nishat Faisal et al. (2006) mentioned the importance of ISM tools to order and structure a complexity of variable relationships. It can easily reveal the interrelationship and hierarchy of risk factors.

In this approach, a systematic application of graph theory is used in such a way that theoretical, conceptual and computational leverages are exploited to explain the complex pattern of contextual relationship among a set of variables. ISM is intended for use when desired to utilize systematic and logical thinking to approach a complex issue under consideration.

Thus, this research uses Interpretative Structural Modelling techniques to develop the interrelationship between different risk factors.

### **3.5.2. Fuzzy Expert System**

Lukasiewicz in the 1920s was the first to propose Fuzzy sets in an attempt to produce systems which were able to represent a range of truth values covering all real numbers from 0 to 1. In the 1960s, Zadeh extended the work on possibility theory into a formal system of mathematical logic for representing and manipulating 'fuzzy' terms, called fuzzy logic.

There are two approaches to construct fuzzy sets; data driven or expert driven. Since this research is based on expert opinion, expert driven fuzzy set construction approach is selected.

A fuzzy expert system is an extension of the classical set theory, i.e. all conclusions derived from the classical set theory remain valid in fuzzy set theory. It uses the degrees of membership in sets rather than strict true/false membership. Using fuzzy logic, sets may be defined on vague, linguistic terms. These terms cannot be defined meaningfully with a precise single value; but fuzzy set theory provides a means by which these terms may be formally defined in mathematical logic. Each element has a value called membership or grade that indicates to what degree the element belongs to the set. A high value, usually in the range of

the real numbers [0:1], indicates a strong membership, and a low value indicates a weak membership. These values reflect a subjective judgement/rating. So, even though the transfer function is in colloquial language quantification it allows for numerically exact output values (Karavezyris et al., 2002).

Hence, the first step in the development of the fuzzy expert system was the creation of a comprehensive list of evaluation criteria. This research used linguistic variables used in describing parameters of construction project risks as an evaluation criterion (Risk Occurrence and Consequence) as shown in Table 3-5 and 3-6.

*Table 3-5 Risk Likelihood Descriptors*

<b>Rating</b>	<b>Description</b>	<b>Likelihood of Occurrence</b>
1	Rare	Highly unlikely, but it may occur in exceptional circumstances. It could happen, but probably never will.
2	Unlikely	Not expected, but there's a slight possibility it may occur at some time
3	Possible	The event might occur at some time as there is a history of causal occurrence in similar institutions.
4	Likely	There is a strong possibility the event will occur as there is a history of frequent occurrence in similar institutions.
5	Almost Certain	Very likely. The event is expected to occur in most circumstances as there is a history of regular occurrence in similar institutions.

*Table 3-6 Risk Consequence Descriptors*

<b>Rating</b>	<b>Description</b>	<b>The Impact of Risks</b>
1	Insignificant	Negligible impact, can be resolved in day-to-day management
2	Minor	Slightly affects the project
3	Moderate	Significant impact on the project
4	Major	Adverse impact and may critically affect the project objective
5	Catastrophic	Disastrous impact on the project objective and may totally fail.

The next step in the development of fuzzy set is creating a membership functions for the variables.

### **A. Estimation of Membership Function**

Membership functions are used to represent linguistic states of a variable. Each element on the relevant scale of a variable is assigned a membership value ranging from 0 (no membership) to 1 (full membership) in each membership function, indicating its degree of belonging in the membership function used to represent the linguistic term.

The form of the membership functions should be reflective of the problem at hand for which the fuzzy sets are constructed. Accordingly, care is taken to mirror the perception of the concepts to be represented and used for this research, the level of details intended to capture, and the context in which the fuzzy expert system is going to be used.

Based on formal assessment of the types of fuzzy set to be used for this research, triangular membership function is found to be suitable due to the appropriateness for most of the risk factors considered in this dissertation.

A triangular fuzzy number A can be defined as a triplet [a, b, c]. Its membership function is defined as:

$$\mu_A(x) = \begin{cases} \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \end{cases}$$

### **B. Fuzzy Set computation**

Since risk magnitude is a multiplication of two factors (occurrence and consequence), a basic multiplication operation is employed.

Multiplication: [a, b] \* [c, d] = [min (ac, ad, bc, bd), max (ac, ad, bc, bd)]

Basically, there exist two fundamental methods to carry out algebraic operations on fuzzy numbers. The first method is based on interval arithmetic and  $\alpha$ -cuts, while the second one employs the extension principle (Pedrycz and Gomide, 2007). In this research, interval arithmetic  $\alpha$ -cut method to perform fuzzy arithmetic is employed because they are important

to develop parametric representation of fuzzy numbers to control their shapes and associated approximation error.

Now, let  $A$  and  $B$  be two fuzzy numbers and let  $*$  be any of the four basic arithmetic operations. Thus, for any  $\alpha \in (0, 1]$  the fuzzy set  $A*B$  is computed using the  $\alpha$ -cuts  $A_\alpha$  and  $B_\alpha$  of  $A$  and  $B$  respectively,

$$(A * B)_\alpha = A_\alpha * B_\alpha$$

Recall that, by definition, the  $\alpha$ -cuts  $A_\alpha$  and  $B_\alpha$  are closed intervals, and therefore the formulas of interval operations can be applied for each value of  $\alpha$ .

If  $A$  and  $B$  are two triangular fuzzy numbers, denoted as  $A(x, a, m, b)$  and  $B(x, c, n, d)$  then their  $\alpha$ -cuts are determined as:

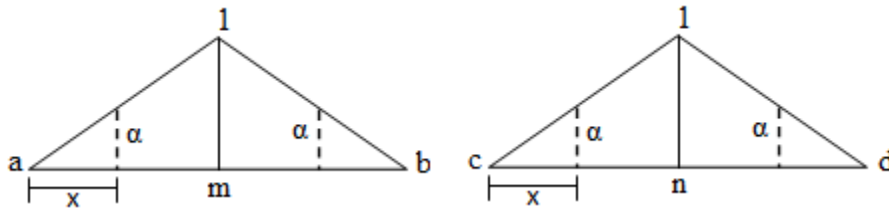


Figure 3-1 Triangular Fuzzy Number

$$A_\alpha = [(m - a)\alpha + a, (m - b)\alpha + b]$$

$$B_\alpha = [(n - c)\alpha + c, (n - d)\alpha + d]$$

### C. Risk magnitude Interpretation

This method focuses on an interval of the Risk Magnitude based on a given  $\alpha$  value. The  $\alpha$  value is equivalent to level of confidence in statistical analysis. For Risk analysis, 85% confidence interval is commonly used in Monte-Carlo simulation based Risk models. After obtaining the two risk magnitude intervals  $z_1$  and  $z_2$ , take the central value of the intervals as the risk magnitude value.

$$Z = \frac{z_1 + z_2}{2}$$

The interpretation of risk magnitude involves a tedious mathematical calculation for all the 51 risk factors identified. Therefore, Microsoft Excel is used as a tool to manipulate the mathematical calculation.

But, considering the risk magnitude alone is not enough for understanding the impact of risks on the project objectives. Rather, it is necessary to study the cascaded effects of risks on the project objectives. Moreover, there are multiple feedback loops in the project operations. Thus, considering the complex interrelated structure of risks resulting from the various feedback processes, System Dynamics (SD) is well suited to perform the risk management process. Hence, in this research a system dynamics-based approach is developed to perform risk analysis and study the effect of each risk factors on the project objectives.

### **3.5.3. System Dynamics**

Forrester (1961), the founder of system dynamics defined SD as the investigation of the information-feedback characteristics of [managed] systems and the use of models for the design of improved organizational form and guiding policy.

SD simulation approach is capable of discovering and representing the feedback processes, which along with stock and flow structures where time delays and nonlinearities determine the dynamics of the system (Sterman, 2000).

Several approaches have been presented in the literature to perform risk analysis phase. However, all of them face one or combination of the following defects (Nasirzadeh et al., 2008b):

- Conventional risk analysis approaches do not consider dynamic nature of risks throughout the life cycle of the project, as well as accounting for feedback loops affecting the overall risk impacts. Due to the systemic nature of risks resulting from cause and effect feedback loops, most of the commonly practiced methods have proved inefficient to assess the actual impact of risks as they do not consider such a systemic nature.
- Traditional risk analysis techniques have not the capability to quantify the full impact of different risks, as they do not consider the indirect effects of risks.

- While potential risk events may have major influences on project cost, time and quality, conventional risk analysis techniques can only assess risk consequences based on their impacts either on the project cost or project time.
- Most of the traditional risk management techniques deal with the risk analysis process from a qualitative point of view.

In comparison to the conventional risk analysis approaches, the SD approach has the capability to quantify the full impact of different risks by considering both direct and indirect effects of each risk through the feedback loop analysis.

SD modelling can be applied adequately to construction domain problems. The reason is that Construction projects (Nasirzadeh et al., 2008b):

- Are extremely complex, consisting of multiple interdependent components
- Are highly dynamic
- Involve multiple feedback processes
- Involve nonlinear relationships
- Involve both hard (quantitative) and soft (qualitative) data.

System dynamics is suited to perform the risk analysis considering the complex interrelated structure of risks resulting from the various feedback processes. Hence, in this research a system dynamics-based approach is developed to perform risk analysis.

System dynamics (SD) has been applied in construction project risk management and qualitative risk analysis (Nasirzadeh et al., 2008c, Nasirzadeh et al., 2014, Nasirzadeh et al., 2008a, Ackermann et al., 2007). Ackermann et al. (2007) mainly describe the approach and highlighted the importance of systematic consideration of risks.

Nasirzadeh et al. (2008a) has efficiently modelled, simulated and quantified different risk factors in construction project in terms of time, cost and quality using system dynamics. However, the model is only risks associated with crashing project duration. The other works of Nasirzadeh et al. (2008c) tries to integrate system dynamics and fuzzy logic modelling for construction risk management using machinery breakdown risk consequences as a demonstration.

Thus, in this research, a causal loops model is constructed using System Dynamics considering all the positive and negative factors influencing the project completion. The phases of the project are modelled and the influences which affect the project objective particularly on the project time and cost are introduced. Emphasis has been given for logical relationship considering different literatures and expert opinion.

The model enables the researcher to easily recognize the deviation of the project objectives caused by each risk factors. The project progress based on time and cost are plotted under normal condition without the effects of the risks. Using the same graph, the time and costs under the influences of risks are plotted which can easily show the effects of risk factors on project objectives. Moreover, by varying the values of individual risk factors, the end effects can be simulated.

Stocks and flows are used to model the flow of work through a project. Stock represent accumulated works and characterize the state of the system and generate the information upon which decisions are based. Flows are the rate of decrease in stocks. Information feedback loops are used to model decisions and project management policies.

The tools used for data analysis of the research are Vensim® PLE.VENSIM® software is applied to system dynamics. It is simulation software developed by Ventana Systems which analyses variable relationships and the structural elements of a diagram using a model equation. It is characterized by a visual output; system behaviour and system status are shown graphically. It is useful for comparative analysis.

### **3.6. Model verification**

According to Sterman (2000), any system dynamics model cannot be validated or verified because all models are limited or simplified representations of the real world. But it is important that the simplified version of the representation must be correctly done. This can only be verified by the experts in the field though it can be subjective.

Hence, the model is verified by the experts in the field of road construction projects. All the relationships between the risk factors and the logic of the project operation are checked and verified by the developed models are applied to measure the deviation of project objectives

(time and cost overrun). Through this process, the feedbacks and valuable inputs of the experts are taken into consideration in model development and results.

### **3.7. Research steps**

The research steps in the conduct of the research are presented in Figure 3-1.

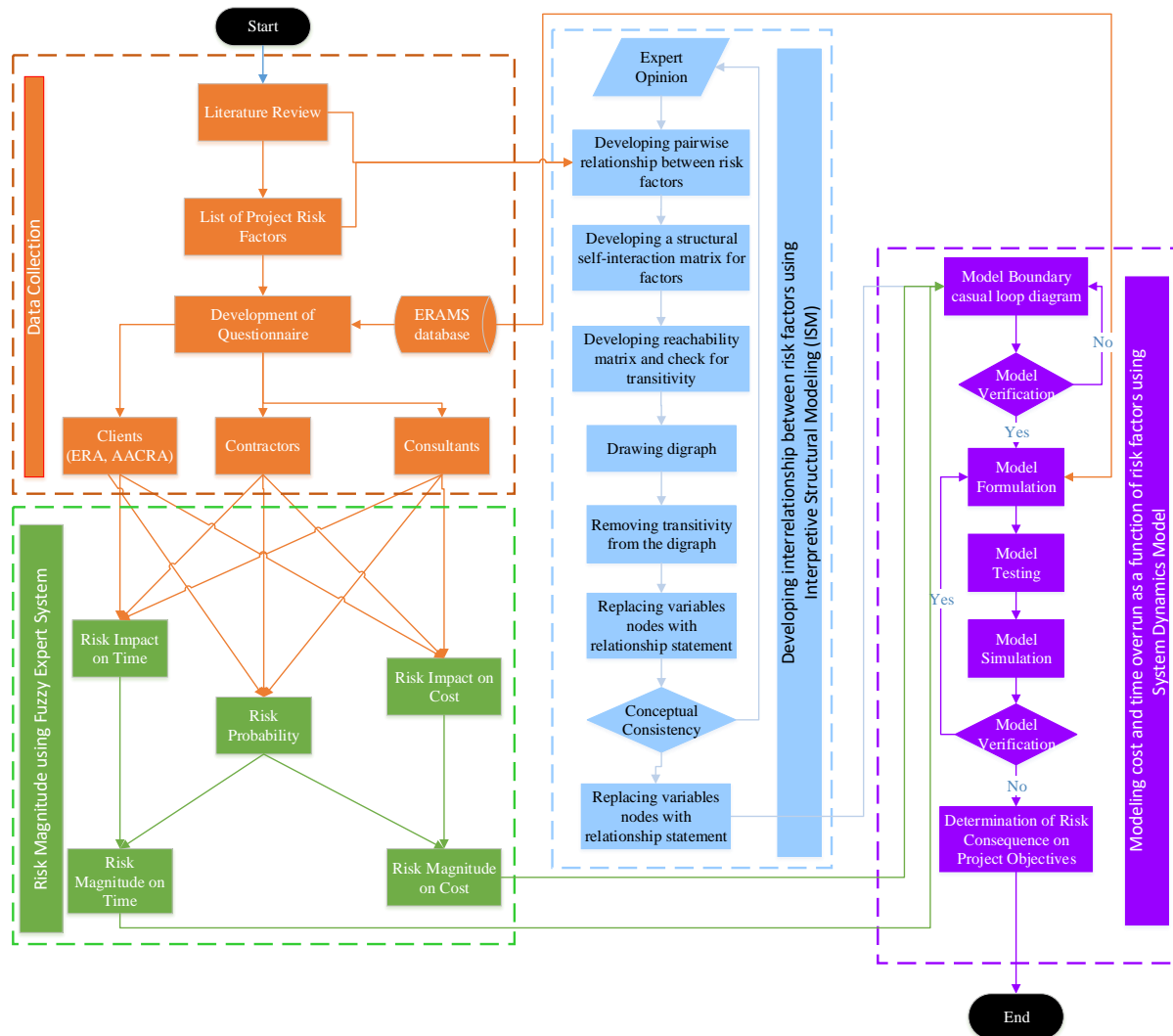


Figure 3-1 Research Steps

### 3.8. Ethical considerations

The use and publication of confidential or commercial-in-confidence project data can be of concern to organizations that have provided the information. This can also limit broader publication of research findings. However, the data compiled for this research were derived from publicly sourced documents and the responses of the individual organizational data were presented anonymously. Thus, there are no ethical considerations required in publishing the data and its subsequent analysis in this dissertation.

### **3.9. Conclusion**

The research methodology reveals the process of identification and analysis of project risks and its impact on project objective particularly on road construction projects within Ethiopia. The adopted methodology for this research includes: literature review on project risks, risk assessment techniques and risk factors. The relationship between the risk factors are developed using high level experts using pairwise comparison matrix and used Interpretative Structural Modelling to systematically develop the interrelationship. Moreover, this research uses questionnaire to rank the risk factors identified from the literature then purified by high level experts. Then the qualitative responses obtained from the questionnaire are analysed by using fuzzy expert system. Finally, system dynamics are used to study the effect of different feedback loop and cascaded effect of the risk factors on project objectives (time and costs).

## Chapter Four Data Analysis and Presentation

### 4.1. Introduction

The research methodology has specified four stages for approaching the research questions. The previous chapter mainly focuses on the research methodology. This chapter answers the first three research questions: *What are the different risk factors associated with road construction projects? What is the interdependencies of different risk factors; Which risk factors are significant for the cost overrun of the road construction projects; and which risk factors are significant for the time overrun of road construction projects?*

To address the first research question, semi-structured interview of experts is used by considering the risk factors obtained from the literature. Moreover, the historical data obtained from the Ethiopian Road Authority was also used. On the other hand, the second research question was addressed by using the identified risk to create a pairwise matrix; the same experts were used to create relationship. Interpretative Structural Modelling is employed as a tool for creating the interrelationship between risk factors

Finally, the third and fourth question is addressed using the results of questionnaires to rank risk factors based on the risk magnitude on the project objective (cost and time). Fuzzy expert is also used as a tool for calculating the risk magnitude.

### 4.2. Risk Identification

Risk identification is a challenging task due to lack of exact procedure and the subjectivity of the risks. Most of the research conducted to identify risk factors is by taking into account the specific sectors and geography of the project. Hence, this research uses experts in the field of road construction to identify risk factors.

The major risk factors that affect the construction project is initially identified through exhaustive literature of section 2.4.1. A total of 51 risk factors obtained from the literature review are used as an input for interviewing the experts. These experts are chosen from different sector of the industry (Owner, contractors and consultants/designers) of the road construction project as indicated in section 3.3.2.

Through the interview, a total of 51 risk factors are identified from different perspectives of the experts as shown in Table 4-1 below.

Table 4-1 Identified risk factors

<b>Risk Factors</b>	
	<b><i>Client related risk factors:</i></b>
1.	Scope changes
2.	Payment delays
3.	Right of way problems
4.	Inadequate site investigation
5.	Schedule pressure by client
6.	Inappropriate intervention by client
7.	Design changes by client
8.	Slow decision making
9.	Slow Site Handover
10.	Clients management ability
	<b><i>Consultant/designer related Risk factors:</i></b>
11.	Design errors
12.	Incomplete design
13.	Poor quality of design
14.	Consultants' lack of experience
15.	Inadequate site information (soil test and survey report)
16.	Inaccurate cost estimation
17.	Design Change
18.	Changes in material types and specifications during construction
19.	Delay in contractor's payment certification by the consultant
20.	Delay in consultant's response to requests for information
21.	Delay in design work
	<b><i>Contractor related risk factors:</i></b>
22.	Poor quality of construction
23.	Contractors' lack of experience
24.	Errors during construction
25.	Unskilled workers
26.	Poor labour productivity
27.	Contractors' poor management capacity
28.	Poor project planning and control
29.	Improper construction methods
30.	Improper Quality control & testing methods
31.	Shortage of plant and equipment
32.	Poor productivity of plant and equipment
33.	Poor site management and supervision
34.	Underestimation of construction costs
35.	Contractual claims, such as, extension of time with cost claims

36.	Low quality of materials
37.	Frequent damage of equipment
	<b><i>Political risk factors</i></b>
38.	Bribery and corruption
39.	Government intervention
40.	Land and property values
	<b><i>Economic risk factors</i></b>
41.	Currency fluctuation
42.	Price inflation of construction materials
43.	Energy cost
44.	Shortage of construction materials in market
	<b><i>Contractual and Legal Risk factors</i></b>
45.	Import restrictions
46.	Contract modifications (addition of new work to the project and change in specification)
47.	Mistakes and discrepancy in contract documents
	<b><i>Environmental risk factors</i></b>
48.	Forced majeure
49.	Weather conditions
50.	Poor site conditions (Location, ground, etc.)
51.	Pollution caused by construction (water, air & noise)

### **4.3. Identification of the interrelationship between risk factors**

Once the risk factors are identified, the need to determine the dependency/ interrelationship between risk factors accurately is highly important. Though there are various research works to determine the effects of individual risk factors on the cost and time overrun of the project, the result obtained from analysing the individual risk factors is different from the effects due to multifaceted risk factors if one risk factor is also dependent on others. Experts in the field agreed that all risk factors are not independent at all. There are factors that can be influenced/triggered by other risk factors. This will amplify the final time and cost overrun of the project as compared to the results obtained from the individual risk factors.

This research uses experts in the field of road construction to identify the dependency/interrelationship between different risk factors. Lists of risk factors obtained from literature review are used and grouped into two (effect on scope and productivity) based on the impact on the project. Then, experts from different group of stakeholders are used based on experiences and educational background to initially understand the relationship between different risk factors using pairwise relationship. However, this is not enough to exhaustively classify the risks as dependent and independent risks. Therefore, a systematic

way of identifying the different levels of risk factors is essential. Hence, Interpretative Structural Modelling is found to be useful to systematically categorize and structure the interrelationship between different risk factors.

The use of expert opinion is necessary for the ISM method through different techniques. Therefore, this study uses six experts through interview from different category of the projects, i.e. owners, contractors and consultants to develop the contextual relationship between different variables. The risk factors obtained from literature and refined by the experts are 51.

Experts with an experience of at least a project manager in road construction projects are consulted for developing the contextual relationship. The examined relationship is that whether one risk factor can trigger another factor in the lists.

The results of the Structural Self Interacting Matrix (SSIM) revealed that, there are two distinct groups of risk factors where some of them can be common for both. Therefore, the subsequent analysis of Interpretative Structural Modelling can be divided into two. The first group of risk factors are related to the rate of progress of the project. Likewise, the second group of the risk factors are those risk factors that affect the contents of the tasks (Scope). To easily identify these two groups the first group is named as productivity-related risk factors, and the other group scope-related risk factors.

Structural self-interaction matrix (SSIM) is a matrix of pairwise contextual relationship between different risk factors obtained from experts' interview of owners, contractors and consultants. Table 4-2 and 4-3 reveal the SSIM or risk factors related to productivity and scope respectively.

Four symbols are used to denote the direction of relationship between the variables (i and j):

- →: risk factor i will trigger risk factor j;
- ←: risk factor k will trigger risk factor i;
- O: risk factor i and j will trigger each other; and
- X: risk factor i and j are unrelated.

Table 4-2 Structural self-interaction matrix (SSIM) of Risk factors related to productivity

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Unskilled labour		←	x	x	x	x	x	X	x	x	x	x	x	x	→	x	x	x	x	x	→	x	x	x	x	x	x	x
2	Labour Unavailability			x	x	X	x	x	X	x	x	x	x	x	x	x	x	x	x	x	x	→	x	x	x	x	x	x	x
3	land and property value				x	X	x	x	X	x	x	x	x	x	x	x	x	x	x	x	x	x	→	x	x	x	x	x	x
4	weather condition					X	x	x	X	x	x	x	x	x	x	x	x	x	x	x	x	x	→	x	x	x	x	x	x
5	poor site condition						x	x	X	x	x	x	x	x	x	x	x	x	x	x	x	x	→	x	x	x	x	x	x
6	inadequate site investigation							x	X	x	x	x	x	x	x	x	x	x	x	x	x	x	→	x	→	→	→	x	x
7	slow decision making								→	x	x	x	x	x	x	x	x	x	x	x	x	x	→	←	←	x	x	x	x
8	payment delay									←	→	x	x	x	x	x	x	x	x	x	x	x	→	x	x	x	x	x	x
9	delay in contractors' payment certification by consultant										x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
10	slow site handover											x	x	x	x	x	x	x	x	x	x	x	→	←	x	x	x	x	x
11	delay in consultants' response to requested information												x	x	x	x	x	x	x	x	x	→	x	→	x	x	x	x	x
12	frequent damage of equipment													x	→	x	x	x	x	x	x	x	x	x	x	x	x	x	x
13	shortage of plant and equipment														→	x	x	x	x	x	x	x	x	x	x	x	x	x	x
14	productivity of plant and equipment															x	x	x	x	x	x	→	x	x	x	x	x	x	x
15	poor labour productivity																x	x	x	x	x	→	x	x	x	x	x	x	x
16	inappropriate intervention by client																	←	x	x	x	→	x	x	x	x	x	x	x
17	schedule pressure																		x	x	x	x	x	x	x	x	x	x	x
18	poor project planning																			x	x	→	x	x	x	x	x	x	x
19	improper quality control and testing																				x	→	x	x	x	x	x	x	x
20	improper construction methods																					→	x	x	←	←	x	x	x
21	productivity																						←	←	←	←	←	x	x
22	Right of ways																							←	x	x	x	x	x
23	delay in design work																								←	x	←	←	x
24	design error																									x	←	←	x
25	incomplete design																										←	←	x
26	Poor quality of design																											←	x
27	designers lack of experience																												←
28	Bribery and corruption																												

Table 4-3 Structural self-interaction matrix (SSIM) of Risk factors related to scope growth

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33		
1	Bribery and Corruption		→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	
2	Consultant's lack of experience			X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
3	Client management ability				X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
4	Heavy flood, landslide,					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
5	weather condition						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
6	poor site condition							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
7	pollution caused by construction								X	X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
8	poor project planning and control									X	X	X	X	X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
9	shortage of construction material										X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
10	import restriction											X	→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
11	low quality of material												→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
12	change in material type													X	X	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	
13	inadequate site investigation														←	X	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	X
14	inadequate site information															→	X	X	X	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	X
15	Incomplete design																←	→	→	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
16	poor quality of design																	→	→	X	X	X	→	X	X	X	X	X	X	X	X	X	X	X	X	X
17	design error																		→	X	X	X	→	X	X	X	X	X	X	X	X	X	X	→	X	X
18	design change																				X	←	X	→	X	X	X	X	X	X	X	X	X	X	X	
19	contract modification																					X	X	→	X	X	X	X	X	X	X	X	X	X	X	
20	Client intervention																						X	→	X	X	X	X	X	X	X	X	X	X	X	
21	government intervention																							→	X	X	X	X	X	X	X	X	X	X	X	X



Once the Structural self-interaction matrix (SSIM) is developed, the next step is to transform it into a binary matrix which is called Reachability matrix. This is done by substituting symbol into either 1's or 0's based on the following rules:

- If the (i, j) entry in the SSIM is  $\rightarrow$ , then the (i, j) entry in the reachability matrix becomes 1 and (j, i) entry becomes 0;
- If the (i, j) entry in the SSIM is  $\leftarrow$ , then the (i, j) entry in the reachability matrix becomes 0 and (j, i) entry becomes 1;
- If the (i, j) entry in the SSIM is O, then the (i, j) entry in the reachability matrix becomes 1 and (j, i) entry becomes 1; and
- If the (i, j) entry in the SSIM is X, then the (i, j) entry in the reachability matrix becomes 0 and (j, i) entry becomes 0;

The initial reachability matrix for the two groups of risk factors (productivity and scope growth related) are presented in Table 4-4 and 4-5 respectively.

The final reachability matrix is constructed considering the transitivity of contextual relationship between risk factors. The transitivity states that if a variable A is related to B and B is related to C, then A is necessarily related to C. Following this, the final reachability matrix is constructed in Table 4-6 and 4-7 respectively.

Table 4-4 Initial Reachability Matrix of risk factors related to Productivity

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Unskilled labour	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
2	Labour Unavailability	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
3	land and property value	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
4	weather condition	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
5	poor site condition	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
6	inadequate site investigation	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0
7	slow decision making	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
8	payment delay	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
9	delay in contractors' payment certification by consultant	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	slow site handover	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
11	delay in consultants' response to requested information	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
12	frequent damage of equipment	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	shortage of plant and equipment	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	productivity of plant and equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
15	poor labour productivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0
16	inappropriate intervention by client	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
17	schedule pressure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
18	poor project planning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
19	improper quality control and testing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
20	improper construction methods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
21	productivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
22	Right of ways	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
23	delay in design work	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0
24	design error	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0
25	incomplete design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0
26	Poor quality of design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	0
27	designers lack of experience	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
28	Bribery and corruption	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Table 4-5 Initial Reachability Matrix of risk factors related to Scope growth

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
1	Bribery and Corruption	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2	Consultant's lack of experience	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Client management ability	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4	Heavy flood, landslide,	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5	weather condition	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6	poor site condition	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	pollution caused by construction	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	poor project planning and control	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
9	shortage of construction material	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	import restriction	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	low quality of material	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	change in material type	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
13	inadequate site investigation	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	inadequate site information	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	Incomplete design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	poor quality of design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
17	design error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
18	design change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
19	contract modification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	Client intervention	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
21	government intervention	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
22	scope change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0
23	Currency Fluctuation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
24	Inflation of Construction material	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0
25	Inaccurate Cost estimation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0
26	Underestimation of construction cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0



Table 4-6 Final Reachability Matrix of risk factors related to Productivity

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28
1	Unskilled labour	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
2	Labour Unavailability	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
3	land and property value	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
4	weather condition	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
5	poor site condition	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
6	inadequate site investigation	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
7	slow decision making	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
8	payment delay	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
9	delay in contractors' payment certification by consultant	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
10	slow site handover	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
11	delay in consultants' response to requested information	0	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
12	frequent damage of equipment	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
13	shortage of plant and equipment	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
14	productivity of plant and equipment	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
15	poor labour productivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0
16	inappropriate intervention by client	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0
17	schedule pressure	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0
18	poor project planning	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0
19	improper quality control and testing	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
20	improper construction methods	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
21	productivity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
22	Right of ways	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
23	delay in design work	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
24	design error	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0
25	incomplete design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0
26	Poor quality of design	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
27	designers lack of experience	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	0
28	Bribery and corruption	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1

Table 4-7 Final Reachability Matrix of Risk Factors related to Scope growth

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	
1	Bribery and Corruption	1	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	1	1	1	1	1	1	1	1	1	0	0
2	Consultant's lack of experience	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	0
3	Client management ability	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
4	Heavy flood, landslide, weather condition	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5	poor site condition	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
6	pollution caused by construction	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
7	poor project planning and control	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
8	shortage of construction material	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
9	import restriction	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
10	low quality of material	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
11	change in material type	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
12	inadequate site investigation	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
13	inadequate site information	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
14	Incomplete design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
15	poor quality of design	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
16	design error	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0
17	design change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
18	contract modification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
19	Client intervention	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	government intervention	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
21	scope change	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0
22	Currency Fluctuation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0

24	Inflation of Construction material	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0
25	Inaccurate Cost estimation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	
26	Underestimation of construction cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0		
27	Contractors' lack of experience	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	
28	Contractual Claim (Extension of time/cost)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0		
29	Contractors' poor management capacity	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1	1	0	0	
30	Poor site management and supervision	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0		
31	Error during construction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0		
32	Poor quality of construction	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	
33	Improper Quality Control	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0

The level of the matrix is determined from the intersection between the reachability and antecedent set obtained from the final reachability matrix. The reachability set describes the risk factors itself and the other risk factors which it may impact, while the antecedent set describes the risk factor itself and other factors which may impact on it.

Thus, the intersection between these two sets are derived for all the risk factors. Based on ISM technique, the risk factors for which the intersection set is the subset of antecedent set occupy the top level in the hierarchy of ISM. This means that the top-level risk factors would not trigger any other risk factors above its own level. Next, the top-level risk factors will be excluded from the two sets and the same process is repeated to determine the successive level of risk factors. Table 4-8 and 4-9 reveal the level of risk factors for the two groups of reachability matrix.

Table 4-8 Level of Risk Factors related to Productivity

Factors	Reachability set	Antecedent Set	Intersection set	Level
Unskilled labour	1, 15, 21	1, 2	1	Level III
Labour Unavailability	1, 2, 15, 21	2	2	Level IV
land and property value	3, 10, 22	3	3	Level IV
weather condition	4, 10, 22	4	4	Level IV
poor site condition	5, 10, 22	5	5	Level IV
inadequate site investigation	6, 7, 8, 10, 20, 21, 22, 23, 24, 25, 26	6	6	Level IX
slow decision making	7, 8, 10, 21, 22	6, 7, 11, 23, 24, 26, 27, 28	7	Level V
payment delay	8, 10, 21, 22	6, 7, 8, 9, 11, 23, 24, 26, 27, 28	8	Level IV
delay in contractors' payment certification by consultant	8, 9, 10, 21, 22	9	9	Level V
slow site handover	10, 21	3, 4, 5, 6, 7, 8, 9, 10, 11, 22, 23, 24, 26, 27, 28	10	Level II
delay in consultants' response to requested information	7, 8, 10, 11, 21, 22, 23	11	11	Level VII
frequent damage of equipment	12, 14, 21	12	12	Level III
shortage of plant and equipment	13, 14, 21	13	13	Level III
productivity of plant and equipment	14, 21	12, 13, 14	14	Level II
poor labour productivity	15, 21	1, 2, 15	15	Level II
inappropriate intervention by client	16, 21	16, 17	16	Level II
schedule pressure	16, 17, 21	17	17	Level III
poor project planning	18, 21	18	18	Level II
improper quality control and testing	19, 21	19	19	Level II
improper construction methods	20, 21	6, 20, 24, 25, 26, 27, 28	20	Level II
productivity	21	1, 2, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28	21	Level I
Right of ways	10, 21, 22	3, 4, 5, 6, 7, 8, 9, 11, 22, 23, 24, 26, 27, 28	22	Level III
delay in design work	7, 8, 10, 21, 22, 23	6, 11, 23, 24, 26, 27, 28	23	Level VI
design error	7, 8, 10, 20, 21, 22, 23, 24	6, 24, 26, 27, 28	24	Level VII
incomplete design	20, 21, 25	6, 25, 26, 27, 28	25	Level III
Poor quality of design	7, 8, 10, 20, 21, 22, 23, 24, 25, 26	6, 26, 27, 28	26	Level VIII

designers lack of experience	7, 8, 10, 20, 21, 22, 23, 24, 25, 26, 27	27, 28	27	Level IX
Bribery and corruption	7, 8, 10, 20, 21, 22, 23, 24, 25, 26, 27, 28	28	28	Level X

*Table 4-9 Level of Risk Factors related to Scope growth*

<b>Risk Factors</b>	<b>Reachability set</b>	<b>Antecedent Set</b>	<b>Intersection set</b>	<b>Level</b>
Bribery and Corruption	1, 2, 15, 17, 18, 22, 24 25, 26, 27, 28, 29, 30, 31	1	1	Level VII
Consultant's lack of experience	2, 15, 17, 18, 22, 28, 31	1, 2	2	Level VI
Client management ability	3, 22	3	3	Level III
Heavy flood, landslide,	4, 22	4	4	Level III
weather condition	5, 22	5	5	Level III
poor site condition	6, 22	6	6	Level III
pollution caused by construction	7, 22	7	7	Level III
poor project planning and control	8, 22	8	8	Level III
shortage of construction material	9, 12, 22	9	9	Level IV
import restriction	10, 12, 22	10	10	Level IV
low quality of material	11, 12, 22	11	11	Level IV
change in material type	12, 22	9, 10, 11, 12	12	Level III
inadequate site investigation	13, 22	13, 14	13	Level III
inadequate site information	13, 14, 15, 22	14	14	Level VI
Incomplete design	15, 17, 18, 22	1, 2, 14, 15, 16	15	Level V
poor quality of design	15, 16, 17, 18, 22	16	16	Level VI
design error	17, 18, 22, 28, 31	1, 2, 15, 16, 17	17	Level IV
design change	18, 22	1, 2, 15, 16, 17, 18, 20	18	Level III
contract modification	19, 22	19	19	Level III
Client intervention	20, 22	20	20	Level III
government intervention	21, 22	21	21	Level III
scope change	22, 28	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22	22	Level II

Currency Fluctuation	23, 24, 28	23	23	Level III
Inflation of Construction material	24, 28	1, 23, 24	24	Level II
Inaccurate Cost estimation	25, 28	1, 25, 26, 27, 29	25	Level II
Underestimation of construction cost	25, 26, 28	1, 26, 27, 29	26	Level III
Contractors' lack of experience	25, 26, 27, 28, 29, 30, 31	1, 27	27	Level V
Contractual Claim (Extension of time/cost)	28	1, 2, 17, 22, 23, 24, 25, 26, 27, 28, 29, 31	28	Level I
Contractors' poor management capacity	25, 26, 28, 29, 30, 31	1, 27, 29	29	Level IV
Poor site management and supervision	30, 31	1, 27, 29, 30	30	Level III
Error during construction	28, 31	1, 2, 17, 27, 29, 30, 31, 32, 33	31	Level II
Poor quality of construction	31, 32	32, 33	32	Level III
Improper Quality Control	31, 32, 33	33	33	Level IV

The level of the factors, identified for Owners, Consultants and Contractors above are used to depict the interrelationship between risk factors. The ISM model is used to structure the risk factors for the project stakeholders hierarchically in a way that risk factors with no influence on the other risk factors will be categorized in the first level and risk factors with the highest influences considering the transitivity will be placed in the last level.

The results of Interpretative Structural Modelling are discussed in Chapter Five.

#### 4.4. Analysis of Risk Factors Using Fuzzy Expert System

Once the interrelationship between the risk factors are identified, the next process is ranking the risk factors based on their magnitude. The magnitude of the risk factor is determined using fuzzy expert system.

The fuzzy set can be constructed first by converting a crisp set of input data gathered into fuzzy set using fuzzy linguistic variables, fuzzy linguistic terms and membership functions as discussed in section 3.5.2 and then mapping the fuzzy output to a crisp output using membership functions.

A Membership Function (MF) is a function that specifies the degree to which a given input belongs to a set, and its value is always limited between 0 and 1; and are used in the fuzzification and defuzzification steps of a FLS (fuzzy logic system), to map the non-fuzzy input values to fuzzy linguistic terms and vice versa.

Since horizontal scheme of membership estimation is selected, the first step is to obtain the membership value of each risk factor. For instance, the risk factor “right of way” is considered for demonstration of membership function;

$(R_3)$  = right of way

Then the membership value is given by:

$$A(R_3) = \frac{P_{R3}}{N} \dots\dots\dots [Equation 4.1]$$

Where,  $A(x_i)$  = Membership value of  $R_1 - R_{49}$

$$\frac{P_{xi}}{N} = \text{Number of positive responses of } R_1 - R_{49}$$

N = Total number of responses (10 respondents from client, 12 respondents from consultant and 19 respondents from Contractor)

For the case of risk assessment from the contractor’s perspective, 41 respondents gave their responses. As shown in Table 4-7, none of the respondents believe that the occurrence of R<sub>3</sub> (right of way) problem is rare. That means, R<sub>3</sub> has “zero” positive or “yes” replies for rare occurrence. Thus, the corresponding Membership value is zero.

On the other hand, twenty-three respondents believe that the probability of R<sub>3</sub> occurring is “Almost certain”. That means, R<sub>3</sub> for “Almost certain” occurrence has “twenty-three” positive or “yes”. Thus, the corresponding Membership value is  $\frac{23}{41} = 0.561$ . The membership

functions between “no” and “yes” value is computed and presented in Table 4-6. Likewise, the corresponding impact of risk factors on the project objective (time and cost overrun) are summarized in the Table 4-8.

*Table 4-4 Membership values for Probability of occurrence of Risk Factor (R<sub>3</sub>)*

<b>Scale</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
<b>No. of respondents</b>	0	2	7	9	23
<b>A(R<sub>3</sub>)</b>	0	0.049	0.171	0.22	0.561

*Table 4-5 Membership values for Impact of Risk Factor (R<sub>3</sub>) on time and cost*

	<b>Time</b>					<b>Cost</b>				
<b>Scale</b>	1	2	3	4	5	1	2	3	4	5
<b>No. of respondents</b>	0	0	12	10	19	0	5	11	7	18
<b>A(R<sub>3</sub>)</b>	0	0	0.293	0.244	0.463	0	0.122	0.268	0.171	0.439

A membership function (MF) is a curve that defines how each point in the input space is mapped to a membership value (or degree of membership) between 0 and 1. Hence, in order to express the membership values in fuzzy set between 0 and 1 each value in Table 4-9 are normalized using Max-Min principle.

$$A(R_3N) = \frac{A(R_3)}{Max.Value} \dots\dots\dots [\text{Equation 4.2}]$$

Table 4-6 Normalized Membership value of Risk Factor (R3) occurrence

	Occurrence				
<b>A(R<sub>3</sub>)</b>	0	0.049	0.171	0.22	0.561
<b>A(R<sub>3</sub>N)</b>	0	0.087	0.304	0.391	1

Table 4-7 Normalized Membership value of Risk Factor (R3) Impact on Time and Cost

	Time					Cost				
<b>A(R<sub>3</sub>)</b>	0	0	0.293	0.244	0.463	0	0.122	0.268	0.171	0.439
<b>A(R<sub>3</sub>N)</b>	0	0	0.632	0.526	1	0	0.278	0.611	0.389	1

The remaining risk factors membership functions are estimated following the procedure and the summary of each risk factor is presented in Appendix II.

The next step is to approximate the curves to triangular membership function with to approximately fit triangular shapes with parameter a, b, c, d (b = c for triangular fit). However, the relative error between the approximate and actual values has to be calculated, and it has to be checked whether the error lies within a certain confidence interval. In cases where there are more options of approximation for the normalized responses, the best approximation can be selected by calculating the error, and the one with lesser error can be selected. The error and confidence interval for each risk factor can be calculated by using the following formula:

$$\text{Error} = \frac{\text{Actual Value} - \text{Approximate Value}}{\text{Actual Value}} \dots\dots\dots [\text{Equation 4.3}]$$

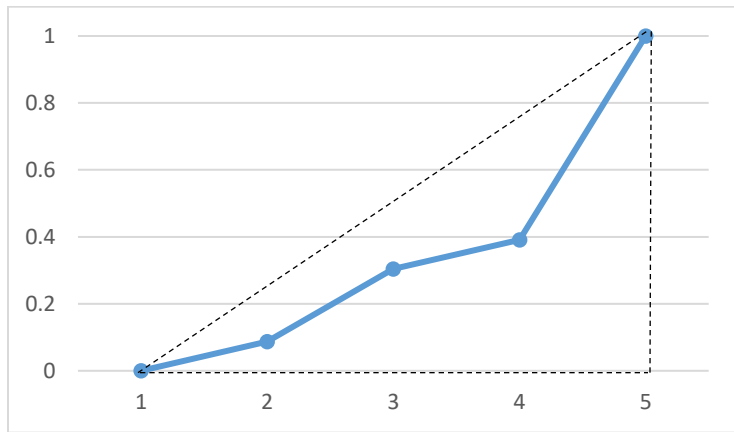


Figure 4-1 Approximation of Triangular Membership Function

Table 4-8 Values used for Error Calculation

Item	Rare	Unlikely	Possible	Likely	Almost Certain
Scale	1	2	3	4	5
Actual Value	0	0.087	0.304	0.391	1
Approximate value	0	0.25	0.50	0.75	1
Error	0	33.03	0.645	0.918	0
Average Error	6.919				

The error and confidence interval are calculated for all normalized responses of each risk factors.

$$\text{Confidence Interval} = \bar{X} \pm Z\sigma \dots\dots\dots [\text{Equation 4.4}]$$

Where,  $\bar{X}$  = mean of actual normalized values

$\sigma$  = standard deviation of actual normalized values

Z = Confidence coefficient

The desired confidence level has to be chosen before calculating the confidence coefficient. The most commonly used confidence levels are 90%, 95% and 99%. The confidence coefficient is calculated with 95% confidence level in this research for likelihood of occurrence, and for impact on cost and time. The result shows that all errors lie within the confidence intervals. For cases where there are two or more approximation options, the approximate value with the lesser error is taken. The normalized and approximate values, and the calculated errors and confidence intervals are included in Appendix III.

As it is mentioned in section 3.5.2, the  $\alpha$ -cuts method of algebraic operation of fuzzy number is suitable to develop the parametric presentation of fuzzy numbers to control their shapes and associated approximation. Hence,  $\alpha$ -cuts methods are used for fuzzy set computation.

An  $\alpha$ -cut of a fuzzy set A, denoted by  $A_\alpha$ , is a set consisting of the elements of the universe whose membership values are equal to or exceed a certain threshold level where  $\alpha \in \{0,1\}$  (Pedrycz and Gomide, 2007).

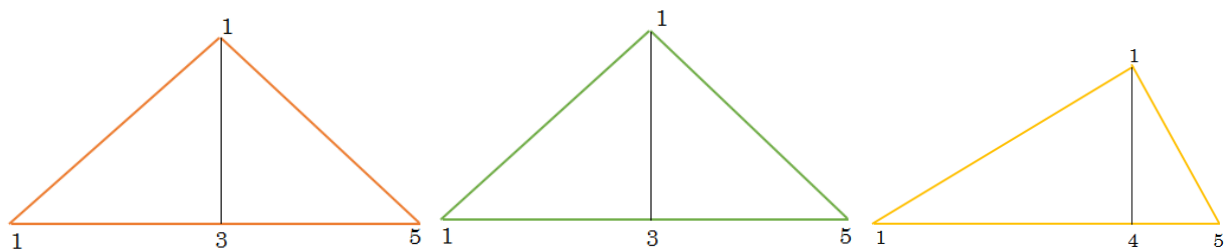
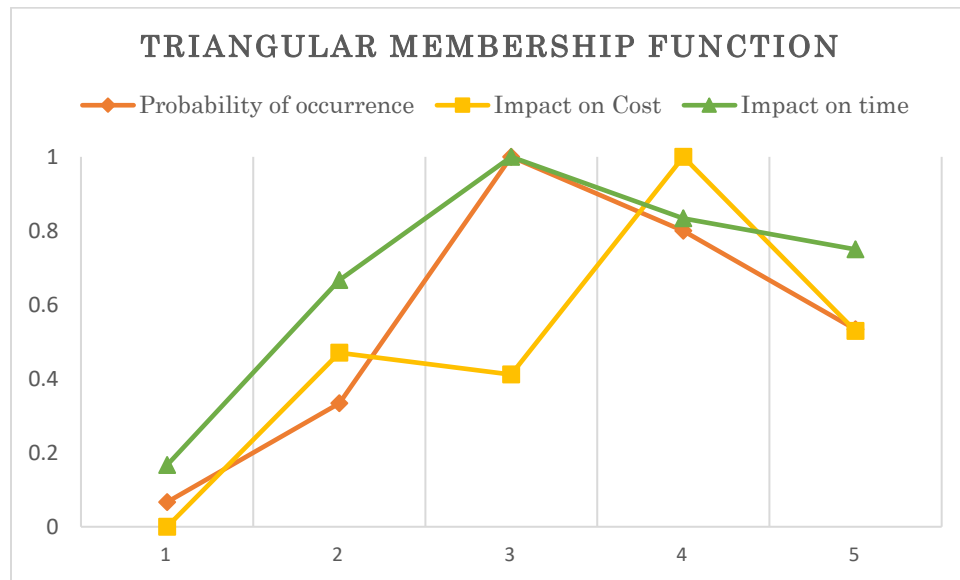
$$A_\alpha = [(m - a)\alpha + a, (m - c)\alpha + c] \dots\dots\dots [\text{Equation 4.5}]$$

$$B_\alpha = [(n - d)\alpha + d, (n - f)\alpha + f] \dots\dots\dots [\text{Equation 4.6}]$$

$$Ca = [(1 - g)\alpha + g, (1 - i)\alpha + i] \dots \dots \dots \text{[Equation 4.7]}$$

Since risk magnitude is a function of its likelihood of occurrence and its corresponding effect on project time/cost, a basic multiplication was developed to perform the arithmetic operations. Thus, the multiplication of the likelihood of occurrence (A) with the impact on cost of the project (B) and with the impact on time of the project (C) gives the risk magnitude on time and cost of the project respectively.

Among the 87 risk factors, inadequate site investigation is used for demonstrating multiplication of the probability of occurrence of risk with the triangular membership function of (1, 3, 5), and the corresponding impact on time (1, 3, 5) and cost (1, 4, 5) of the project as follows.



(A) Probability of Occurrence

(B) Impact on Time

(C) Impact on Cost

Figure 4-2 Best Fit Triangular Membership Function for Inadequate Site Investigation

$$A\alpha = [(3-1)\alpha + 1, (3-5)\alpha + 5] = [2\alpha + 1, -2\alpha + 5]$$

$$B\alpha = [(3-1)\alpha + 1, (3-5)\alpha + 5] = [2\alpha + 1, -2\alpha + 5]$$

$$C\alpha = [(4-1)\alpha + 1, (4-5)\alpha + 5] = [3\alpha + 1, -\alpha + 5]$$

The magnitude of risks on project schedule is:

$$\begin{aligned} A\alpha \times B\alpha &= [2\alpha + 1, -2\alpha + 5] \times [2\alpha + 1, -2\alpha + 5] \\ &= [\min\{4\alpha^2 + 4\alpha + 1, 4\alpha^2 - 20\alpha + 25\}, \max\{4\alpha^2 + 4\alpha + 1, 4\alpha^2 - 20\alpha + 25\}] \end{aligned}$$

The magnitude of risks on project cost is:

$$\begin{aligned} A\alpha \times C\alpha &= [2\alpha + 1, -2\alpha + 5] \times [3\alpha + 1, -\alpha + 5] \\ &= [\min\{6\alpha^2 + 5\alpha + 1, 2\alpha^2 - 15\alpha + 25\}, \max\{6\alpha^2 + 5\alpha + 1, 2\alpha^2 - 15\alpha + 25\}] \end{aligned}$$

As it is explained in section 3.5.2. C, this research uses 85% confidence interval for  $\alpha$ -value for  $\alpha$ -value. Thus, the two equations give the Min and Max value which is regarded as the range of the risk magnitude.

$$A\alpha \times B\alpha = [7.29, 10.89]$$

$$A\alpha \times C\alpha = [9.585, 13.695]$$

Based on section 3.5.2 c, the central value of the interval is calculated to find the risk magnitude.

$$\text{Central value (time)} = (7.29 + 10.89)/2 = 9.09$$

$$\text{Central value (Cost)} = (9.585 + 13.695)/2 = 11.64$$

The rating scale for both likelihood of occurrence, impact on time and cost are out of 5. Therefore, the result of the central value for risk magnitude shown above is out of 25. The minimum and maximum value of the multiplication is 1 and 25 respectively. Therefore, the percentage value of the risk magnitude is obtained by dividing the central value by 25.

$$\text{Risk magnitude (time)} = 9.09/25 = 0.3636$$

$$\text{Risk magnitude (Cost)} = 11.64/25 = 0.4656$$

Based on the above steps, each risk magnitude is calculated for all risk factors obtained from risk identification.

The magnitude of the individual risk factors with the time and cost of the project is presented and discussed in chapter five.

#### **4.5. Conclusion**

This chapter discussed the data analysis techniques used for the questionnaire and the pairwise relationship obtained from experts. The interrelationship between the risk factors are conducted using Interpretative Structural Modelling by dividing the risk factors into two major groups namely productivity and scope growth related risk factors. Each group has 33 risk factors where some risks are common for both groups.

On the other hand, the questionnaire has been analysed using fuzzy expert system. The techniques and steps used for fuzzy expert system is presented in this chapter step by step for determining the risk magnitude on both cost and time overrun of the project.

## Chapter Five Results and Discussion

### 5.1. Introduction

The previous chapter mainly dealt with the data collection and analysis techniques used in this dissertation. This chapter discusses the results obtained from the data analysis specifically on the interrelationship between risk factors and risk ranking.

### 5.2. Interrelationship between risk factors

The result of the ISM model for scope growth related risk as shown in Figure 5-1 revealed that four risk factors are the immediate predecessors of level I risk factor which is the scope growth. The contractual claim is the first level of the hierarchy. The four risk factors (Scope change, errors during construction, inaccurate cost estimation and inflation of construction materials) are the risk factors that affect contractual claim risks. These four risk factors are grouped into level II of the hierarchy in the interrelationship between the risk factors. However, the occurrence of these four risk factors is also dependent on other risk factors.

Among the level II risk factors is scope change. The scope change is also dependent on twelve risk factors (government intervention, inadequate site investigation, change in material type, client manageability, forced majeure such as landslide, flood or earthquake, poor site condition, pollution caused by construction, poor project management, contract modification, client intervention and design change). Among these risk factors only two of them (Change in material type and design change) are dependent on other risk factors. The other ten risk factors are considered as an exogenous risk factors. All these risks are grouped into level III.

Change in material type and design change are affected by other risk factors. i.e. the two risk factors can be triggered by the occurrence of other risk factors. Three risk factors (import restriction, shortage of construction material and low quality of material) affect the change in material type risk factor. Likewise, the design change occurs because of the design error risk factor. Thus, the three risk factors affecting the change in material type and design error are level IV in the ISM diagram.

However, the risk factor design error is dependent on other risk factor namely incomplete design. Therefore, incomplete design is level V. Again, incomplete design is a dependent risk factor on three different risk factors (poor quality of design, inadequate site investigation and

consultants' lack of experience) which are level VI in the diagram. Among these, poor quality of design and inadequate site information are exogenous risk factors. Exogenous risk factors are independent of other risk factors. Thus, all the above risk factors related to this risk factor are endogenous risk factors. However, the risk factor Consultants' lack of experience are dependent of bribery and corruption named as level VII.

The risk factor error during construction is dependent on the risk factors poor quality of construction and poor site management and supervision. These two risk factors are included in level II of the structure. Poor quality of construction is dependent on improper quality control which is an exogenous risk factor.

On the other hand, the risk factor inaccurate cost estimation is determined by underestimation of construction costs. However, both the risk factor poor site management and supervision and underestimation of construction cost are dependent on contractors' poor management capacity. Both Improper quality control and contractors' poor management capacity are in level IV of the structure. But the risk factor contractors' poor management capacity is dependent on contractors' lack of experience which is located in level V. The contractors' lack of experience risk factor is in turn affected by the bribery and corruption risk factors.

The last risk factor affecting the contractual claim risk is inflation of construction material and grouped in level II of the structure. But this risk factor is also affected by level III of the risk factor namely currency fluctuation.

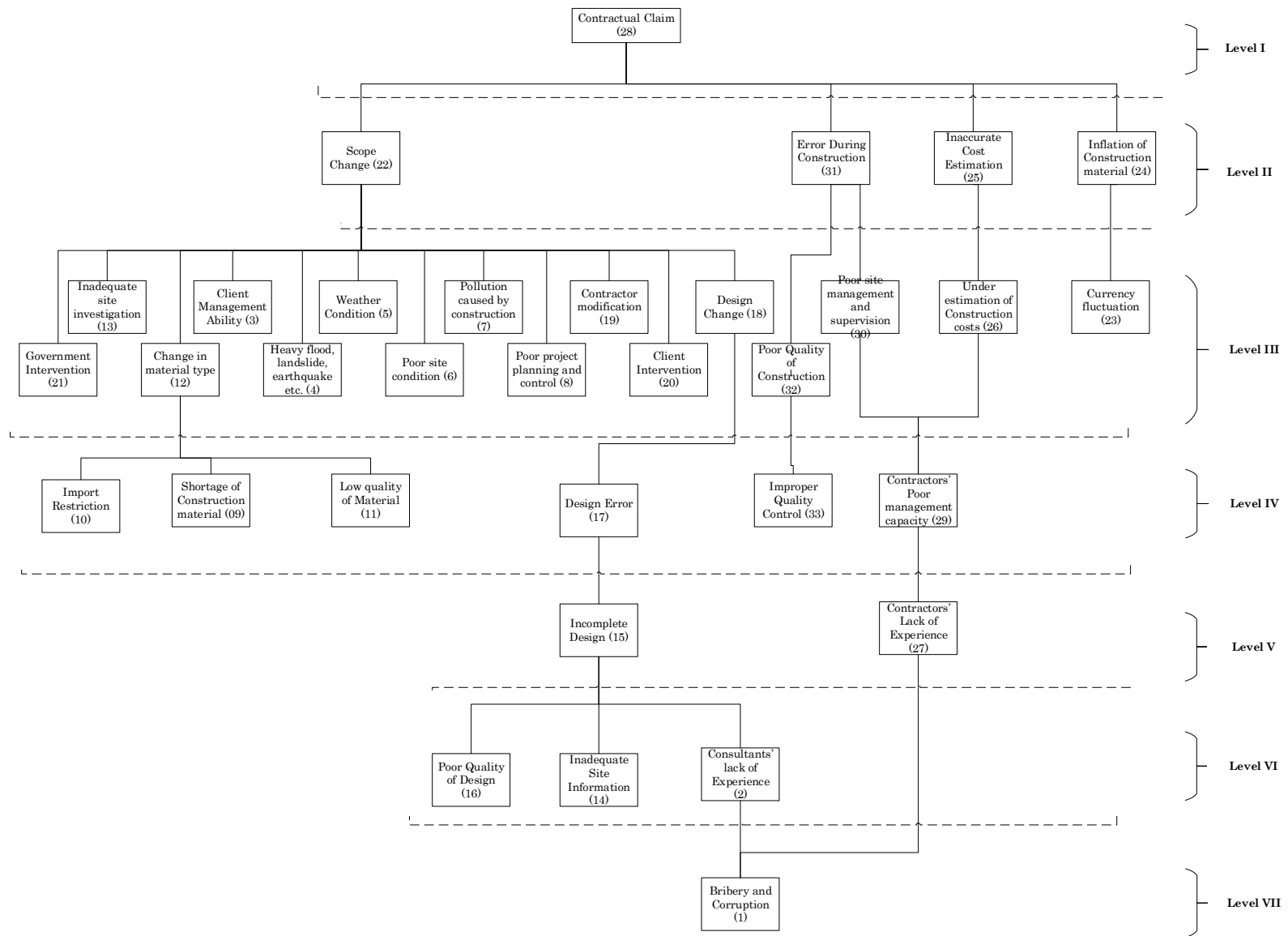


Figure 5-1 Relationship diagram of risk factors under Scope growth

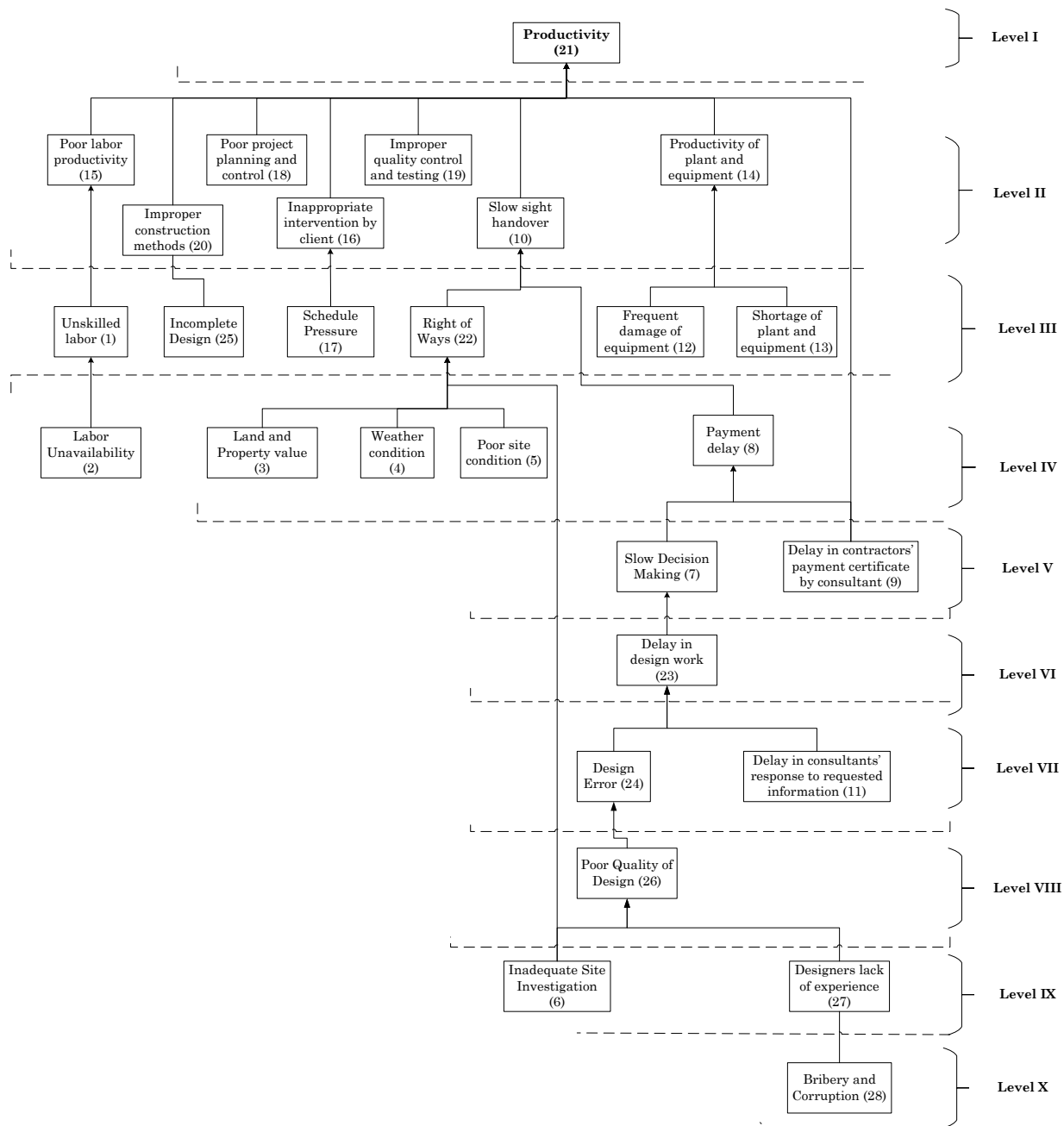


Figure 5-2 Relationship diagram of risk factors under Productivity

As shown in Figure 5-2, the interrelationship diagram between risk factors grouped under productivity are grouped into ten level. The first level in the ISM structure is the productivity risk factor. This risk factor is directly affected by eight risk factors (improper construction methods, inappropriate intervention by client, poor project planning and control, delay in consultants' response to the requested information, slow site handover, improper quality control and testing, productivity of plant and equipment and poor labour productivity) which

is immediately followed by based on the specified structure in level II. Among these, three of the risk factors (poor project planning and control, delay in consultants' response to requested information and improper quality control and testing) are exogenous risk factors.

In level III of the structure there are six risk factors, namely incomplete design, schedule pressure, right of ways, frequent damage of equipment, shortage of plant and equipment and unskilled labour. The risk factor incomplete design directly affects improper construction methods risk. Likewise, the schedule pressure risk factor affects inappropriate intervention by client in level II of the risk factors. The productivity of plant and equipment is affected by two risk factors (frequent damage of equipment and shortage of plant and equipment). Poor labour productivity is triggered by unskilled labour risk factor located in level III of the structure. Slow site handover can be affected by the risk factor in level III namely right of ways and payment delay from level IV of the structure.

The right way risk factor is also an endogenous risk factor affected by four risk factors located in level IV (land and property value, weather condition, poor site condition and inadequate site investigation). Likewise, the risk factor unskilled labour is affected by labour unavailability from level IV.

The payment delay is also dependent on slow decision making by the client and delay in contractors' payment certificate by consultant risk factors. But the risk factor slow decision making is affected by delay in design work which may be caused by the design error or delay in consultants' response to requested information risk factors. The result also revealed that the design error is affected by the quality of design and further by inadequate site investigation and designers' lack of experience.

The exogenous risk factor for designers' lack of experience is bribery and corruption risk factor.

## **5.3. Risk Ranking**

### **5.3.1. Risks affecting project duration**

The results of the questionnaire survey revealed the risk magnitude by multiplying the occurrences of the risks with the impact on time or cost of the project objectives as discussed

in section 3.5.2. The results of the risk magnitude enable the research to easily prioritize and rank risks.

Thus, this research evaluated the magnitude of forty-nine risk factors affecting the project objectives using fuzzy expert system.

*Table 5-1 The risk magnitude and rank on project duration*

<b>No.</b>	<b>Risk Factors</b>	<b>Risk Magnitude</b>	<b>Rank</b>
Q 01	Scope changes	0.4656	5
Q 02	Payment delays	0.3636	6
Q 03	Right of way	0.8872	1
Q 04	Inadequate site investigation	0.3636	6
Q 05	Schedule pressure by client	0.3636	6
Q 06	Inappropriate intervention by client	0.4656	5
Q 07	Design changes by client	0.3636	6
Q 08	Slow decision making	0.5965	3
Q 09	Slow Site Handover	0.3347	7
Q 10	Clients management ability	0.1885	9
Q 11	Design error	0.5676	4
Q 12	Incomplete design	0.4656	5
Q 13	Poor Quality of design	0.5965	3
Q 14	Consultants' lack of experience	0.3636	6
Q 15	Inadequate site information (soil test and survey report)	0.4656	5
Q 16	Inaccurate cost estimation	0.3636	6
Q 17	Design Change	0.5965	3
Q 18	Change in material types and specifications during construction	0.4656	5
Q 19	Delay in contractor's payment certification by the consultant	0.3636	6
Q 20	Delay in consultant's response to requests for information	0.3636	6
Q 21	Delay in design work	0.5965	3
Q 22	Poor quality of construction	0.5676	4
Q 23	Contractors' lack of experience	0.3636	6
Q 24	Error during construction	0.5676	4
Q 25	Unskilled workers	0.3636	6
Q 26	Poor Labour Productivity	0.5965	3
Q 27	Contractors poor management capacity	0.7274	2
Q 28	Poor Project planning and Control	0.5965	3
Q 29	Improper construction methods	0.2616	8

Q 30	Improper Quality control & testing methods	0.3347	7
Q 31	Shortage of plant and equipment	0.7274	2
Q 32	Poor Productivity of plant and equipment	0.5965	3
Q 33	Poor site management and supervision	0.5965	3
Q 34	underestimation of construction costs	0.5965	3
Q 35	Contractual claims such as extension of time with cost claims	0.8872	1
Q 36	Low quality of materials	0.1154	10
Q 37	frequent damage of equipment	0.5965	3
Q 38	Bribery and Corruption	0.5676	4
Q 39	Government intervention	0.3636	6
Q 40	Land & property values	0.2616	8
Q 41	Currency fluctuation	0.3636	6
Q 42	Price inflation of construction materials	0.3636	6
Q 43	Energy cost	0.3636	6
Q 44	Shortage of construction materials in market	0.5676	4
Q 45	Import and export restrictions	0.2616	8
Q 46	Contract modification (addition of new work to the project and change in specification)	0.5965	3
Q 47	Mistakes and discrepancy in contract documents	0.4656	5
Q 48	Heavy Flood, landslide, earthquake etc.	0.3636	6
Q 49	Weather conditions	0.3347	7
Q 50	Poor site condition	0.5965	3
Q 51	Pollution caused by construction (water, air & noise)	0.1885	9

The results of the fuzzy expert system revealed that Right of Way and Contractual claim are found to have a significant magnitude 0.8872. These risk factors are ranked as first as the magnitude is large as compared to the other. Hence, these risk factors are considered as the critical risks affecting the project duration. It constitutes 4.08% of the total risk factors.

The results obtained from ISM revealed is triangulated from the results of fuzzy expert system that the contractual claim can be triggered by any of the risk factors.

The second most significant risk factors are Contractors' poor management capacity and poor productivity of plant and equipment with 0.7274 magnitude. These risk factors are ranked second. These group also constitute 4.08% of the total risk factors.

There are eleven risk factors (slow decision making, poor quality of design, design change, delay in design work, poor labour productivity, poor productivity of plant and equipment, poor site management and supervision, underestimation of construction costs, frequent

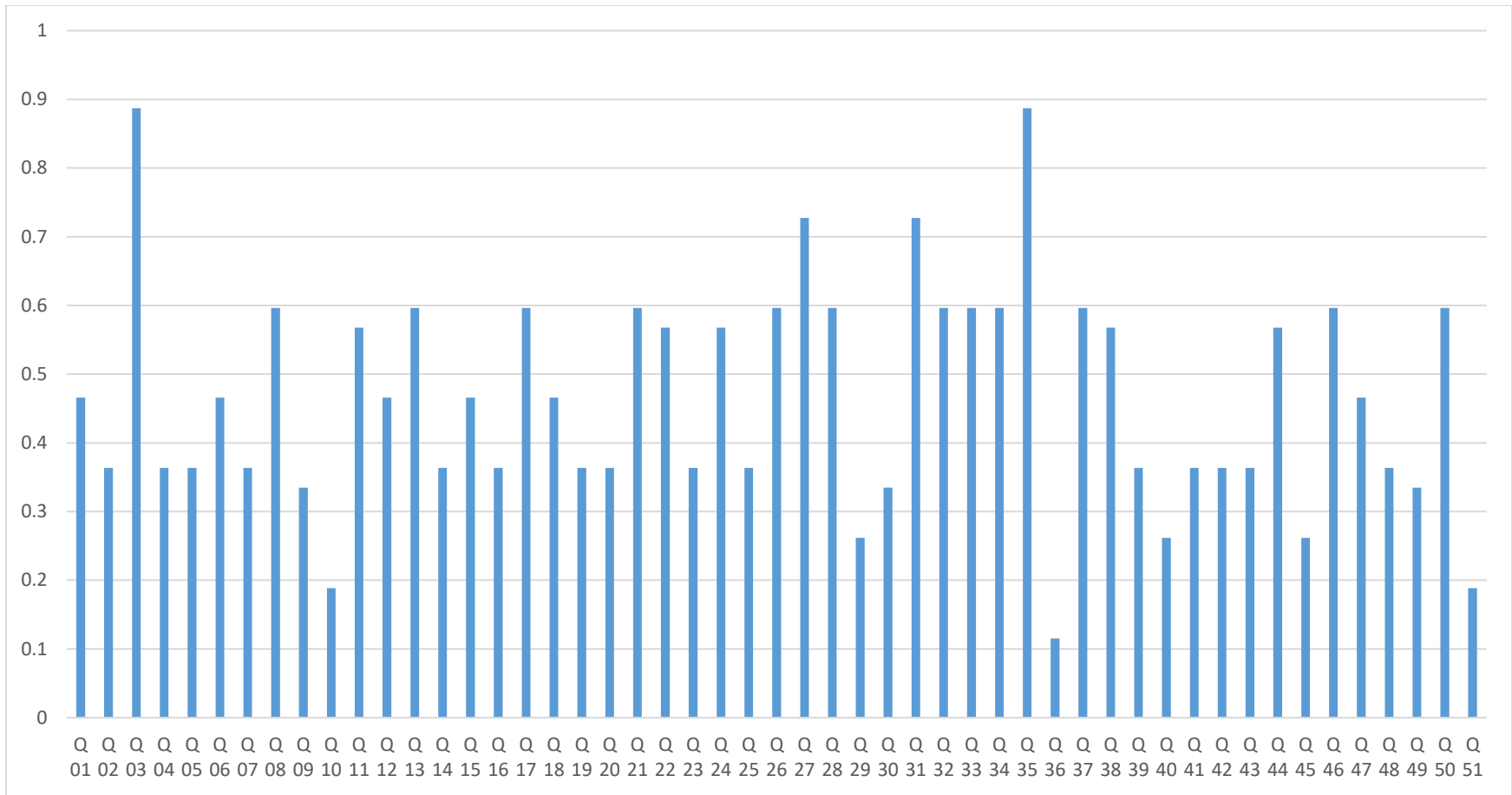
damage of equipment, contract modification and poor site condition) with the same magnitude of 0.5965 on the project duration. Its ranked third based on the risk magnitude and accounts 22.44% of the total risk factors. Moreover, 30.61% of the total risk factors have the magnitude of above 0.59.

Thus, to meet the project deadline, the project manager shall focus on the 30.61% of the risk factors as these risk factors have significant risk magnitude.

Five risk factors (design error, poor quality of construction, error during construction, bribery and corruption and shortage of construction materials) affecting the project duration are ranked as four based on the risk magnitude of 0.5676. The share of risks in this group are 10.22 percent of the total risk factors.

The fifth ranking risk factors affecting the project duration are scope changes, inappropriate intervention by the client, incomplete design, inadequate site information, change in material types and specification during construction and mistakes and discrepancy in contract documents with the magnitude of 0.4656. The next group or risks with the magnitude of 0.3636 are payment delays, inadequate site investigation, schedule pressure by the client, consultants' lack of experience, inaccurate cost estimation, delay in contractors' payment certification by the consultant, delay in consultants' response to the requested information, contractors' lack of experience, unskilled workers, government intervention, currency fluctuation, price inflation of construction materials, energy cost, and forced majeure (landslide, heavy flood, earthquake, etc.). This risk factors are ranked as six based on the effects on the project duration.

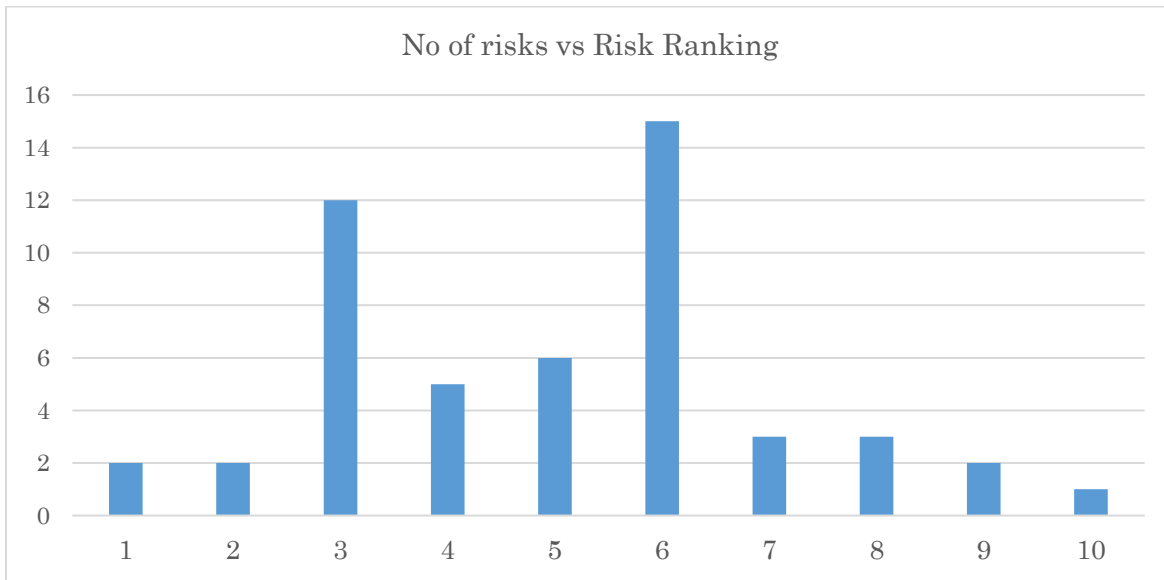
Three risk factors (slow site handover, improper quality control and testing method and weather conditions are ranked as seven with the magnitude of 0.3347.



*Figure 5-3 the individual risk magnitude on project duration*

The eighth ranking risk factors are three (improper construction methods, currency fluctuation and import restriction risk factors) that affect the project duration. Two risk factors affecting the project duration are pollution caused by construction and client management ability ranked as nine. The last ranking risk is low quality of materials.

The frequency of risk factors in each risk rank is show in Figure 5-3.



*Figure 5-4 the frequencies of risk factors and the risk rank for project duration*

### 5.3.2. Risks affecting Project Costs

The first ranking risks that affect the project costs are contractual claim and right of way problems with the risk magnitude of 0.8872. It constitutes 4.08% of the total risk factors. The top-ranking risks that affect the project costs and durations are found to be the same.

The second top ranking risks are contractors' poor management capacity, poor productivity of plant and equipment and poor site condition with the risk magnitude of 0.7274. However, as compared with the same rank of risks affecting project duration, the only common risk factor is contractors' poor management capacity.

Five risk factors (poor quality of design, design change, underestimation of construction costs, contract modification and mistake/discrepancy in contract document have the risk magnitude of 0.5965 and ranked as third. It has 10.2% share of the total risk factors. Excluding the risk

factor mistake and discrepancy in contractor document, four of the risk factors affecting the project costs ranking three, also affects the project duration.

The fourth ranking risk factors are those risk factors with magnitude of 0.5676. These risk factors are five (design errors, inaccurate cost estimation, error during construction, bribery and corruption and price inflation of construction materials). It also accounts for 10.2% share of the total risk factors. Three of the risk factors (design error, error during construction and bribery and corruption) have equal risk magnitudes on both project duration and cost.

There are 17 risk factors ranking fifth that affect the project costs. The Majority of the risk factors 36.65% have the magnitude of 0.4656 and accounts for this rank. These risk factors are scope change, inadequate site investigation, incomplete design, consultants' lack of experience, inadequate site information, change in material types and specification during construction, delay in design work, poor labour productivity, improper construction methods, shortage of plant and equipment, frequent damage of equipment, currency fluctuation, energy costs, shortage of construction materials, forced majeure (heavy flood, landslide, earthquake, etc.) and poor project planning and control.

Four risk factors are found to have common risk magnitude for both project cost and duration. These risk factors are scope change, incomplete design, inadequate site information and change in material types and specification during construction.

The next risk factors ranking six are schedule pressure, inappropriate intervention by client, delay in contractors' payment certification by consultant, poor quality of construction, contractors' lack of experience, unskilled worker, the need to change the design by client and government intervention. These risk factors have the magnitude of 0.3636 on project costs. Among these risk factors six of them (schedule pressure, delay in contractors' payment certification by the consultant, contractors' lack of experience, unskilled workers, the need to change the design by client and government intervention) are common with the same magnitude of risk factors affecting project duration.

Four risk factors (slow decision making, slow site handover, improper quality control and testing methods, import restriction) have the magnitude of 0.3347 on project costs. These

group of risks are ranked as seven. Slow site handover and improper quality control and testing methods have the same risk magnitude for both project cost and durations.

The eighth ranking risk factors that affect the project durations are payment delays, client management ability, delay in consultants' response to the requests for information and land and property values. The magnitude of these risks is 0.2616. Land and property value risk is the only common risk magnitude for both project cost and duration.

The risk factors low quality of materials has the risk magnitude of 0.248 and ranking based on the magnitude.

*Table 5-2 The risk magnitude and rank on project Cost*

<b>No.</b>	<b>Risk Factors</b>	<b>Risk magnitude</b>	<b>Rank</b>
Q 01	Scope changes	0.4656	5
Q 02	Payment delays	0.2616	9
Q 03	Right of way problems	0.8872	1
Q 04	Inadequate site investigation	0.4656	5
Q 05	Schedule pressure by client	0.3636	6
Q 06	Inappropriate intervention by client	0.3636	6
Q 07	Design changes by client	0.3636	6
Q 08	Slow decision-making	0.3347	7
Q 09	Slow Site Handover	0.3347	7
Q 10	Clients management ability	0.2616	8
Q 11	Design errors	0.5676	4
Q 12	Incomplete design	0.4656	5
Q 13	Poor quality of design	0.5965	3
Q 14	Consultants' lack of experience	0.4656	5
Q 15	Inadequate site information (soil test and survey report)	0.4656	5
Q 16	Inaccurate cost estimation	0.5676	4
Q 17	Design Change	0.5965	3
Q 18	Changes in material types and specifications during construction	0.4656	5
Q 19	Delay in contractor's payment certification by the consultant	0.3636	6
Q 20	Delay in consultant's response to requests for information	0.2616	8
Q 21	Delay in design work	0.4656	5
Q 22	Poor quality of construction	0.3636	6
Q 23	Contractors' lack of experience	0.3636	6

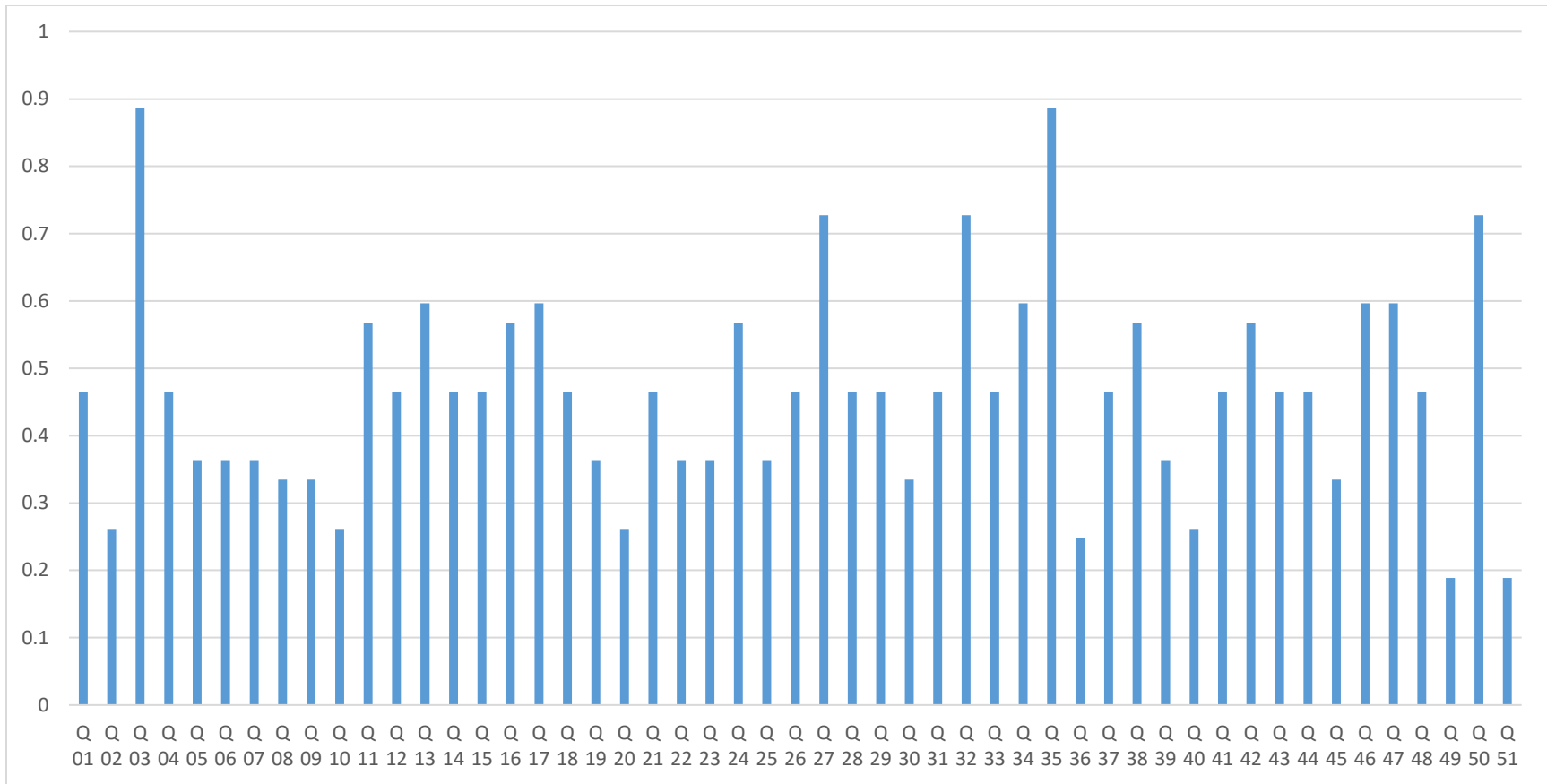
Q 24	Errors during construction	0.5676	4
Q 25	Unskilled workers	0.3636	6
Q 26	Poor Labour productivity	0.4656	5
Q 27	Contractors' poor management capacity	0.7274	2
Q 28	Poor project planning & control	0.4656	5
Q 29	Improper construction methods	0.4656	5
Q 30	Improper Quality control & testing methods	0.3347	7
Q 31	Shortage of plant and equipment	0.4656	5
Q 32	Poor productivity of plant and equipment	0.7274	2
Q 33	Poor site management and supervision	0.4656	5
Q 34	Underestimation of construction costs	0.5965	3
Q 35	Contractual claims, such as, extension of time with cost claims	0.8872	1
Q 36	Low quality of materials	0.248	9
Q 37	Frequent damage of equipment	0.4656	5
Q 38	Bribery and corruption	0.5676	4
Q 39	Government intervention	0.3636	6
Q 40	Land & property values	0.2616	8
Q 41	Currency fluctuation	0.4656	5
Q 42	Price inflation of construction materials	0.5676	4
Q 43	Energy cost	0.4656	5
Q 44	Shortage of construction materials in market	0.4656	5
Q 45	Import and export restrictions	0.3347	7
Q 46	Contract modifications (addition of new work to the project and change in specification)	0.5965	3
Q 47	Mistakes and discrepancy in contract documents	0.5965	3
Q 48	Heavy Flood, landslide, earthquake etc.	0.4656	5
Q 49	Weather conditions	0.1885	10
Q 50	Poor site conditions (Location, ground, etc.)	0.7274	2
Q 51	Pollution caused by construction (water, air & noise)	0.1885	10

The last group of risk factors ranking ten is weather condition and pollution caused by construction with the magnitude of 0.1885. Pollution caused by construction has equal magnitude for both project duration and costs.

Overall, 46.93% of the risk factors have the same magnitude for both. The top ten risk factors affecting both project cost and duration are right of ways, contractual claims, contractors' poor management capacity, poor quality of design, design change, underestimation of construction costs, design errors, errors during construction and bribery and corruption.



*Figure 5-5 the frequency of risk factors in each rank for project costs*



*Figure 5-6 Risk magnitudes affecting project costs*

## 5.4. Conclusion

This chapter has presented and discussed the results of the analysis mainly obtained from ISM and fuzzy expert system. Using the ISM technique, the researchers are able to create a visual relationship diagram between individual risk factors using the data obtained from experts' interview. The relationship diagram is divided into two for ease of presentation. These diagrams are named as risk factors related to scope growth and productivity. The results of the diagram revealed that there are seven and ten hierarchy level for scope growth and productivity related risks respectively as shown in Figure 5-1 and 5-2.

On the other hand, the risk factors affecting project duration and costs are ranked based on the risk magnitude using fuzzy expert system. The result indicates that 46.93% of the risk factors affect the project duration and cost with the same magnitude. Moreover, the top-ranking risks are found to be the same.

Furthermore, the top ten common risks are also checked against the risk relationship diagram. The result indicates that six risk factors (error during construction, design change, underestimation of construction costs, design error, contractor's poor management capacity, poor quality of design and bribery and corruptions) are related to scope growth, whereas four risk factors (right of ways, design error, poor quality of design and bribery and corruptions) are related to productivity. Three risk factors are common for both productivity and contractual related risk factors.

# Chapter Six System Dynamics Model development

## 6.1. Introduction

This chapter answers the last research question: *what is the Effects of risk factors on time and cost overrun of Road Construction Project?* This chapter mainly deals with system dynamics model development. The objective of this model development is to study the effect of compounded risk factors on project cost and time overrun of the project by varying the magnitude of the exogenous risk factors.

System Dynamics (SD) is a method to describe, model, simulate and analyse dynamically complex issues and/or systems in terms of the processes, information, organizational boundaries and strategies. SD starts from the assumption that the behaviour of a system is largely caused by its own structure. System structure consists of physical and informational aspects as well as the policies and traditions important to the decision-making process in a system (Pruyt, 2013).

The SD approach was developed at the end of the 1950s and the beginning of the 1960s by Jay W. Forrester, at the Sloan School of Management of the Massachusetts Institute of Technology (Forrester, 1961). He argued that the traditional methods for solving problems provided insufficient understanding of the strategic processes involved in complex systems.

Wolstenholme (1990) defined SD as a rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organizational boundaries and strategies; which facilitates quantitative simulation modelling and analysis for the design of system structure and behaviour.

There are quite a number of definitions of SD, but Coyle (1996) offers a more robust definition as an approach that “deals with the time-dependent behaviour of managed systems with the aim of describing the system and understanding, through qualitative and quantitative models, how information feedback governs its behaviour, and designing robust information feedback structures and control policies through simulation and optimization”.

The two major characteristics of SD that is useful for simulation and managing are: (1) the changes over time are possible, and (2) it allows the feedback of information. The feedback processes are represented with stock and flow, time delays and non-linearity. Stocks and

flows are used to model the flow of work and resources through a project (Nasirzadeh et al., 2008a).

Stocks represent stored quantities and characterize the state of the system and generate the information upon which decisions are based. Flows are the rate of increase or decrease in stocks. Information feedback loops are used to model decisions and project management policies.

Recently, SD has been successfully applied to issues ranging from social, industrial and environmental to project management systems. The art of system dynamics approach is to discover and represent the feedback processes, which, along with stock and flow structures, time delays and nonlinearities determine the dynamics of the system (Sterman, 2000, Nasirzadeh et al., 2008d)

The construction project consists of many different tasks where these tasks are associated with risks. These risks are interrelated to one another where the effects cannot be understood easily through mental model or traditional analytic-based approach (De Marco and Rafele, 2009). Thus, SD method allows representing the feedback interrelationships between a number of variables as an influence diagram (Coyle, 1996).

Considering the complex interrelated structure of risks resulting from the various feedback processes, SD is well suited to perform the risk management process (Nasirzadeh et al., 2008d).

According to Sterman (2000), there are four important steps for effective system dynamics model. These are:

- Problem articulation
- Formulation of dynamic behaviours
- A simulation model formulation
- Validation

## **6.2. Problem Articulation**

As mentioned in section 6.1 of this chapter, construction projects involve multiple interdependent variables. These interdependent variables have a cascaded and unintended

effect on the project objective. Thus, to study the effect of the change of one risk factor on the project cost and duration, system dynamics model is found to be suitable. The objective of this research is to develop a model that represents the relationship between project objectives (time and cost) with risk factor in construction project.

The use of system dynamics model is to:

1. capture the effect of risk factors which impact the project cost and duration of road construction projects.
2. Provide the necessary information to investigate and analyse relationship between the project risks with multiple interdependencies with each other and project objective
3. Examine critical variables that affect the project objective particularly time and cost of the project.

Different researchers attempt to determine the effects of project risks on its objective. However, as mentioned in the literature review, they do not consider the interrelationship between risk factors. Rather, most of them focused on determining the impact of the individual risks on the project objective. But, the result could not be the same due to the causal relationship between one another.

Thus, this research considers the interrelationship between risk factors and attempts to determine the cascaded effects of the interrelated risk factors on the project objective. The model enables the practitioner and researcher to examine the risk factors based on the intensity of impact on the project cost and time.

The purpose of the model is to study the cascaded effect of risk factors in road construction project on project objective mainly time and cost of the project. Moreover, the model is used to estimate the time and cost overrun of the project due to the interrelated risk factors occurring during the course of the project.

Although there are enormous factors affecting the project objectives, this research is mainly concerned with the effects of risk factors leading to cost and time overrun. Hence, the following assumptions are considered to avoid the model complexity

- a) The relationship between risk factors are assumed to have linear relationship between each other.
- b) The costs of each tasks within the project are equal
- c) The duration of each tasks within the project are equal
- d) The work progress is affected by the risk factors under consideration
- e) The initial project size requires 1 Million hours of work
- f) The progress of the project and the schedule adjustment time is reviewed every month; thus, the rate of work progress is adjusted every thirty days.
- g) The additional work is revised every three month (90 days)
- h) The planned project cost is 100 Million Birr.

### 6.2.1. Key Variables

Several variables are used to model the effects of project risks on project objective (time and costs). These variables are defined in the Table 6-1.

*Table 6-1 Key variables used in SD simulation*

<b>Variables</b>	<b>Description</b>
Scope changes	Any additional or modification of tasks from the initial scope of tasks
Payment delays	The delay in the release of payment to the contractor from the owner
Right of way problems	Any obstruction of infrastructures that requires relocation based on the design
Inadequate site investigation	Insufficient considerations of the technical issues caused due to the particular site conditions.
Schedule pressure by client	The enforcement of the owners to complete the project regardless of the constraints in executing
Inappropriate intervention by client	The intervention of owner/client during the execution of the project without boundary
Slow decision making	The delayed responses of the owner due to extended bureaucratic procedure or lack of commitment of management
Slow Site Handover	The delayed mobilization period for the contractor after the date of award
Design errors	The frequent revision of designs due to the substandard quality of works and results redesign

Incomplete design	The incomplete design of the project during planning or tendering time
Poor quality of design	The narrow details and descriptions of the design which leads to ambiguity
Consultants' lack of experience	Experiences of the awarded consultant on the specific type of project and insufficient of preset standards
Inadequate site information (soil test and survey report)	The geotechnical data on the specific site
Inaccurate cost estimation	The consideration of all costs associated in the project during the tendering
Design Change	The amendment or modification of design by the owner or other third party
Poor project planning and control	The effectiveness of project management by the stakeholders in the project
Changes in material types and specifications during construction	The change of any material from the initial bill of quantity
Delay in contractor's payment certification by the consultant	The delayed approval for the payment request of the contractor by the consultant will hamper the release of the payment by the owner
Delay in consultant's response to requests for information	The delayed feedback of the consultant for the clarification, approval and information for the contractor
Delay in design work	The prolonged delay of design work by the designer/consultant
Poor quality of construction	Execution of project using substandard quality of material or
Contractors' lack of experience	The possession of experiences of the contractor is not up to the preset standards of the project type
Errors during construction	The execution of work out of the preset standards and requirement
Unskilled workers	The stated knowledge and experiences of the worker in not in line with the available one
Poor labour productivity	The failure to meet the predetermined work standards for the labour
Contractors' poor management capacity	The inadequate experience and organization system to handle the project
Improper construction methods	The adopted methods by the contractor results in weak productivity, error, rework, etc.
Improper Quality control and testing methods	the quality control and testing methods used is not in line with the standards set

Shortage of plant and equipment	The available plant and equipment is below the standard
Poor productivity of plant and equipment	the performances of the plant and equipment are less than expected
Poor site management and supervision	The control of material, worker and progress of work is weak and creates wastage
Underestimation of construction costs	The actual construction costs are much larger than the standard
Contractual claims, such as, extension of time with cost claims	Any variation from the initially agreed scope caused by stakeholders other than may result in claim for extension of time or additional cost
Low quality of materials	The substandard materials
Frequent damage of equipment	The failure of the plant and equipment during the construction period
Bribery and corruption	Any tasks that jeopardize the standard and quality of work
Government intervention	The change in the scope tasks due to the local/federal government
Land and property values	the value and investment laid on the land
Currency fluctuation	The rate of change of foreign exchange
Price inflation of construction materials	The rise in the price of construction materials
Energy cost	The costs of fuel, electricity and other sources of energy
Shortage of construction materials in market	The limitation of material availability in the market
Import restrictions	The country law and bureaucracy on import
Contract modifications	The addition of new work to the project and change in specification
Mistakes and discrepancy in contract documents	The existence of errors and inconsistency of contract articles
Forced majeure	The prevalence of earthquake, landslide, heavy flood etc.
Weather conditions	Harsh weather such as heavy rain or high temperature affect the actual working days of the project duration
Poor site conditions (Location, ground, etc.)	The subsurface condition of the site affects the project execution and may result in additional tasks and costs
Pollution caused by construction (water, air and noise)	High level of dusts, water pollution and noise occur during construction which incur more costs on the project
Fraction completed	The ratio of work actually done by total work to do
Work to be done	The accumulated number of tasks the project has initially
Initial project size	The total number of tasks the project initially has

Time to discover rework	The time between the occurrence of error and identification of error
Error Fraction	The errors occurred out of the instantaneous work progress
Error Generation	The instantaneous rate of executing error per day
Work actually done	The accumulated works that have been executed
Fraction actually done	The ratio of work actually done over the initial project size
Progress	The rate of executing the project
Progress adjustment time	The time required to adjust the rate of progress
Work variation	The additional works added to the project due to any risk factors
Cost overrun	The additional costs required to complete the project beyond the planned budget
Unit cost of task	The cost required to perform a task
Additional work	Equivalent to work variation
Variation progress	The rate of executing the additional work
Work fully completed	The accumulation of executed additional work
Variation fraction completed	The ratio of additional work over the variation

To determine the time horizon of the simulation, the ERAMS software data is used. The data contains information on 59 road construction project owned by ERA. The planned duration of the project ranges from 459 – 1460 days. Thus, the model uses 1500 days for simulation.

This enables the model to view the complete lifespan of the project. Therefore, influences of the project risks considered above can be easily reflected during the time horizon of the project.

### **6.3. Formulation of dynamic behaviours**

#### **6.3.1. Model Boundary**

The model boundary chart summarizes the scope of the model by listing which key variables are endogenous, exogenous and excluded from the model (Sterman, 2000). It is very important process because the variables will have a clear division and helps to build successful model.

This research uses literature review, experts' opinion and results of ISM analysis to determine the endogenous and exogenous variables.

Endogenous variables are the primary factors of the model to be considered all the time of simulation and it can be modified in conformity with the simulation environments. The project objectives are the considerable key factors for this research model. The risk factors occurring during the course of the project affects the project cost and time. Moreover, some risk factors occur due to the occurrences of another factor. Thus, these endogenous risk factors are dependent and changes due to the change in the independent risk factors.

Exogenous variables are defined and set by users and do not change during the simulation. These variables are independent of any factors within the subsystem. The values do not change for the analysis of endogenous variables during simulation. But the values can be changed for the purpose of simulation.

The excluded variables are thoughtfully not considered in the simulation model because it is beyond the scope and purpose of simulation model. The factors such as types of contract, weather condition, financing method may affect the project objective. However, this research excludes these variables due to the scope of the research.

There are three subsystems in the model. These subsystems are the productivity, scope growth and project execution. Thus, each of the subsystem have its own model boundary as illustrated in Table 6-2, 6-3 and 6-4.

*Table 6-2 Model boundary of productivity subsystem*

<b>Endogenous</b>	<b>Exogenous</b>	<b>Excluded</b>
Productivity	Bribery and corruption	Design and work standards
Labour productivity	Delay in consultants' response to the requested information	Workers motivation and incentive
Improper construction methods	Land and property value	Occupation safety
Inappropriate intervention by client	Weather condition	Constructability of design
Slow site handover	Poor site condition	Information flow of the organization
Poor productivity of plant and equipment	Delay in contractors' payment certificate by consultant	Organizational management system
Unskilled labour	Labour unavailability	Machinery maintainability

Right of ways problem	Shortage of plant and equipment	Absenteeism
Payment delay	Frequent damage of equipment	resource planning and allocation
Slow decision making	Project planning and control	Labour turnover
Delay in design work	Improper quality control and testing	Accident and injuries
Design error		Risk response
Poor quality of design		Risk mitigation
Designers lack of experience		
Inadequate site investigation		
Schedule pressure		
Incomplete design		

*Table 6-3 Model boundary for Scope growth subsystem*

<b>Endogenous</b>	<b>Exogenous</b>	<b>Excluded</b>
Consultants' lack of experience	Bribery and corruption	Type of contract
Incomplete design	Inadequate site information	Breach of contract
Contractors' lack of experience	Poor quality of design	Law and arbitration
Contractors' poor management capacity	Improper quality control	Bankruptcy
Design error	Low quality of material	Method of financing
Change in material type	Import restriction	Sources of finance
Design change	Government intervention	Liquidity
Poor quality of construction	Weather condition	Accuracy of time and cost estimation
Poor site management and supervision	Poor site condition	Unethical practices of the stakeholder
Underestimation of construction costs	Pollution caused by construction	Country/ region political stability
Inflation of construction material	Poor project planning and control	The relationship between the stakeholders
Inaccurate cost estimation	The need to change the design by the client	Long bureaucratic procedure
Error during construction	Currency fluctuation	Prosecution
Scope change	Heavy flood, landslide, earthquake etc.	Clarity of contract
Contractual claim		Prolonged court case

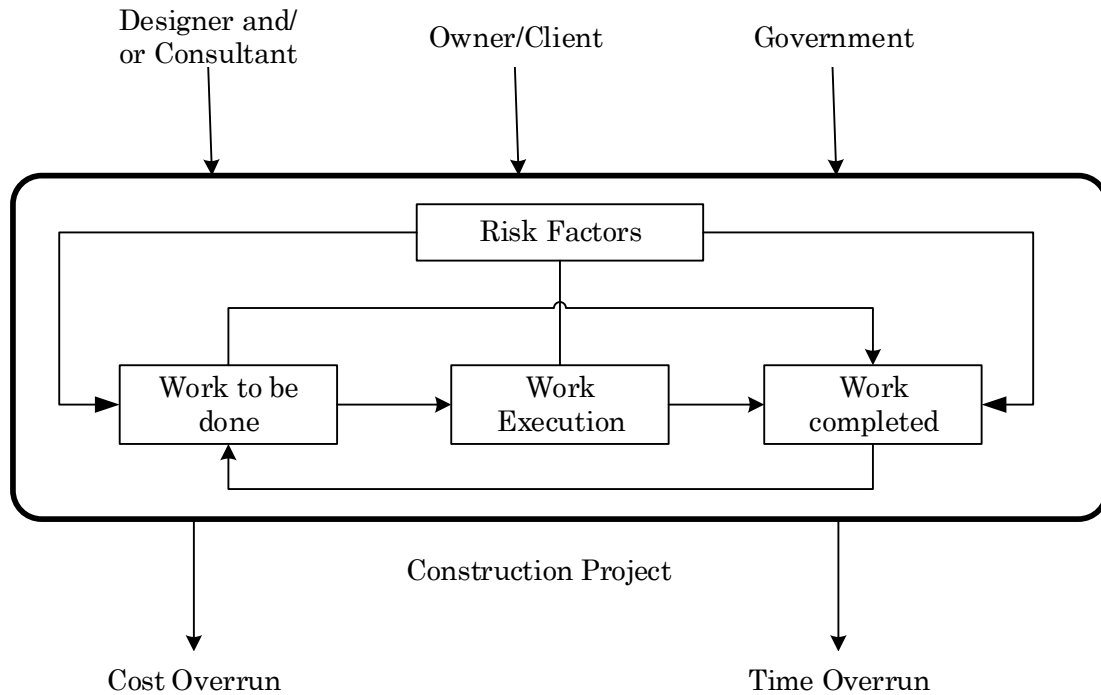
Shortage of construction material		Third party delay
Contractor modification		Risk response
Inadequate site investigation		Risk mitigation strategies
Client management ability		

*Table 6-4 Model boundary for project execution subsystem*

<b>Endogenous</b>	<b>Exogenous</b>	<b>Excluded</b>
Work actually done	Work to be done	The number of workers
Error Fraction	progress	The number and type of resources
Initial project size	Error	Resource constraint
Progress adjustment time	Undiscovered rework	Delayed financial expenditure
	Rework discovery rate	Risk response
	Rework to do	Organizational factors
	Total work to do	
	Fraction completed	
	Fraction actually done	

The road construction risk analysis system has a number of sub-systems and each of them is controlled by a number of variables as identified from the literature. In this model, hard data such as cost would be measurable while soft data such as risk factors would be intangible. For simplifying the model, three variables are grouped into three subsystems.

The ultimate goal of the system dynamics model is to estimate the cost and time overrun of the project when it is subjected to multiple interdependent risk factors. Thus, it explores the relationship between these risk factors with the project objective (time and cost). Figure 6-1 depicts the subsystem diagram for the construction project.



*Figure 6-1 Construction project subsystem diagram*

#### **6.4. A simulation model formulation**

System Dynamics Modelling processes includes two important stages: (1) causal loop diagrams development and (2) the Stocks and Flows diagrams development. Causal loop diagrams identify key variables and capture relationship with other variables in the system. Stocks and Flows diagrams capture the mathematical functions of these variables. The following sections describe the causal loop and Stocks and Flows diagrams of construction project subjected to different interrelated risks.

#### **6.5. Causal loop diagrams**

Causal loop diagrams of each sub systems of construction project risk analysis model describe the system structure qualitatively. They present how various variables in the system affect each other. They also portray whether the relationships are positive or negative. But they do not provide information about the quantitative relationships between the variables.

The causal loop diagrams are developed in consultation with the same experts used for developing the interrelationship diagram of the risk factors. The loop is divided into two based on the same criteria used for ISM analysis i.e. scope growth and productivity related

risk factors. Most of the scope growth occurred due to the risk related to consultants and/or designer, clients and the federal/regional government. However, the problems related to contractors are mostly reflected in form of error and productivity.

The client, consultants and/or design related risks system is one of the sub models in road construction project risk analysis model. The sub model describes the interrelations among potential risk factors related to these stakeholders that have impact on project cost and duration. The variables are identified to define the boundary of the risk system and are classified as endogenous and exogenous variables.

The causal loop diagram of client related risk system is depicted in Figure 6-2 below. The diagram shows the interrelations between different causes which affect the project objectives, mainly time and cost of the project.

There are four feedback loops and all are reinforcing loops in this causal loop model. The type and variables of the loops are illustrated in Table 6-5.

*Table 6-5 The variable and types of loops in Scope growth-related causal loop diagram*

<b>Loop No.</b>	<b>Variable within the loop</b>	<b>Types of loops</b>
Loop Number 1	<ul style="list-style-type: none"> <li>• Scope change</li> <li>• Additional work</li> <li>• Work completed</li> </ul>	Reinforcing
Loop Number 2	<ul style="list-style-type: none"> <li>• Scope change</li> <li>• Additional work</li> <li>• Contract modification</li> <li>• Client related risk factors</li> </ul>	Reinforcing
Loop Number 3	<ul style="list-style-type: none"> <li>• Scope change</li> <li>• Additional work</li> <li>• Client management ability</li> <li>• Client related risk factors</li> </ul>	Reinforcing
Loop Number 4	<ul style="list-style-type: none"> <li>• Scope change</li> <li>• Additional work</li> <li>• Client management ability</li> </ul>	Reinforcing

	<ul style="list-style-type: none"> <li>• Inappropriate intervention by client</li> <li>• Client related risk factors</li> </ul>	
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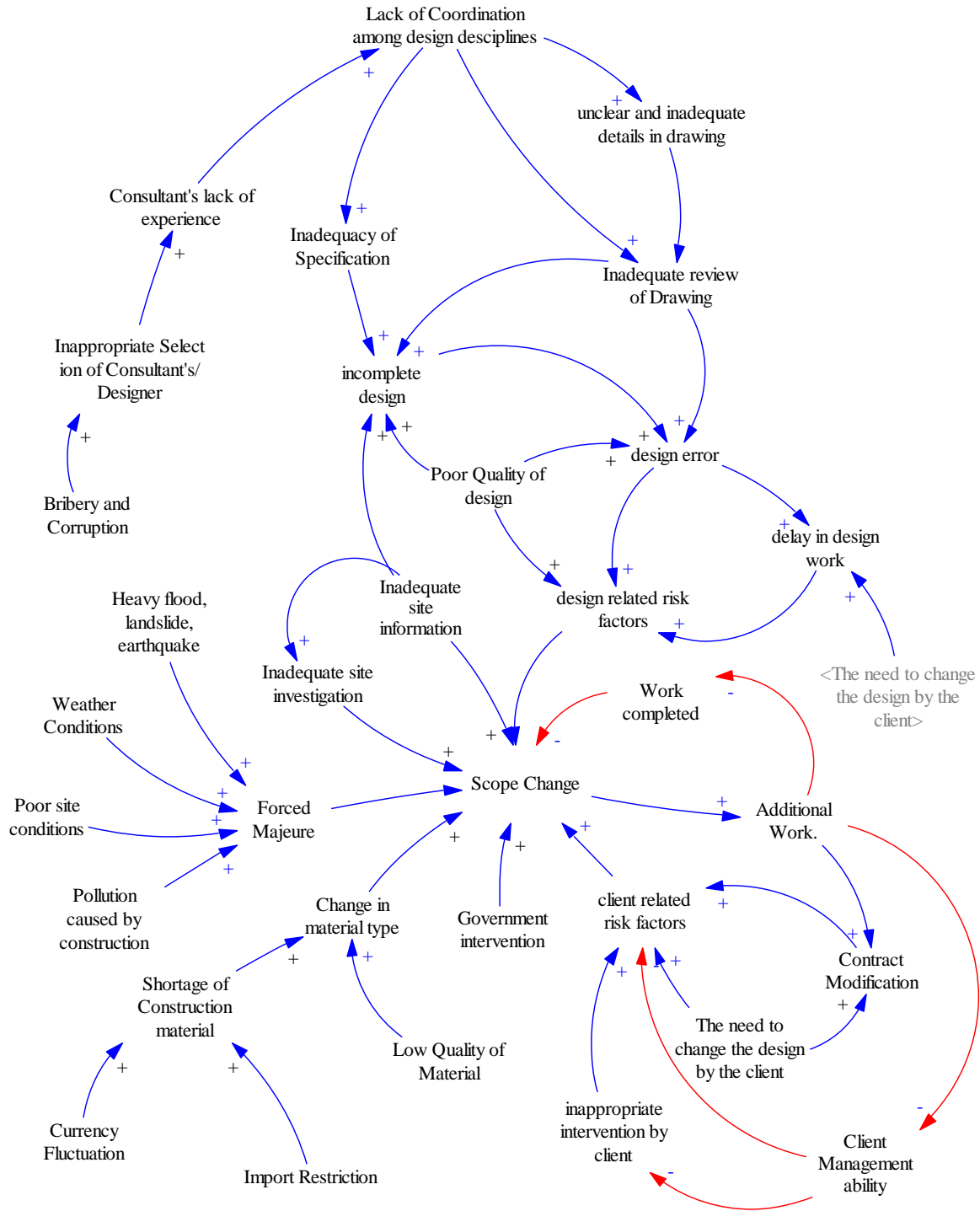


Figure 6-2 Closed Loop diagram for Scope growth related risks

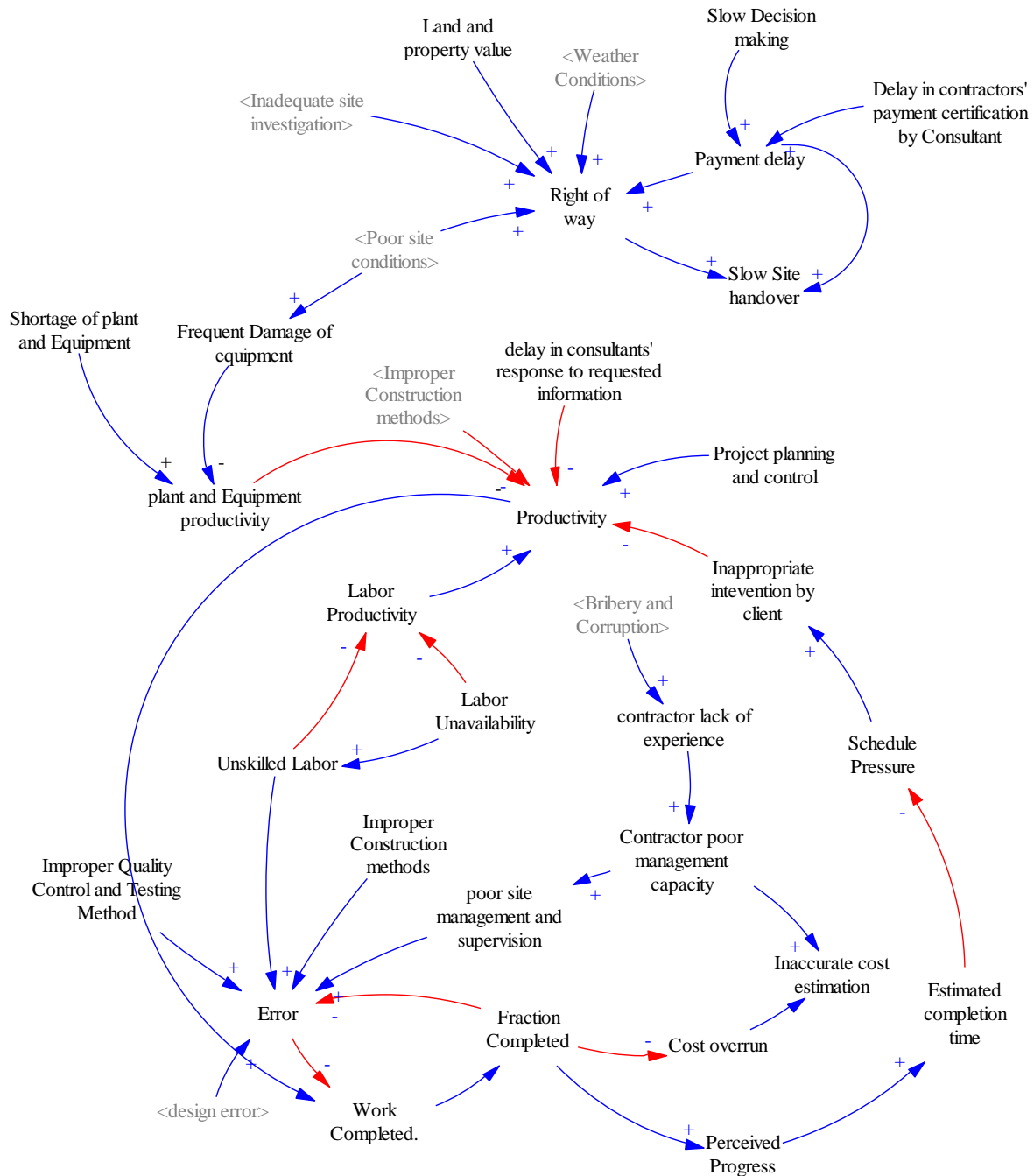


Figure 6-3 Causal Loop diagram for Productivity Related Risks

On the other hand, the causal loop diagram for risk factors affecting the project progress either through productivity or error during construction are illustrated separately. Some risk factors have effects on the project both with addition of scope/scope growth and error/productivity of the project. The interaction of these potential project risks is

encountered during construction processes. The interrelationship of these factors is shown using polarity of the links. The CLD is shown beneath in the Figure 6-3.

*Table 6-6 The variable and types of loops in productivity related causal loop diagram*

<b>Loop No.</b>	<b>Variable within the loop</b>	<b>Types of loops</b>
Loop Number 1	<ul style="list-style-type: none"> <li>• Productivity</li> <li>• Work completed</li> <li>• Fraction completed</li> <li>• Perceived progress</li> <li>• Estimation completion time</li> <li>• Schedule pressure</li> <li>• Inappropriate intervention by client</li> </ul>	Reinforcing
Loop Number 2	<ul style="list-style-type: none"> <li>• Error</li> <li>• Work completed</li> <li>• Fraction completed</li> </ul>	Reinforcing

There are two reinforcing loops related to productivity and error.

Although the loops for both scope growth and productivity illustrated above is limited to four and two respectively, the whole construction process (considered in this research) has too many feedback loops as discussed in section 6.7.

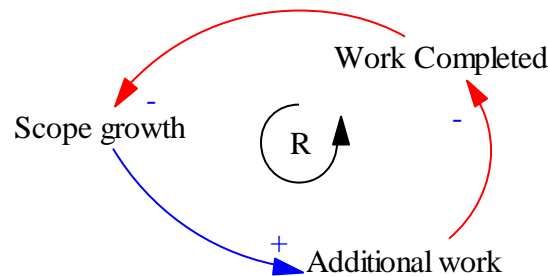
## **6.6. Model Description**

### **6.6.1. Scope Growth Causal Loop Model**

The purpose of developing the model is to describe the relationship between risk factors and characterize the feedback loops existing within both the scope growth and productivity feedback loop. The main concerns of this research are to study the unintended impacts of risk factor on project time and cost overrun. Moreover, simple addition of risk factor is different from the cascaded effects of the total project risks. Thus, the feedback loops presented in Table 6-4 and 6-5 are explained subsequently.

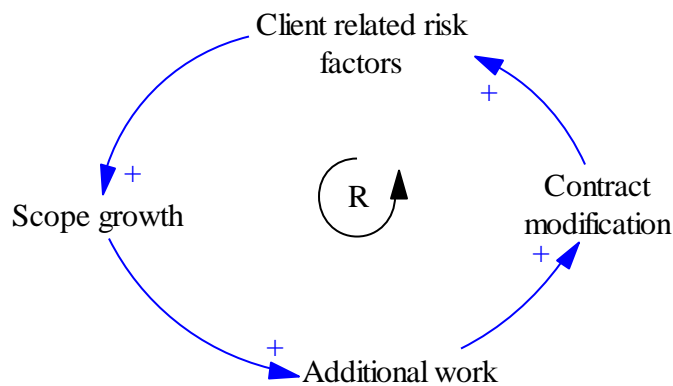
As mentioned in section 6.5, the scope growth model has four reinforcing feedback loops. The first feedback loop is scope change – additional work – work completed. An increase in scope results in more addition of works in the project, thus it has direct relationship. However, an

increase in more work in the project has an inverse relationship with the completed work. This is due to more unprocessed work will increase, likewise, the more the work is completed and the less likely the scope is to be changed. In this loop, two negative relations exist. Accordingly, the loop is reinforcing.



*Figure 6-4 Reinforcing loop of Scope growth, additional work and work completed*

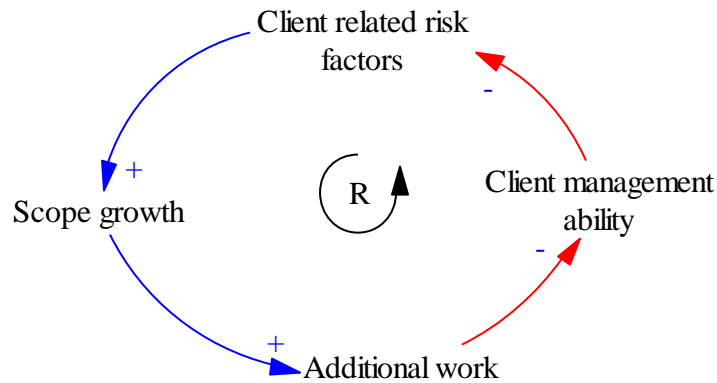
On the other hand, the increase in the scope growth increases the additional work of the project. An increase in additional work that are out of the contract requires for contract modification. Hence, direct relationship exists between additional work and contract modification. The frequent modification of contract is also directly related to client related risk factors. The higher client related risk factors result in more scope growth. Accordingly, this loop is reinforcing loop due to the positive relation among each other.



*Figure 6-5 Reinforcing loop of Scope growth, additional work, contract modification and client related risk factors*

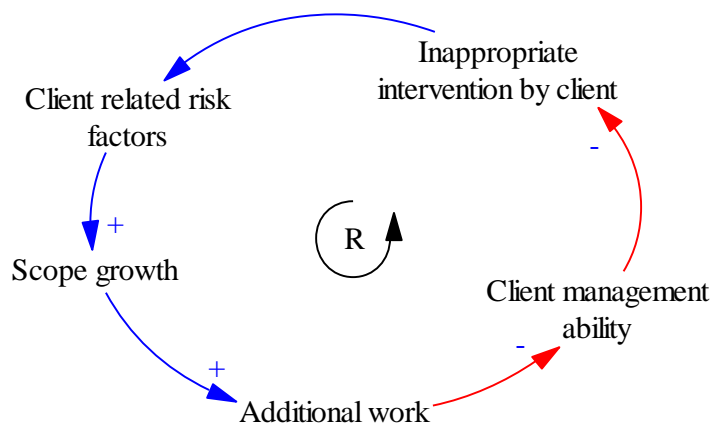
The increase in the additional work has an inverse impact on the client management ability due to the unintended and unplanned actions which is not considered in the contract of the project. This inhibits the overall progress of the work. Likewise, the client management

ability has also an indirect relationship with client related risk factors. The more the client has the capacity and ability to manage, the lesser the clients related risk factors. Therefore, this loop is also a reinforcing loop due to the presence of two positive and negative relationship



*Figure 6-6 Reinforcing loop of Scope growth, additional work, Client management ability and client related risk factors*

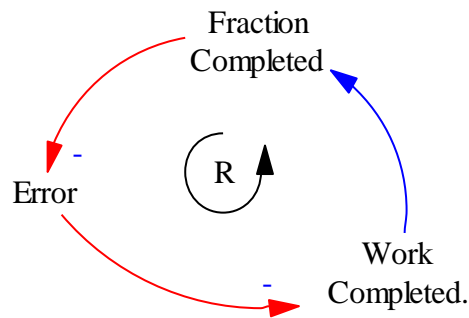
The last loop in this category is the addition of inappropriate intervention by client variable from the loop in Figure 6-6. The client management ability and inappropriate intervention by client has indirect relationship. However, there is direct relationship between inappropriate intervention by client and client related risk factors. The loop is reinforcing due to the presence of two negative relationship existing in this loop.



*Figure 6-7 Reinforcing loop of Scope growth, additional work, Client management ability, inappropriate intervention by client and client related risk factors*

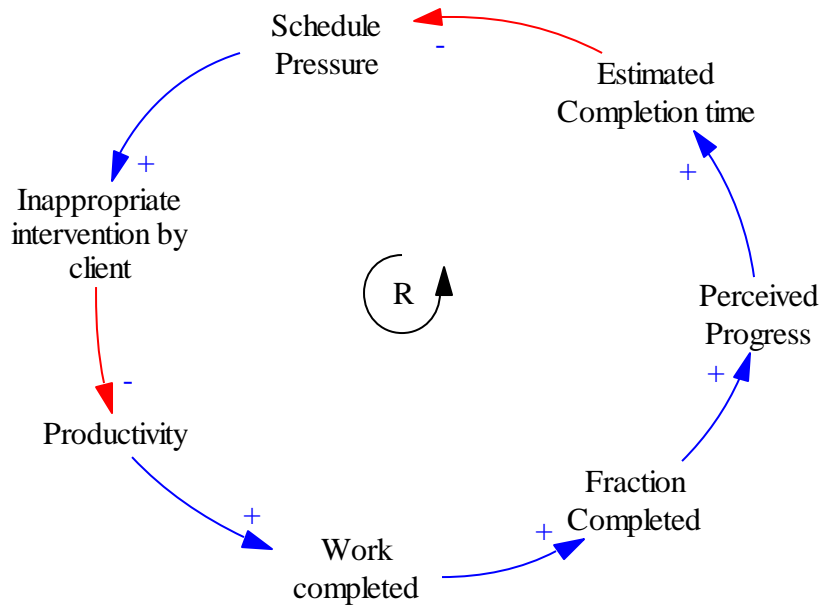
### 6.6.2. Productivity Causal Loop Model

The productivity causal loop diagram has only two reinforcing loop. The first loop diagram related to Error is shown in Figure 6-8. The relationship between error and work completed is inverse. The higher the percentage error, the lesser the work completed. However, the work completed has direct relationship with fraction completed. Lastly, an increase in fraction completed results a decrease in percentage error committed. Therefore, two negative relation exists and results the loop to be reinforcing.



*Figure 6-8 Reinforcing loop of error, work completed and fraction completed*

Another causal loop is related to productivity as shown in the Figure 6-9. It is illustrated in the figure that the higher productivity has a direct relation with work completed and also the fraction of work completed within the project. The higher the percentage completion of the project results in an increased perception of progress and accuracy of estimated completion time. However, an increase in estimated completion time has an inverse relation with the schedule pressure. This is because the client urges the contractor to finish the project, when the client perceive that the project is delayed. The occurrence of schedule pressure increases the intervention of the clients during the project work. Thus, it has a direct relationship. But the increase in the client intervention results the decline in productivity. Overall, it is a reinforcing loop due to the even number of negative relationship between the variables.



*Figure 6-9 Reinforcing loop of productivity, work completed, fraction completed, perceived progress, completion time, schedule pressure and inappropriate intervention of clients*

## 6.7. Stocks and Flows

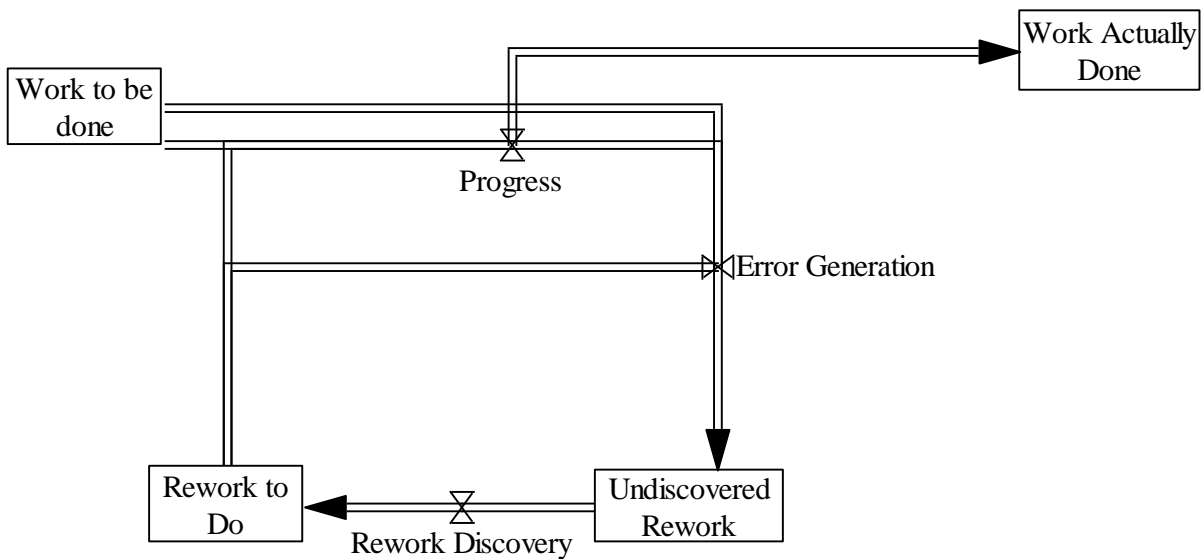
Stock and Flow structures capture the quantitative aspects of the construction project risk analysis system. Stock and Flow structures are developed from the causal loop diagrams by adding levels and rates variables. They provide the information about the values of various variables and the rate at which those values are associated with them.

This research uses the basic model of the project management cycle to capture the accumulated work and the rework cycle.

the first rework cycle model was developed by Cooper (1980), contains four stocks of work. During the start of the project, all the works need to be worked are defined in the stock called “Work to be Done”. This stock defines the range of tasks to be executed during the planning stage. This stock is defined in terms of the total project time required to conduct the project. This stock is decreased by the flow called “Progress”. This is the efforts of performing the range of tasks. However, some efforts exerted to perform the tasks contain error. Thus, all the preformed tasks are not going directly to the stock “Work Actually Done”. Only those tasks done correctly enters to this stock that never need rework. The fraction of works

containing error enters to the stock “Undiscovered Rework” based on the rate of error generation.

The errors performed are not recognized and detected immediately. Rather, they are recognized while doing other subsequent works or during the quality control and testing. Hence, the accumulated rework is recognized based on the rework discovery rate and it is dependent on the time required to discover the rework. The discovered rework will be accumulated in the stock called “Rework to do” which requires additional effort and adds the volume of work required to be performed. The basic model is depicted in Figure 6-10.



*Figure 6-10 The Basic Model of Project management*

The rate of work done is directly related to the productivity of the work, the volume of work to be done, the fraction of work completed and time required to adjust the progress. Moreover, the actual progress of the work in reality is the slow start-up or constant work progress during the start of the project followed by an acceleration of work for some period of time. Next, the rate of progress decreases and decelerate after a certain period of time. Mathematically, the progress must be an inverted parabolic graph with a positive number. This results the “Work Actually Done” stock to follow S-Shape. Thus, this result is checked when the relationship for “Progress” flow is defined at this stage. Moreover, additional variables are introduced to clarify the relationship within the stock and flow diagram.

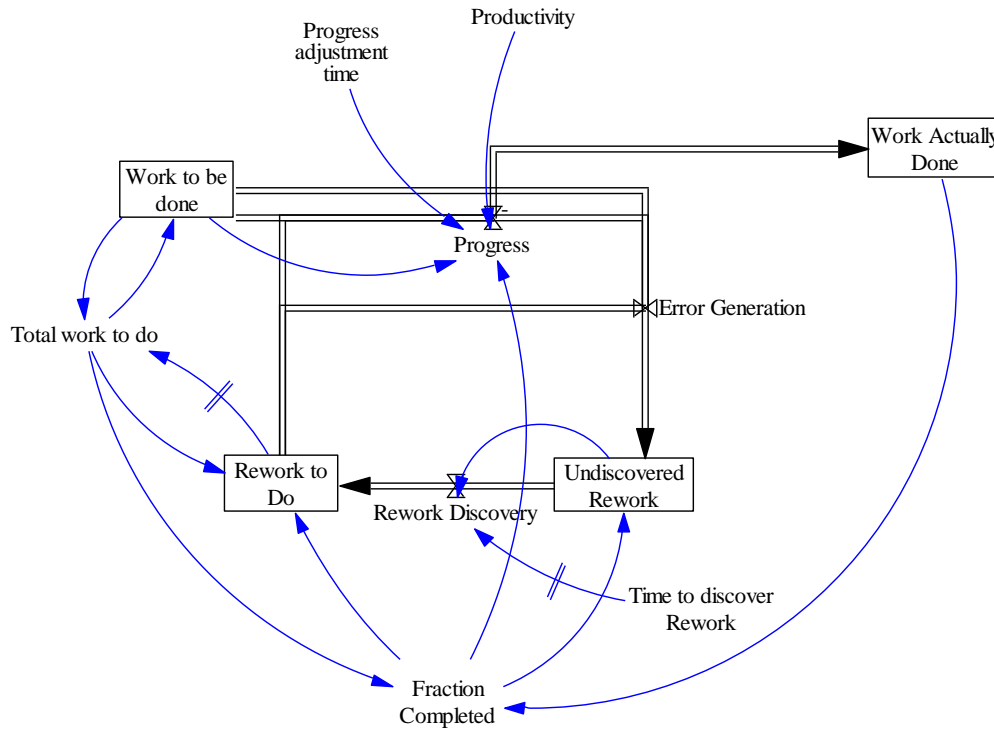


Figure 6-11 Creating the relationship for the work progress

Once the basic model is developed properly, three independent stock and flows are defined for additional work and project costs. The stock “Additional Work” is defined to accumulated work that evolves from the clients or other stakeholders due to the scope growth. The scope growth has its own multifaceted causes illustrated in Figure 6-2. The scope growth rate is dependent on the rate of change of scope and the scope change induced by many factors.

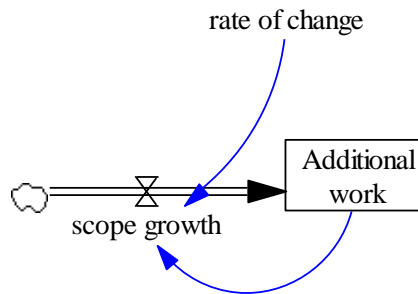


Figure 6-12 Additional Work Stock and Flow Model

Similarly, the addition of more work beyond the planned range of tasks within the project results in an addition of more cost and time overrun, generally deviation from the project objective. In addition, the occurrence of time overrun within the project affects the indirect

costs of the project. Consequently, the direct relationship between time overrun and cost overrun are considered. Furthermore, the accuracy of cost estimation of the contractor during the bidding stage determines the cost overrun. Inaccurate cost estimation results cost overrun during the execution of the project.

The change in the project cost is affected by rework discovery rate and scope growth as shown in Figure 6-13.

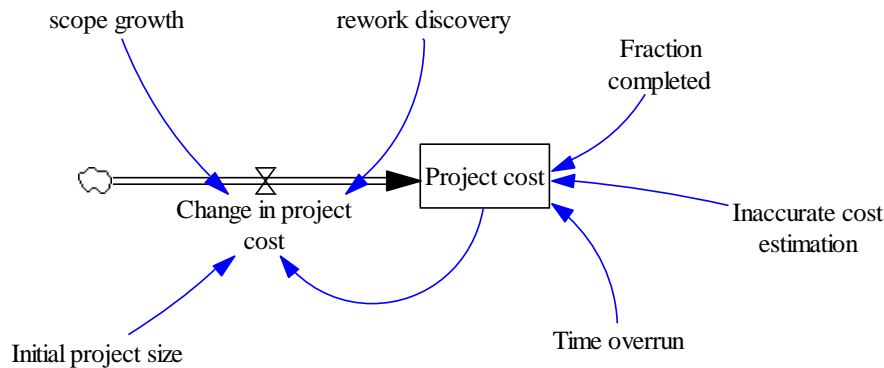


Figure 6-13 Stock and Flow model for Project cost

Likewise, the project duration of the project is influenced by considering the time required to process the additional work and the rework. The accumulated duration of the project is depicted using the stock and the rate of accumulation is represented by flow model as illustrated in Figure 6-14.

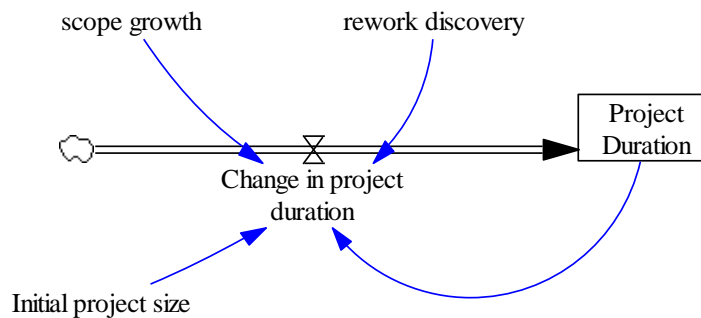


Figure 6-14 Stock and Flow Model for Project Duration

The overall SD model for the Cost overrun and time overrun of the project is constructed by integrating of the above three stock and flow models namely the additional work, project duration and project cost with the basic models shown in the Figure 6-11.

The overall system dynamics model contains enormous feedback loop. However, the research mainly focuses on scope change, productivity, error, time overrun and cost overrun variables. Scope change has thirty-four, productivity has twelve, error has eleven, time overrun has one and cost overrun has two feedback loops.

## 6.8. Mathematical Formulation

The mathematical equations of the overall system dynamics model are formulated based on the causal loop diagram and their impact on each other through simulation time. Moreover, the dynamic behaviours of each risk factor on the project objectives are taken into consideration during model formulation. Table 6-7 shows the mathematical equations for all variables within the overall system dynamics model.

*Table 6-7 Mathematical formulae for each variable used for SD Model*

<b>Variable</b>	<b>Mathematical Relation</b>	<b>Unit</b>
Additional work	INTEG (scope growth, 0.001)	Hour
Bribery and Corruption	Constant	Dmnl
Change in material type	Shortage of Construction material + Low Quality of Material	Dmnl
Change in Project cost	Project cost*(scope growth + Rework Discovery) /Initial Project size	Birr/Day
Change in project duration	Project duration * (scope growth + Rework Discovery)/Initial Project size	hour/Day
Client Management ability	Fraction of additional work	Dmnl
client related risk factors	Contract Modification + inappropriate intervention by client + The need to change the design by the client - Client Management ability	Dmnl
Consultant's lack of experience	Inappropriate Selection of Consultant's/Designer	Dmnl
Contract Modification	The need to change the design by the client*(1-Fraction of additional work)	Dmnl
contractor lack of experience	Bribery and Corruption	Dmnl
Contractor poor management capacity	contractor lack of experience	Dmnl
Cost overrun	Project cost/Planned project cost	Dmnl
Currency Fluctuation	Constant	Dmnl

delay in consultants' response to requested information	Constant	Dmnl
Delay in contractors' payment certification by Consultant	Constant	Dmnl
delay in design work	(design error + The need to change the design by the client )*(1- Fraction of additional work)	Dmnl
design error	Poor Quality of design + incomplete design + Inadequate review of Drawing	Dmnl
design related risk factors	delay in design work + design error + Poor Quality of design	Dmnl
Error	(1+design error) * Error Fraction (Fraction Completed) *(1+poor site management and supervision)	Dmnl
Error Fraction	Lookup ([[0,0)-2.5,1]), (0,0.005), (0.1,0.0235), (0.2,0.0545), (0.3,0.075), (0.4,0.085), (0.5,0.087), (0.6,0.087),(0.7,0.089), (0.8,0.091), (0.9,0.093), (1,0.093), (2.5,0.093))	Dmnl
Error Generation	Progress*Error Fraction (Fraction Perceived Done) * (1+Improper Construction methods) * (1+Improper Quality Control and Testing Method) *(1+Unskilled Labour)	Hour/Day
FINAL TIME	2800	Day
Forced Majeure	"Heavy flood, landslide, earthquake" + Pollution caused by construction + Poor site conditions +Weather Conditions	Dmnl
Fraction Completed	Work Actually Done/(Work Actually Done + Total work to do)	Dmnl
Fraction of additional work	Additional work/Total work to do	Dmnl
Fraction Perceived Done	Work Actually Done/(Initial Project size + Undiscovered Rework)	Dmnl
Frequent Damage of equipment	Poor site conditions	Dmnl
Government intervention	Constant	Dmnl
"Heavy flood, landslide, earthquake"	Constant	Dmnl
Import Restriction	Constant	Dmnl
Improper Construction methods	Constant	Dmnl

Improper Quality Control and Testing Method	Constant	Dmnl
Inaccurate cost estimation	Contractor poor management capacity + Cost overrun	Dmnl
Inadequacy of Specification	Lack of Coordination among design disciplines	Dmnl
Inadequate review of Drawing	unclear and inadequate details in drawing + Lack of Coordination among design disciplines	Dmnl
Inadequate site information	Constant	Dmnl
Inadequate site investigation	Inadequate site information	Dmnl
inappropriate intervention by client	1-Client Management ability	Dmnl
"Inappropriate Selection of Consultant's/Designer"	Bribery and Corruption	Dmnl
incomplete design	Inadequate site information + Poor Quality of design + Inadequacy of Specification + Inadequate review of Drawing	Dmnl
Initial Project size	Constant	Hour
Labour Productivity	Labour Unavailability + Unskilled Labour	Dmnl
Labour Unavailability	Constant	Dmnl
Lack of Coordination among design disciplines	Consultant's lack of experience	Dmnl
Land and property value	Constant	Dmnl
Low Quality of Material	Constant	Dmnl
Payment delay	Delay in contractors' payment certification by Consultant + Slow Decision making	Dmnl
Perceived Progress	Work Actually Done/(Undiscovered Rework + Work Actually Done)	Dmnl
Planned project cost	Constant	Birr
Planned project duration	Constant	Hour
plant and Equipment productivity	Frequent Damage of equipment + Shortage of plant and Equipment	Dmnl

Pollution caused by construction	Constant	Dmnl
Poor Quality of design	Constant	Dmnl
Poor site conditions	Constant	Dmnl
poor site management and supervision	Contractor poor management capacity	Dmnl
Productivity	1- (delay in consultants' response to requested information + Improper Construction methods + Inappropriate intervention by client + Labour Productivity + plant and Equipment productivity + Project planning and control)	Dmnl
Progress	Productivity*Work to be done*Fraction Completed *(1-Error) * (1-Slow Site handover)/Progress adjustment time	hour/Day
Progress adjustment time	Constant	Day
Project cost	NTEG (change in project cost * Fraction Completed *(1+Inaccurate cost estimation) * (1+Time overrun), 100,000,000)	Birr
Project duration	INTEG (Change in project duration, 1,000,000)	Hour
Project planning and control	Constant	Dmnl
rate of change	Constant	Dmnl
Rework Discovery	Undiscovered Rework/Time to discover Rework	Hour/Day
Rework to Do	INTEG (Rework Discovery-Error Generation *Rework to Do/Total work to do + Progress * Rework to Do /Total work to do) *(1-Fraction Completed), 0)	Hour
Right of way	Land and property value +Payment delay + Poor site conditions + Weather Conditions + Inadequate site investigation	Dmnl
Schedule Pressure	1-Perceived Progress	Dmnl
Scope Change	(1-Fraction Completed) * (Change in material type +Inadequate site investigation + Government intervention +Inadequate site information + Forced Majeure + client related risk factors + design related risk factors)	Dmnl
scope growth	(Scope Change*Additional work)/rate of change	Hour/Day
Shortage of Construction material	Currency Fluctuation + Import Restriction	Dmnl
Shortage of plant and Equipment	Constant	Dmnl
Slow Decision making	delay in design work	Dmnl

Slow Site handover	Payment delay + Right of way	Dmnl
The need to change the design by the client	Constant	Dmnl
Time overrun	Project duration/Planned project duration	Dmnl
Time to discover Rework	WITH LOOKUP (Fraction Perceived Done, ((0,0)-(2.5,400)],(0,30),(0.1,30),(0.2,30),(0.3,30),(0.4,28.5),(0.5,24),(0.6,10.5),(0.7,6),(0.8,4.5),(0.9,3),(1,3),(2.5,3) )	Day
Total work to do	Rework to Do + Work to be done + Additional work	Hour
unclear and inadequate details in drawing	Lack of Coordination among design disciplines	Dmnl
Undiscovered Rework	INTEG ((1-Fraction Completed) * (Error Generation-Rework Discovery), 0)	Hour
Unskilled Labour	Labour Unavailability	Dmnl
Weather Conditions	Constant	Dmnl
Work Actually Done	NTEG (Progress, 0.001)	Hour
Work to be done	INTEG (-Progress*Work to be done/Total work to do-Error Generation*Work to be done/Total work to do, Initial Project size)	Hour

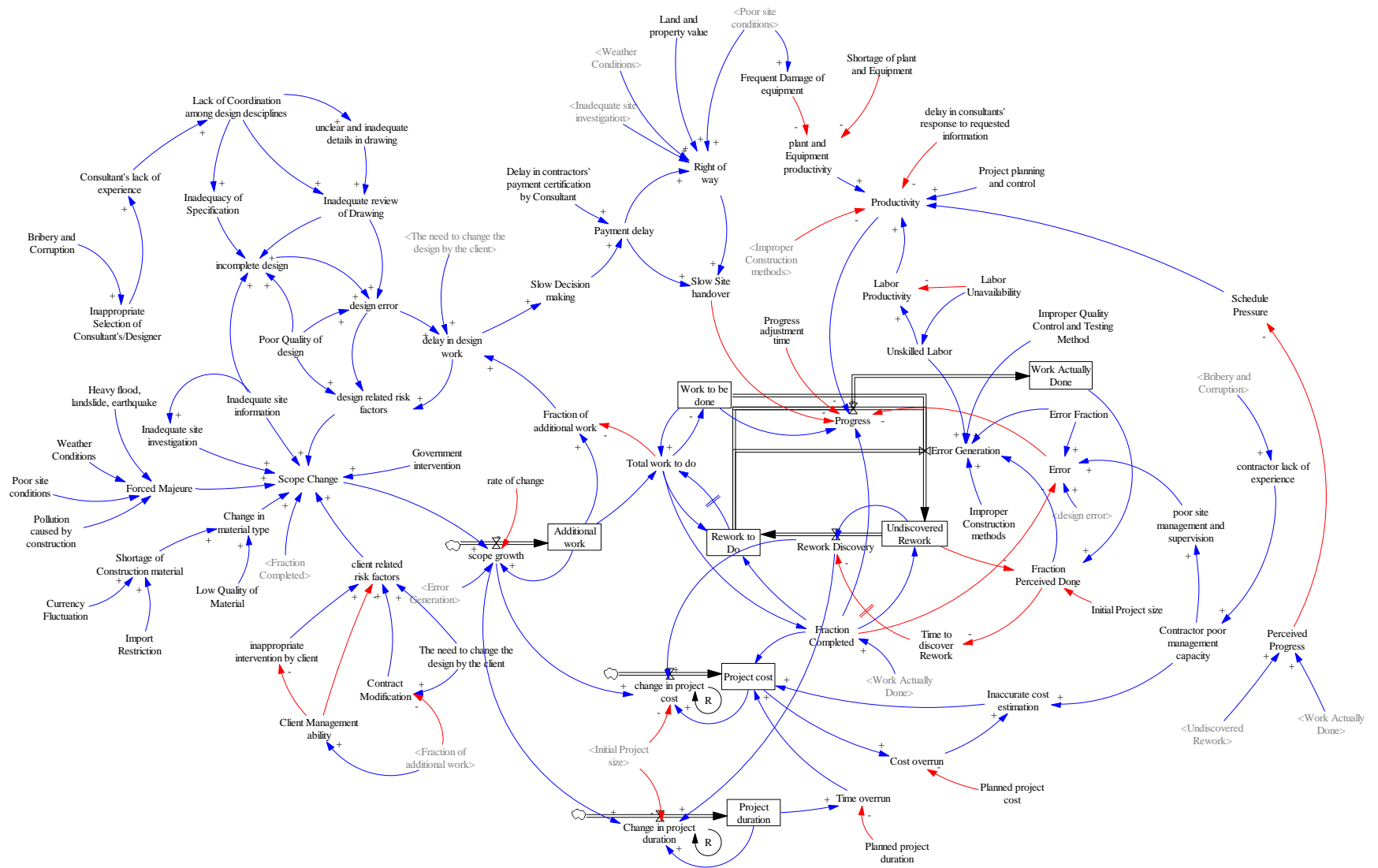


Figure 6-15 The overall SD model for Time and Cost Overrun of a project

## 6.9. Conclusion

This chapter mainly discusses about system dynamics modelling of project risk factors, project cost and time overrun. A system dynamics model is chosen due to the capability of the technique to accommodate the changes of variables over time and the information of feedback loop can be linked. Hence, the developed system dynamics model enables the researcher to capture the effects of risk factors on the project cost and time overrun. In doing so, the relationship between the risk factors and project objectives. Finally, the critical variables are presented.

The model contains sixty-six key variables both endogenous and exogenous. The model boundaries for the model are categorized into three groups (productivity, scope growth and work execution) based on the effects where there are some common variables among these groups. Furthermore, the variables are differentiated as exogenous and endogenous based on the dependencies. The productivity group contains eleven exogenous variables and seventeen endogenous variables. The Scope growth contains fourteen exogenous and nineteen endogenous variables. The work execution group contains nine exogenous and four endogenous variables.

The causal loop diagram for the scope growth and productivity related risk factors are developed containing four and two feedback loop respectively. Next, the stock and flow model is developed by taking the basic model of project management and introducing the two causal loops developed by this research and considering two additional loops for project cost and time. Finally, the mathematical formulae between each interconnection of variables are defined by considering the logical relationship.

# Chapter Seven Results and Testing of Models

## 7.1. Introduction

The previous chapter presents the modelling techniques, assumptions, the type and representation of the variables. This chapter discusses the results of the system dynamics simulation. The relationship between key variables mainly exogenous risk factors against the project cost and duration will be presented.

In addition, the sensitivity analysis of a group of risk factors will be conducted and presented. The sensitivity analysis will be done by varying the aggregation of risk factors within the category with some range and the results of this aggregation on the project cost and time will be discussed.

## 7.2. Simulation run and results

The SD model developed for studying the relationship between different risk factors occurring in road construction project with the time and cost overrun is simulated for 1800 days. Initially, the theoretical project execution is tested for the project cost and schedule where all the exogenous risk factors are set to be zero. Then, each of the exogenous variables are varied by 5 and 10 percent and the impact on the project duration and cost are studied. The results are presented based on the two classification of the variables used in the previous chapters i.e. scope growth and productivity.

### 7.2.1. Effects of Design change on work addition, project cost and time

The first exogenous variable considered from the scope growth category is the need to change the design by the client risk factor. This risk factor is an exogenous variable which directly affects delay in the design work. An increase in the need to change the design by the client increases the delay in design work. However, this factor declines as the project progressed as shown in Figure 7-1. The inflection point for decline varies based on the percentage of the design change.

The 5 or 10% increment of the design change results proportional increment of delay in the design work. However, it is only true for a certain period of time. The first increment (5%) on the need to change the design by client results 5% increment on the delay design but as the work is executed, the delay in design work decreases. This rate of change is visible from 712

days onward. Likewise, the delay in design work decreases as the time goes specifically from 562 days onward for the graph design change by client 10%.

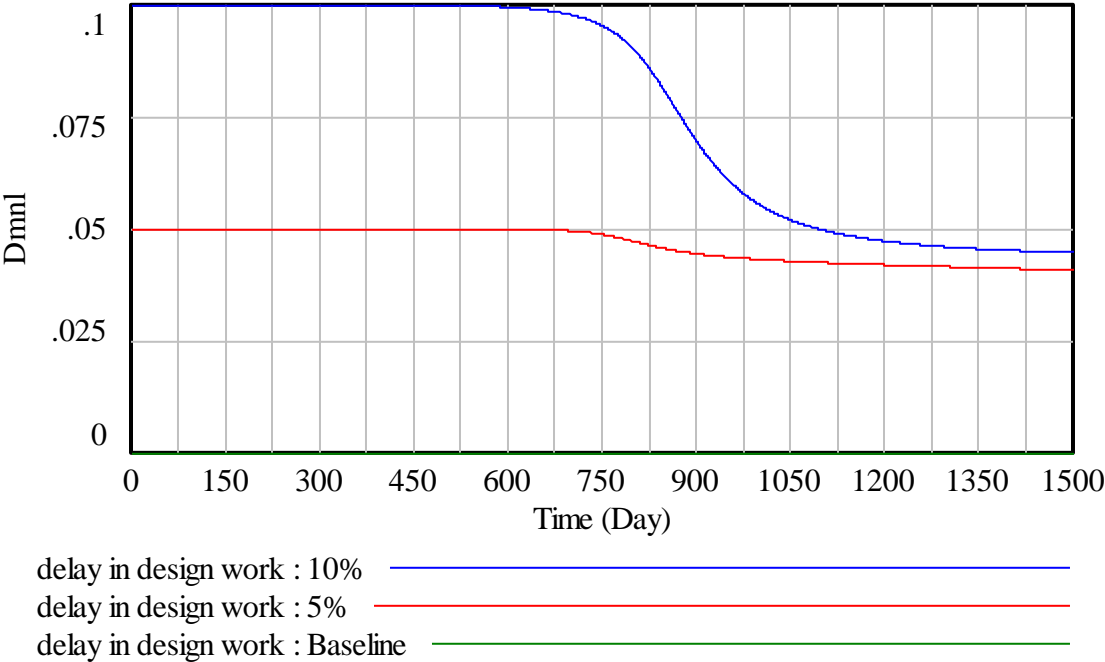
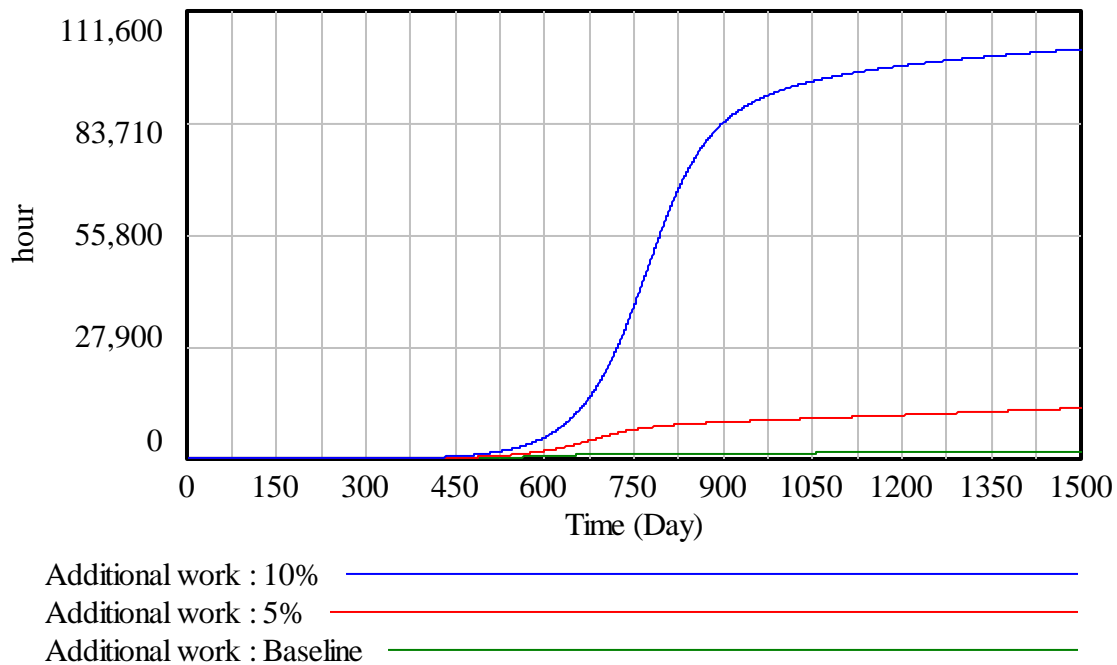


Figure 7-1 Simulation result of delay in design work by varying the need to change the design by the client risk factor with 5 and 10%

On the other hand, the effects of the design change by the client on the additional work is presented in Figure 7-2. The need to change the design by the client affects directly the additional work in the project. However, the scale of addition is significant between 5 and 10% variation on the need to change the design by the client. The total of 12,669 hours of work are added due to the 5% change in the value of the design change. However, there is 102,100 hours of work are added due to the 10% change in the value of design change.

The difference between the 5 and 10% change in the value for the need to change the design by the client is only 10 hrs until 242 days. On day 333, the variation between these two is 50 hrs. after 43 days from this, the difference is going to be doubled and the variation is 100 hrs. The figure illustrates that the additional work for 10% change is growing exponentially until 875 days and declines from this day onward.



*Figure 7-2 Simulation result of Additional Work by varying the need to change the design by the client risk factor with 5 and 10%*

The relationship between the risk factor “the need to change the design by the client” with project cost is shown in Figure 7-3. The result indicates that the increase in the risk factor “the need to change the design by the client” results in an increase in project cost but the visibility of the effect of this variation on the project cost is delayed as the risk factor magnitude increases. When the risk magnitude is set to be zero, the rate of change of project cost increases after 675 days. However, for 5% and 10% increment on the risk magnitude, the rate of change of project cost increases after 750 and 825 days.

The total project cost has increased from 158 Million to 160 Million for 5% change and to 195 Million for 10% change in the risk factor under consideration. Thus, the addition of 10% change in the risk factor results in 95% additional costs.

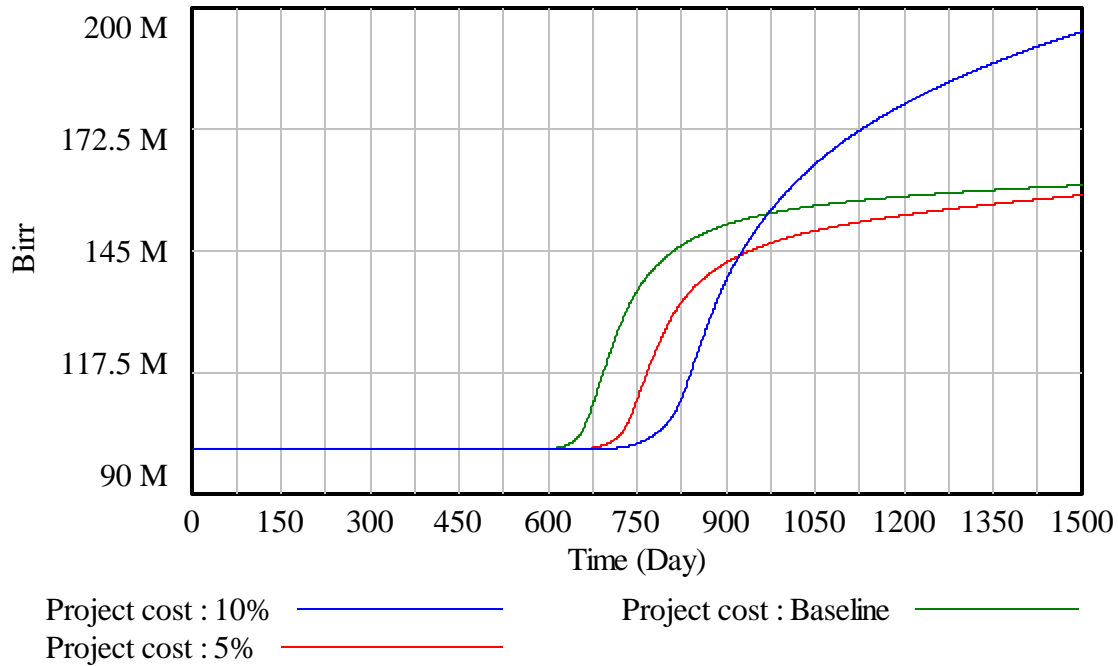


Figure 7-3 Simulation result of Project Cost by varying the need to change the design by the client risk factor with 5 and 10%

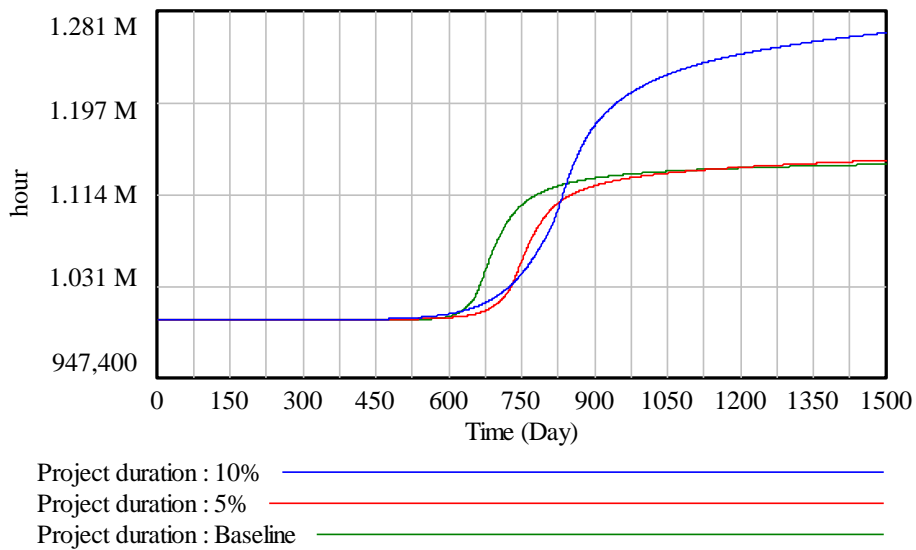


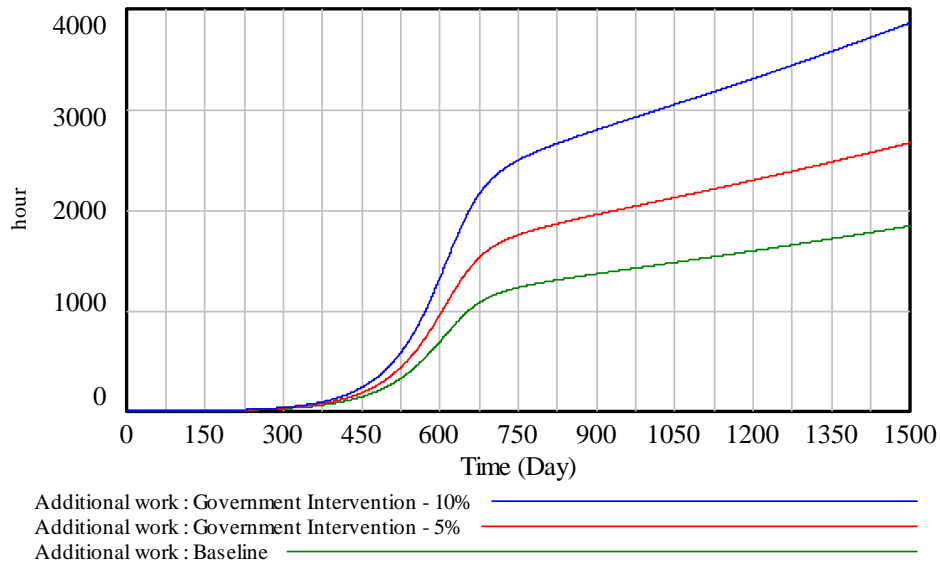
Figure 7-4 Simulation result of Project Duration by varying the need to change the design by the client risk factor with 5 and 10%

The project duration is also affected by the percentage change in the magnitude of risk factor the need to change design by the client. The additional time required for the change in the

risk magnitude by 5% is only 3,400 hours of work. However, the additional time required for the change in the risk magnitude by 10% is about 119,340 hours of work which is significant.

### 7.2.2. Effects of Government Intervention on project time and cost

The effect of risk factor by government intervention is also studied by varying the magnitude of the risk factor by 5 and 10 percent and seeing the results of additional work, project cost and time. The result revealed that the change in this risk factor increases the additional work proportionally. For every 5% increment in magnitude of this risk factor results in 44.67% increase in the work. The total work addition at the end of 1500 days due to 5 and 10% addition of work is 2669 and 3861 hours of work.



*Figure 7-5 Simulation result of Additional work by varying the government intervention risk factor with 5 and 10%*

The change in the total project cost is also analysed based on the increment of the risk factor by government intervention. The result indicates that the change in the total project cost as compared to the investment is not significant. The change in the magnitude of the risk factor by 5% results in an additional cost of 210,000 birr additional cost on the project. Likewise, 330,000 birr additional cost is incurred in the project due to the addition of another 5% on the risk magnitude.

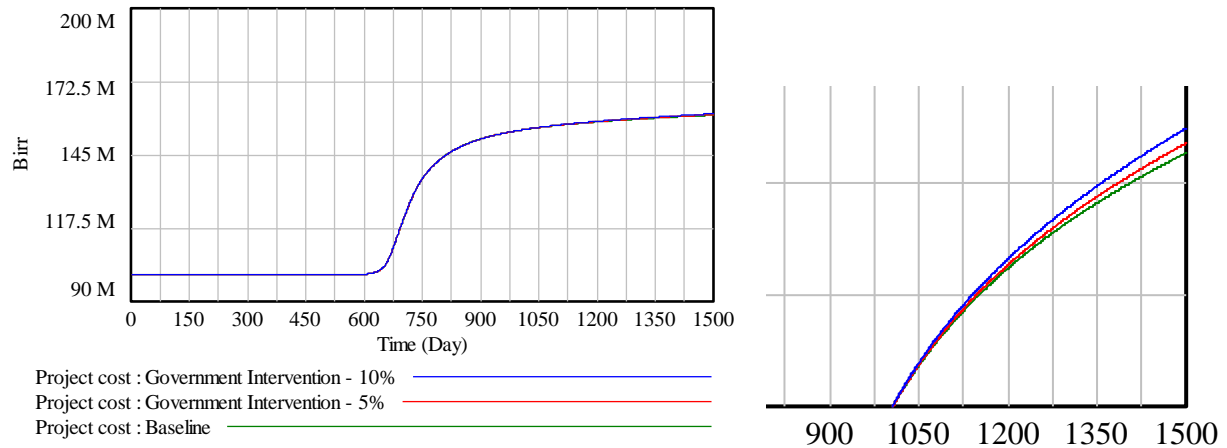


Figure 7-6 Simulation result of Project cost by varying government intervention risk factor with 5 and 10%

Similarly, the change in the magnitude of the project affects the project duration but not significantly as compared to the project lifespan. The effect of the total project duration due to the 5 and 10% addition of magnitude on the government intervention risk factor is 750 and 1100 hours of work.

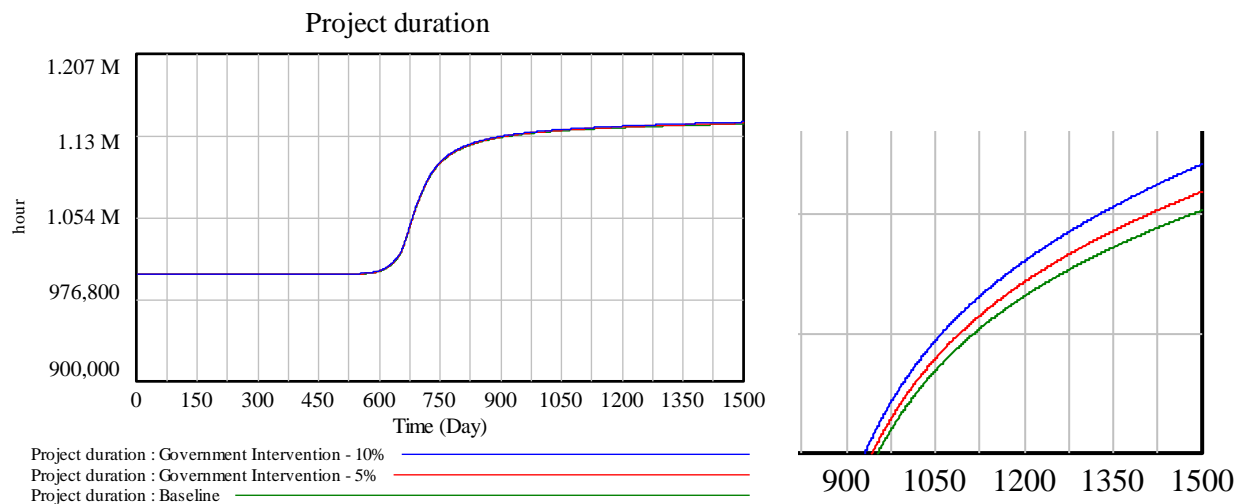


Figure 7-7 Simulation result of Project duration by varying government intervention risk factor with 5 and 10%

This result can be used for other risk factors having the same relationship with scope change. These risk factors are risks related to forced majeure (heavy flood, landslide, earthquake, weather condition, poor site condition), pollution caused by construction, currency

fluctuation, import restriction, and low quality of material. These risk factors have the same relation like that of the government intervention on the scope change.

### 7.2.3. Effects of Inadequate site information on project time and cost

Another exogenous risk factor affecting the project objective is inadequate site information. The effect of this risk factor on work addition, project cost and time are shown in Figure 7-8, 7-9 and 7-10.

The change in the additional work due to the 5% increment on the risk factor inadequate site information is 28,774 hours of work. However, if the increment on the risk factor is 10% the additional work on the project is amplified to 589,213. The net additional work for the net increment from 5% to 10% is 558,597 which is 19.4 times higher than the net increment for the first 5%. This may be the cascaded effects of this risk factor on scope change, scope growth, incomplete design, design error, inadequate site investigation and right of way risk factors.

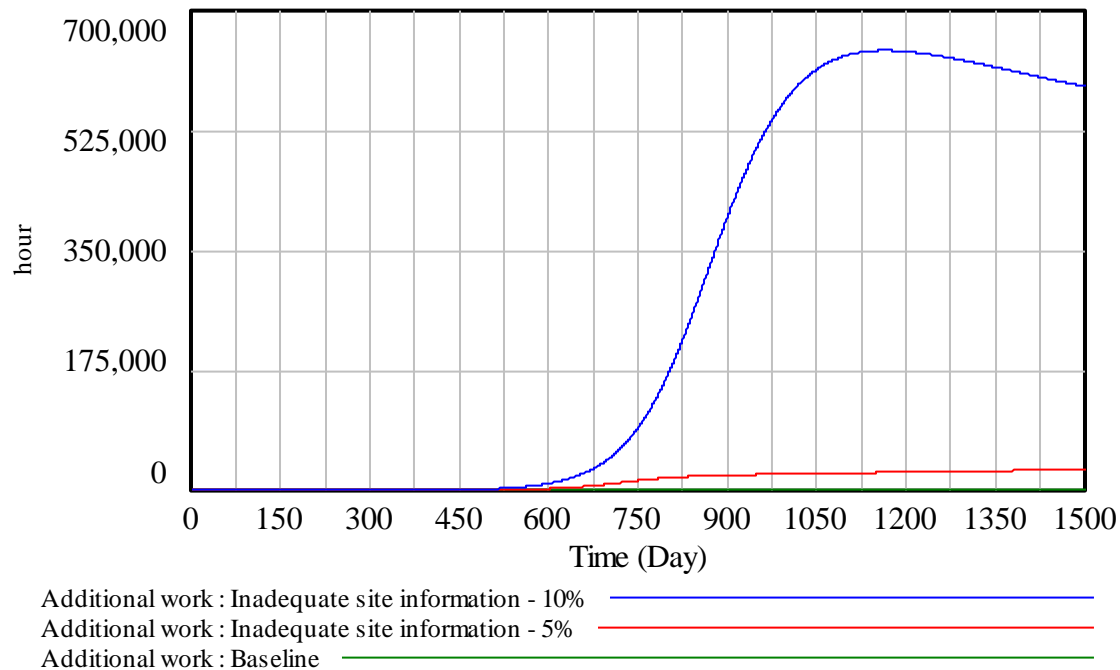
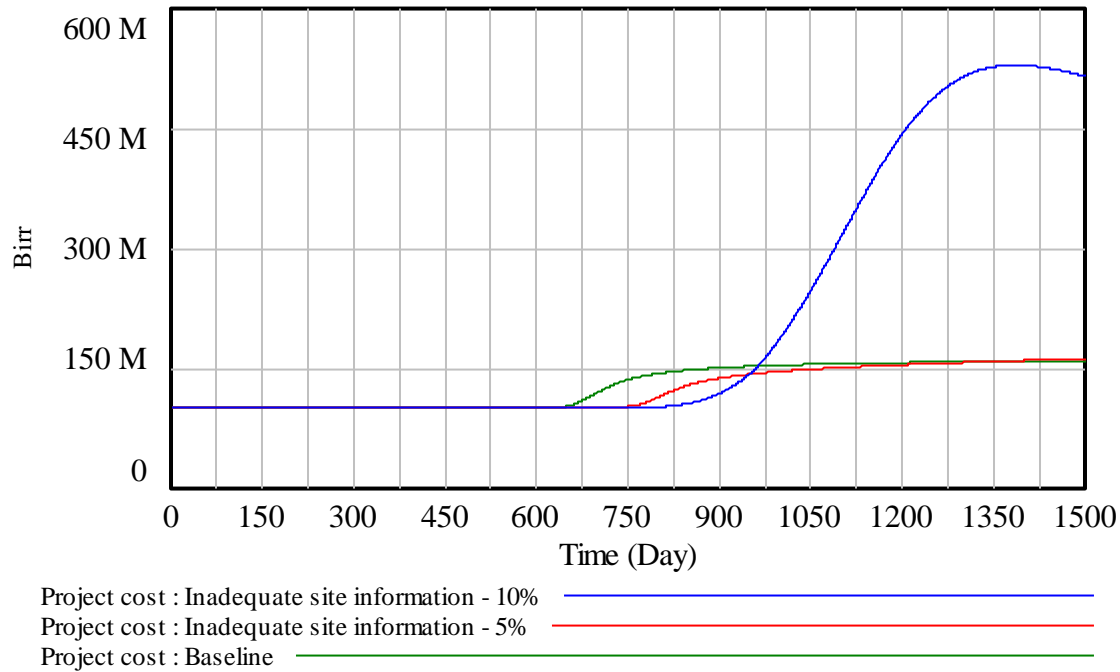


Figure 7-8 Simulation result of Additional Work by varying Inadequate site information risk factor with 5 and 10%

The effect of total project cost due to the variation on the magnitude of risk factor inadequate site investigation has the same pattern like that of the additional work. The additional cost

due to the 5% change on this risk magnitude is 2,342,000 birr. However, 10% increment in the risk magnitude from the baseline results in 353,100,000 birr additional cost.

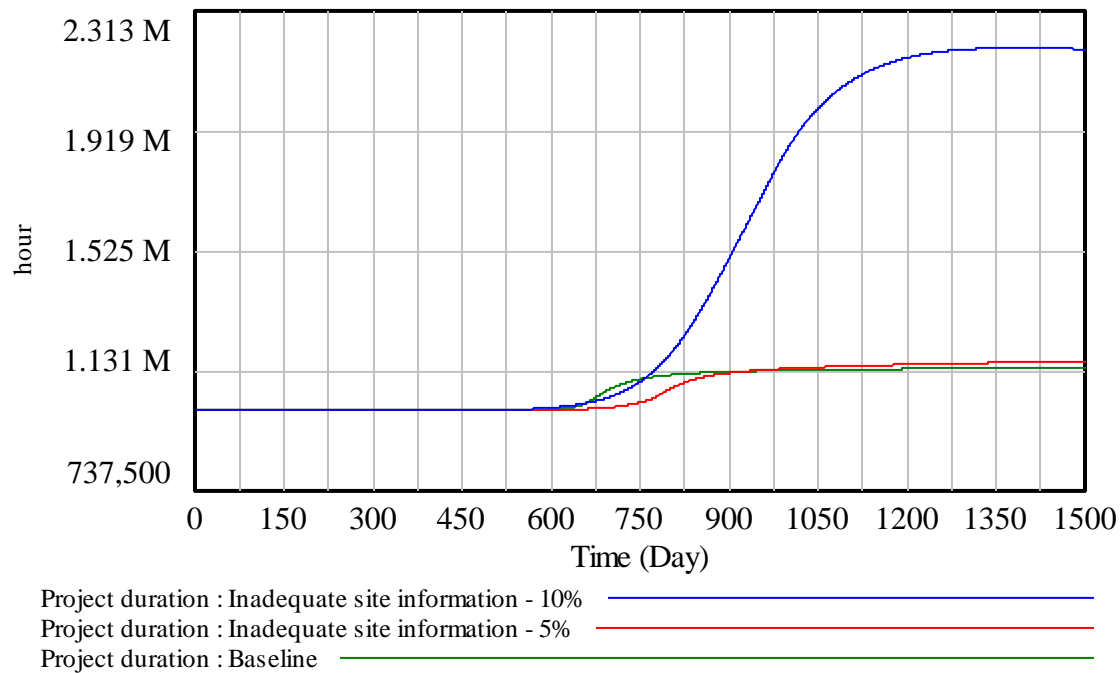
Although this risk is ranked fourth in section 5.3.2, the cascaded effects of this risk will have a significant effect on the total project costs. Thus, the result shows that the individual effects of risk on project cost is different from the cascaded effect.



*Figure 7-9 Simulation result of Project cost by varying Inadequate site information risk factor with 5 and 10%*

The relationship between the risk factor inadequate site information and project duration is depicted in Figure 7-10. The 5% change in the risk magnitude has insignificant impact on project duration as compared to the 10% change in the risk magnitude. The result shows that the 5% change in the magnitude increases the project duration by 21,340 hours of work. However, another 5% increment on the risk magnitude results in 1,023,950 hours of work which will double the total project duration.

The ranking of this risk factor using fuzzy expert system is fourth with the magnitude of 0.4656 as discussed in section 5.3.1. However, this result was obtained by considering the individual risk factor. The cascaded effects of the risk factor on the project duration is different from the individual effect.



*Figure 7-10 Simulation result of Project duration by varying Inadequate site information risk factor with 5 and 10%*

#### **7.2.4. Effects of poor quality of design on project time and cost**

The effect of a risk factor poor quality of design on the project cost and time is analysed by varying the magnitude of the risk factors into 5, 7.5 and 10% values. The change in the magnitude of this risk magnitude by 5% results in 72,642 hours of work. Likewise, an increment of the risk factors by 2.5% from the previous magnitude results in 382,509 hours of work. An additional increment of risk factor by 2.5% results in a substantial addition of work in a project as shown in Figure 7-11.

The impact of these additional work on the project cost and time is reflected for 5 and 7.5% of the risk factors in Figure 7-12 and 7-13. However, the impact 10% increment on the risk magnitude of poor quality of design is not visible on the total project cost. Nevertheless, the project duration is increased thirty times from the baseline. As it is shown in Figure 7-12, an increase in the magnitude of the risk factor results in a delayed project mobilization. Thus, the cost expenditure is not significant during the courses of the project. i.e. 1500 days are

spent without some significant activities within the project due to an increase in this risk factor. This result is also the same for the risk factor “Bribery and Corruption”.

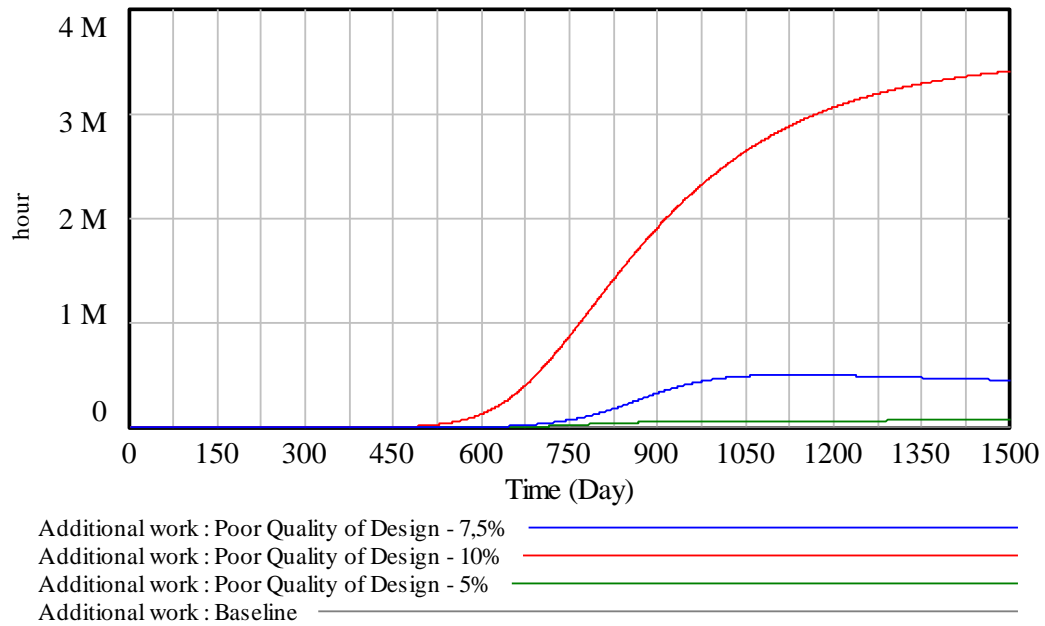


Figure 7-11 Simulation result of Additional Work by varying Poor quality of design risk factor with 5, 7.5 and 10%

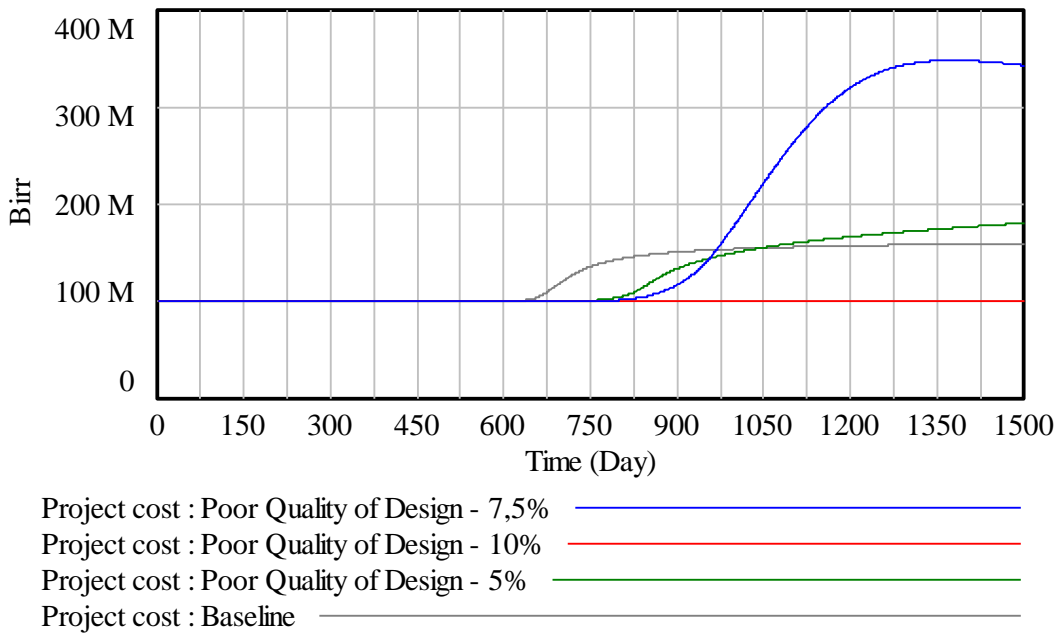
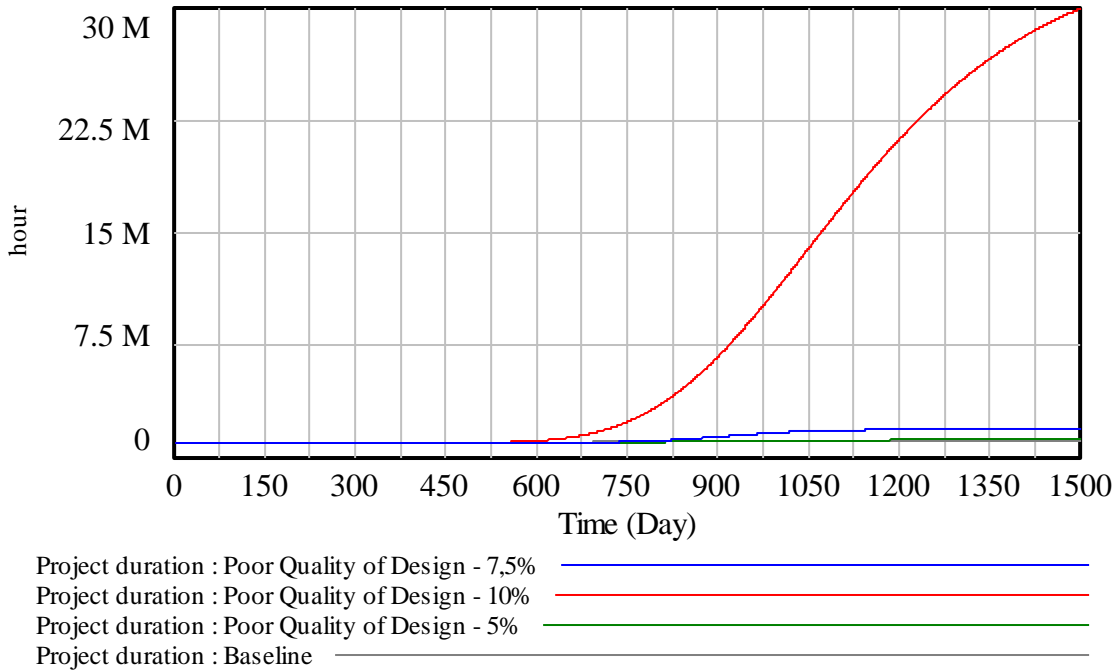


Figure 7-12 Simulation result of Project cost by varying Poor quality of design risk factor with 5, 7.5 and 10%



*Figure 7-13 Simulation result of Project time by varying Poor quality of design risk factor with 5, 7.5 and 10%*

### **7.2.5. Effects of delay in contractors' payment certification by consultant on project cost and time**

The value of the risk factor delay in contractors' payment certification by consultant is varied by 5 and 10% to study the impact on the project progress and ultimately project time and cost. The result indicates that the delay in payment certificate affect the rate of progress of the project. Figure 7-14 revealed that the increase in the magnitude of this risk factor results in the shift in the progress of the project to the right. This mean the project execution momentum will be prolonged. Initially, the rate of progress is increasing the momentum between the period 375-450 days. However, an increase in the risk factor by 5% results in the shift of the momentum after 450 days. Likewise, an additional 5% increment in the risk factor magnitude delayed the momentum to be after 525 days.

In addition, the peak progress rate per day decreases as the magnitude of the risk factor increases. This is due to the impact of this risk factor on the productivity of the project work.

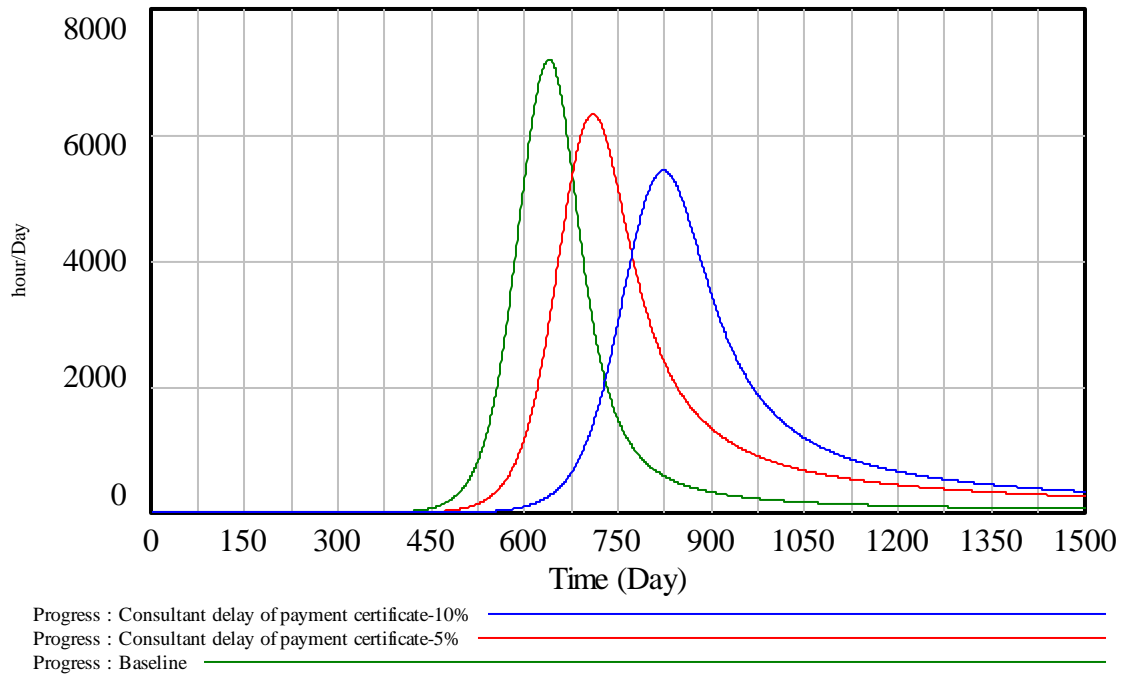


Figure 7-14 Simulation result of project progress by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%

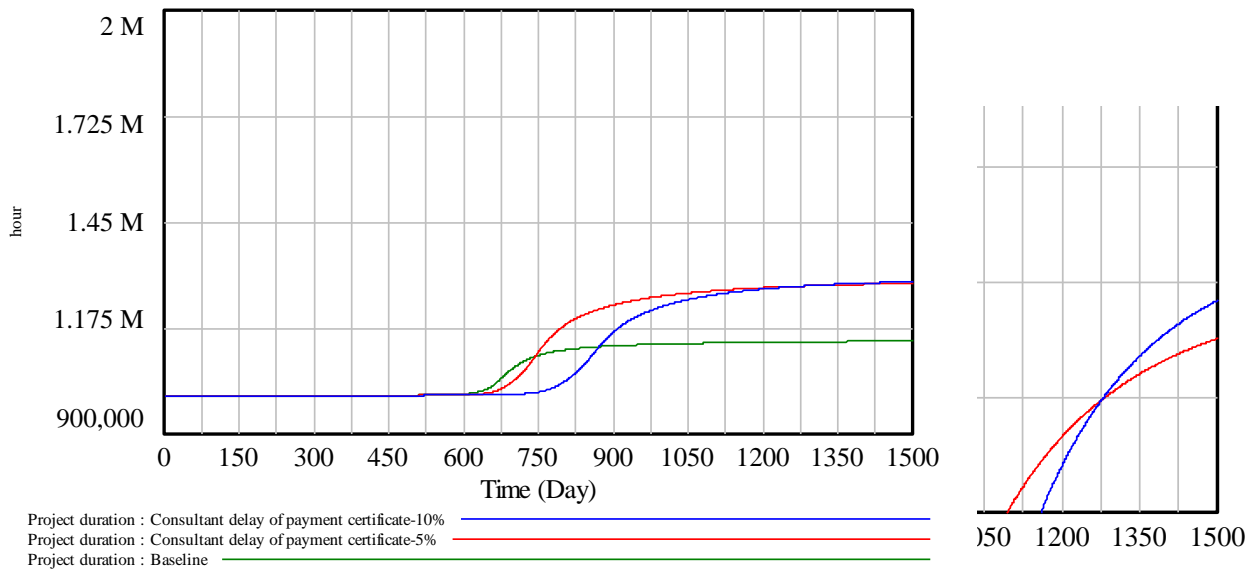
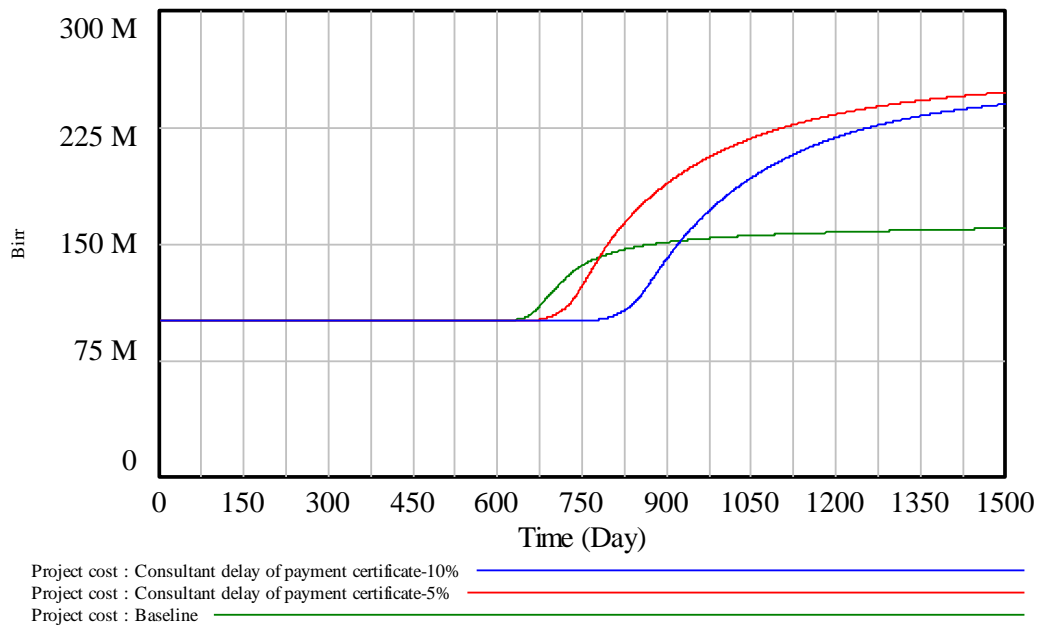


Figure 7-15 Simulation result of project duration by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%

The project duration is also affected by the change in the magnitude of this risk factor. Figure 7-15 shows the effects of this risk factor on the total project duration. An increase in the magnitude of risk factor delays the project execution and results in additional time extension from the original plan. A 5% increment on the risk magnitude results in an additional time of 149,440 hours of work. Also, the project duration will be extended by 153,760 hours due to the 10% magnitude of this risk factor.

However, the effect of the additional risk factor is not visible on the project cost due to the delayed project progress results in a delayed financial expenditure as shown in Figure 7-16. However, if the project period is extended, the impact of an increment in the risk magnitude can be reflected.

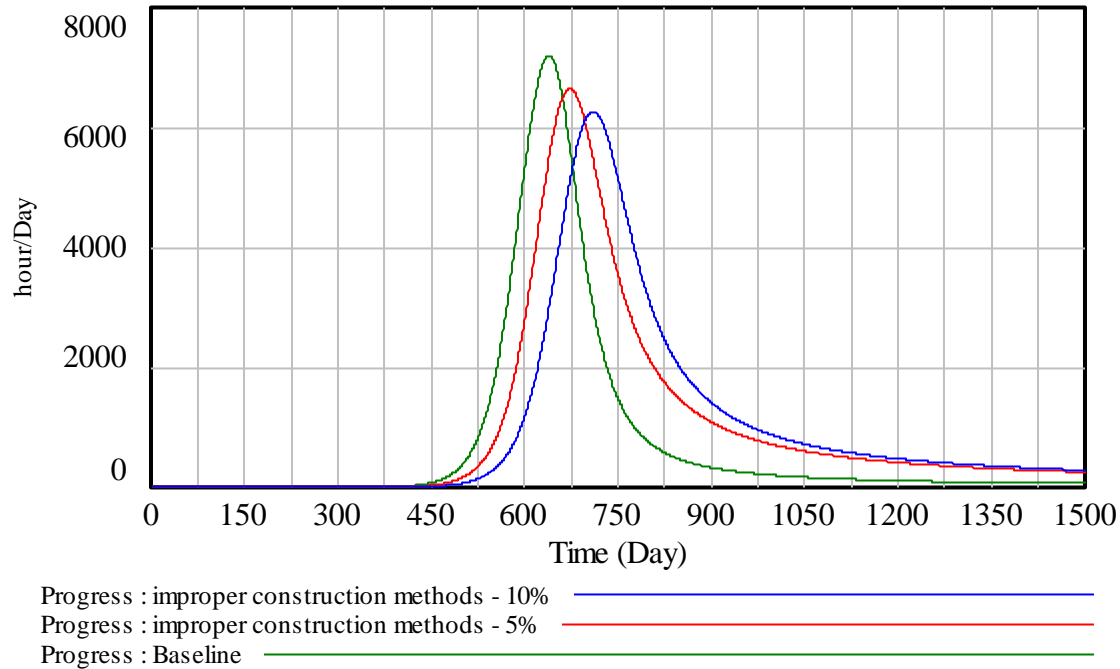


*Figure 7-16 Simulation result of project cost by varying delay in contractors' payment certification by consultant risk factor with 5 and 10%*

The same relationship can be obtained with the risk factor of land and property value, project planning and control and delay in consultant response to the requested information.

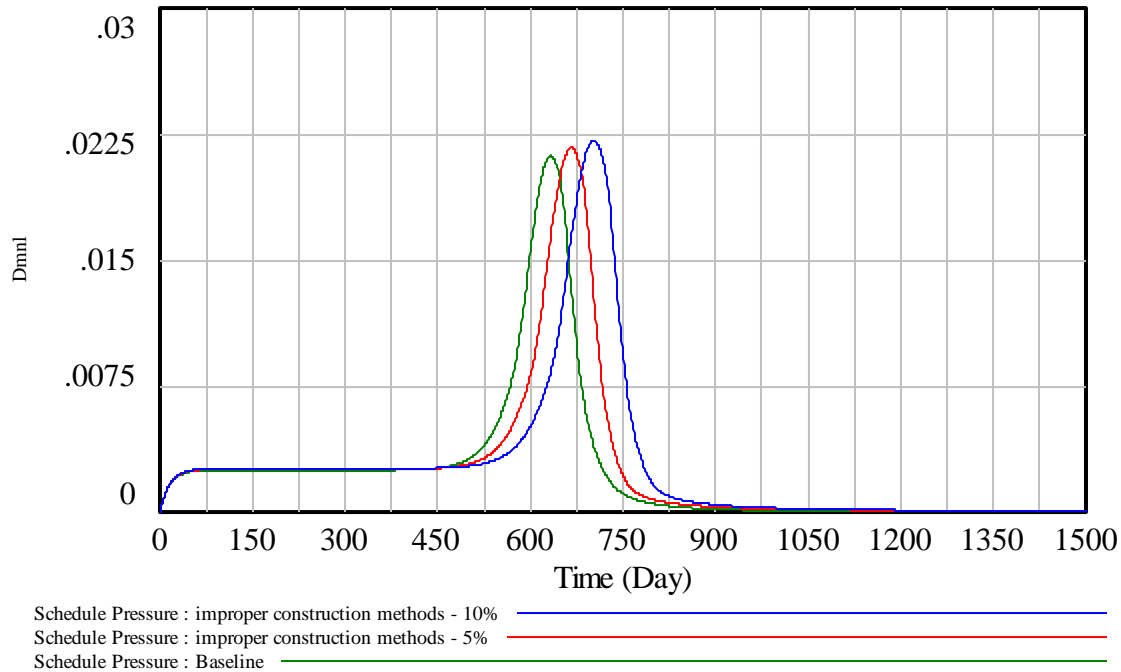
### 7.2.6. Effects of Improper construction method on project cost and time

The impact of improper construction method on the project progress is depicted in Figure 7-17. An increase in the magnitude of the risk factor affects the project progress negatively and the progress declines and shifts to the right.



*Figure 7-17 Simulation result of project progress by varying improper construction method risk factor with 5 and 10%*

Due to the decline in the project progress, the schedule pressure by the client is increasing and an additional risk factor is propagating as shown in Figure 7-18. The moment the project is started the schedule pressure by the client increases up to 0.25% and changes insignificantly until the period of 450 days. Thereafter, the schedule pressure will increase to the magnitude of 2.21% on the 702 days of the project period and then declines when the risk factor improper construction method has the magnitude of 10%. Due to the increment of this risk factor, the intensity of schedule pressure over the period changes.



*Figure 7-18 The change in the risk magnitude of schedule pressure due to the change in the improper construction methods.*

The project time and cost is also affected directly due to the increase in the magnitude of the risk factor improper construction methods. The effect of this risk factor on the project objective is delayed by a certain period of time as shown in Figure 7-19 and 7-20. Thereafter, the rate of change of project time and cost increased at a higher rate when the risk magnitude increased.

Thus, due to the change in the risk magnitude by 5% results in an increase in the project duration by 167,910 hours of work. Similarly, the increment of the risk magnitude by 10% results in an increment of the project duration by 185,940 hours.

Whereas, the project cost has increased by 109,456,000 and 126,027,000 birr due to the increase in the risk magnitude improper construction methods by 5% and 10%.

The result of this relationship can be extrapolated for other exogenous risk factors such as shortage of plant and equipment and labour unavailability. This is due to the existing relationship between the risk factors with the productivity specifically and the whole system in general.

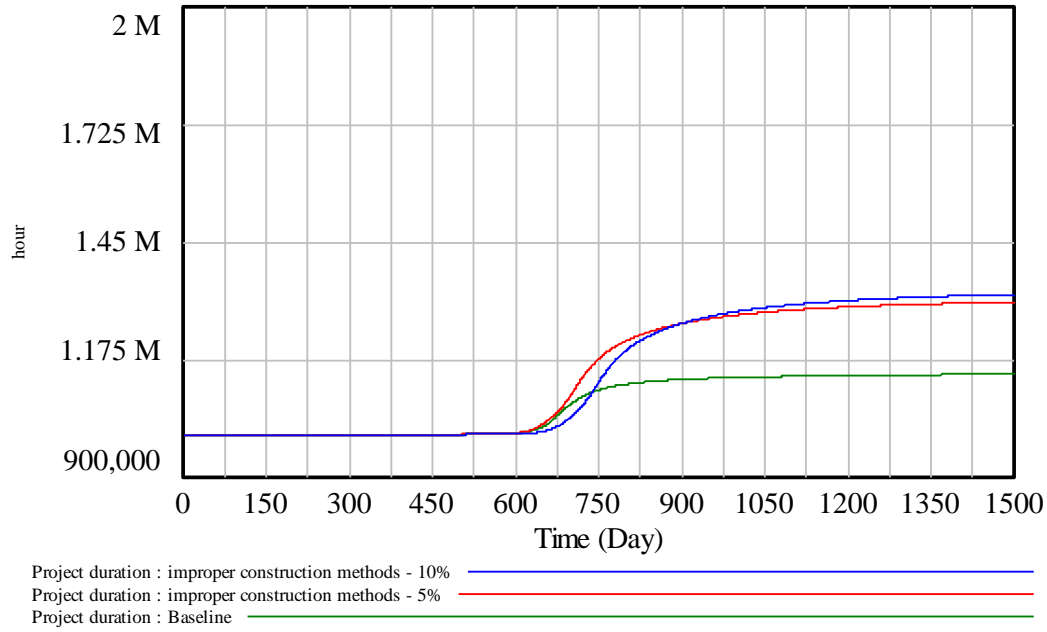


Figure 7-19 Simulation result of project duration by varying improper construction methods risk factor with 5 and 10%

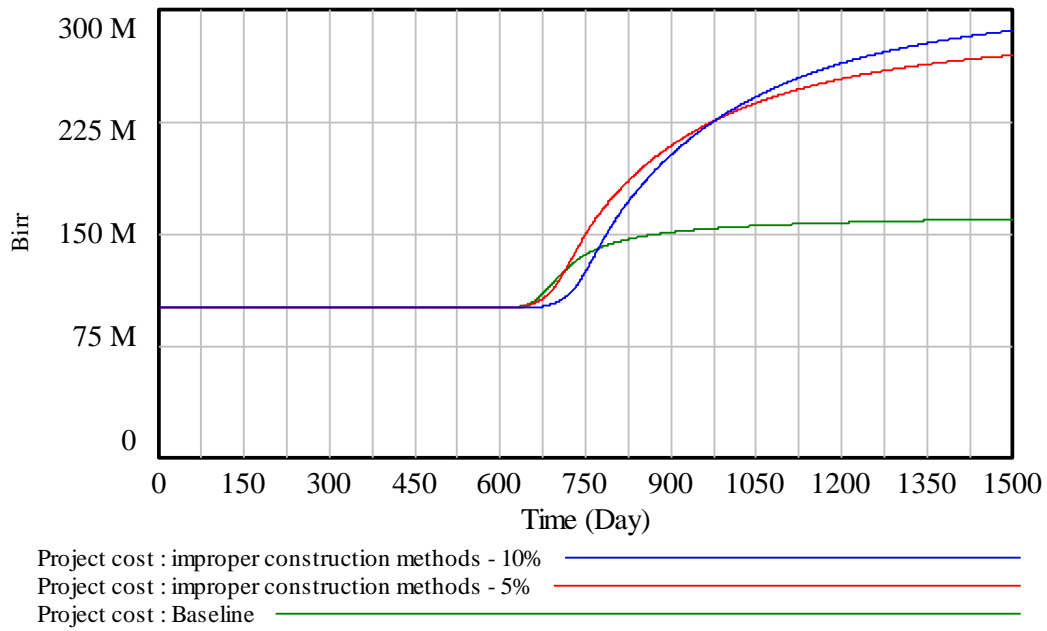


Figure 7-20 Simulation result of project cost by varying improper construction methods risk factor with 5 and 10%

### **7.3. Sensitivity analysis**

Sensitivity analysis is examining the impact of changes in the input (nature and magnitude) on the outputs (Shearer et al., 2010). Aggregation of risk factors are used to vary the magnitude and study the impact on project time and costs. Thus, to study the collective impacts of risk factors on the project objective, it should be grouped. The grouping of risk factor can be based on the nature of risks and sources of risks. Broadly, these risks are grouped into the following five categories i.e. environmental, stakeholder, site, economic and contractor related risks. Therefore, the respective risk factors are under each category is examined for the sensitivity analysis by varying the magnitude of risk factors from 0 to 0.1.

The type of sensitivity analysis this research is concerned with is on numerical and behaviour mode. The results are examined for the change in the numerical values and pattern by changing the magnitude of the risk factors. The dynamic confidence interval for the variables are obtained by running 500 monte carlo simulation. Accordingly, the results show 50%, 75% and 95% confidence bounds for each category. The results of the sensitivity analysis for each category is discussed as follows.

#### **7.3.1. Environmental related Risks**

Three risk factors are grouped into this category, namely forced majeure, weather condition and pollution caused by construction. The aggregation of this risks is grouped together to simulate the sensitivity analysis by varying it from 0 to 0.1 magnitude as mentioned above.

Forced majeure, weather condition and pollution caused by construction are all assumed to be distributed normally and independently. With this assumption, the result indicates that there is 50% chance that the project cost will be between 275 and 303 million birr at the end of the project. The 75% confidence interval for the project cost is between 266 and 319 million birr. There is 95% chance that the project cost will be between 256 and 350 million. Graphical representation of the project cost sensitivity due to environmental related risk factors are depicted in Figure 7-21.

The project duration is also evaluated with three different degrees of confidence as shown in the Figure 7-22. The result indicates that the range of project duration with 50% degree of confidence is between 1.32 and 1.35 million of hour. The project duration lies between 1.31

and 1.37 million of hour for 75% degree of confidence. Similarly, the 95% confidence interval for project duration is between 1.3 and 1.4 million of hour.

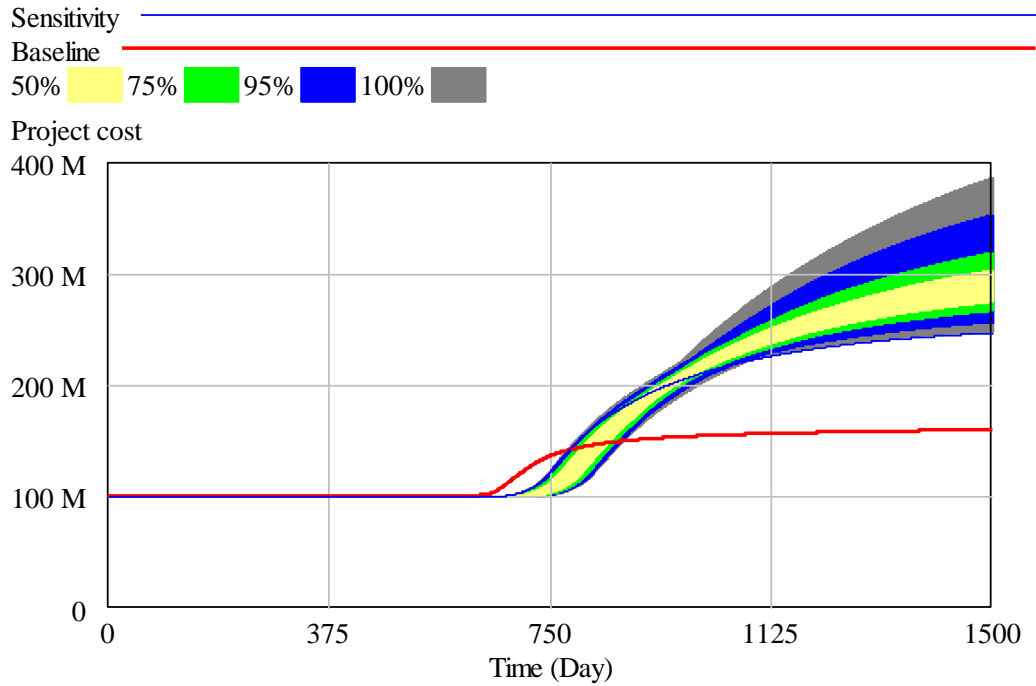


Figure 7-21 Sensitivity graph for project cost due to Environmental related risk factors

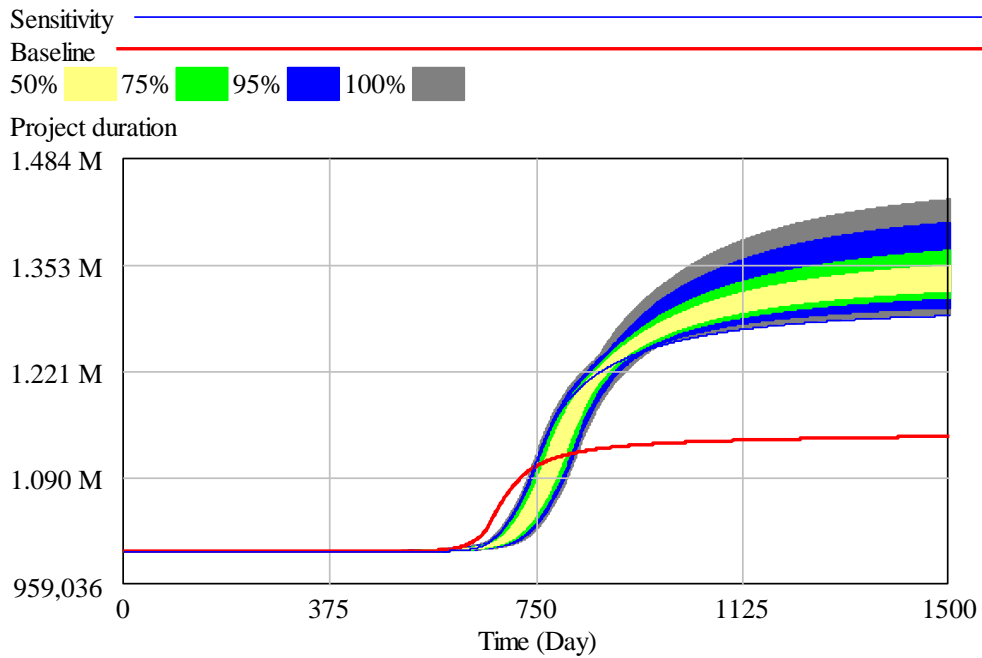


Figure 7-22 Sensitivity graph for project duration due to Environmental related risk factors

### 7.3.2. Stakeholder related risk factors

Those risks related to government, client, consultants and designers are grouped in this category. There are six risk factors under this group namely; government intervention, the need to change the design by the client, bribery and corruption, poor quality of design, delay in consultants' response to requested information and delay in contractor's payment certificate by consultant. All risks are assumed to be uniformly distributed and the same range of magnitude is given for all the risk factors between 0 and 0.1. The simulation results of this multivariate risk factors on project cost and time is shown in Figure 7-23 and 7-24 respectively.

The results of the sensitivity analysis of the project cost due to the change in the magnitude of the stakeholder related risk factors shows except the 95% confidence interval, the range of interval is insignificant for 50% and 75% confidence interval. The project cost ranges between 100 to 100.06 million birr for 50% confidence interval. Likewise, the range of project cost for 75% confidence interval is between 100.06 to 101.91 million birr. However, the 95% confidence interval ranges between 101.91 and 163.25 million birr. Thus, high project cost variability can only be visible for this groups of risk factors with 95% confidence interval.

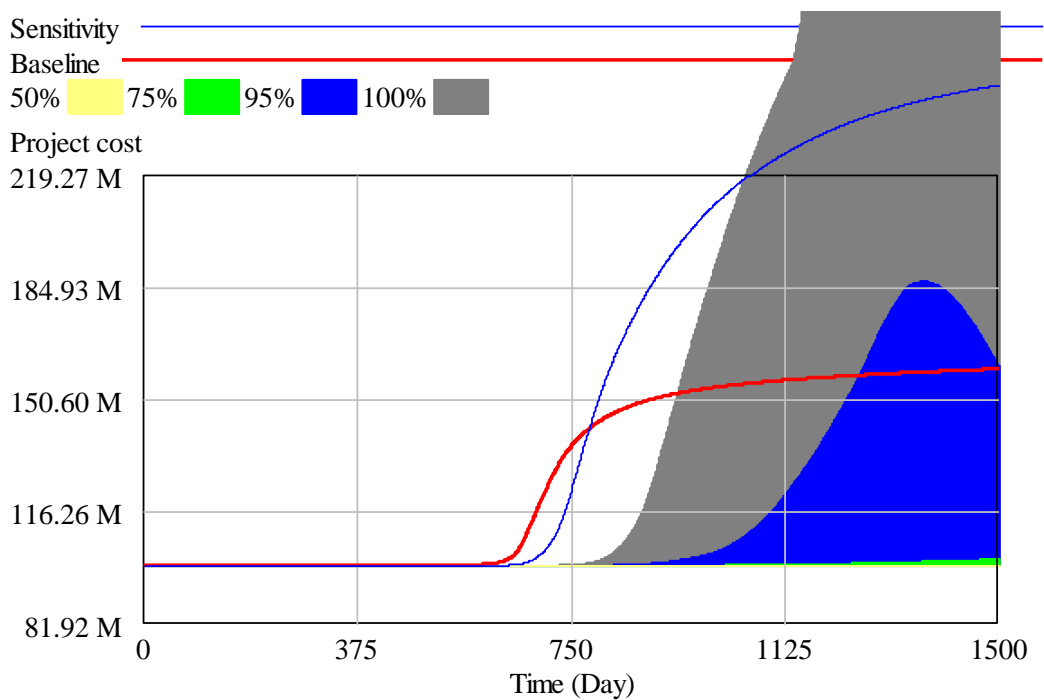


Figure 7-23 Sensitivity graph for project cost due to stakeholder related risk factors

However, the sensitivity results of this category of risk on the project duration is found to be very inflated and highly sensitive to the variation on the magnitude of stakeholders related risk factors. The range of project duration for 50% confidence interval is between 12 and 273 million of hour work on the project. The range of project duration for 75% and 95% confidence interval is highly amplified.

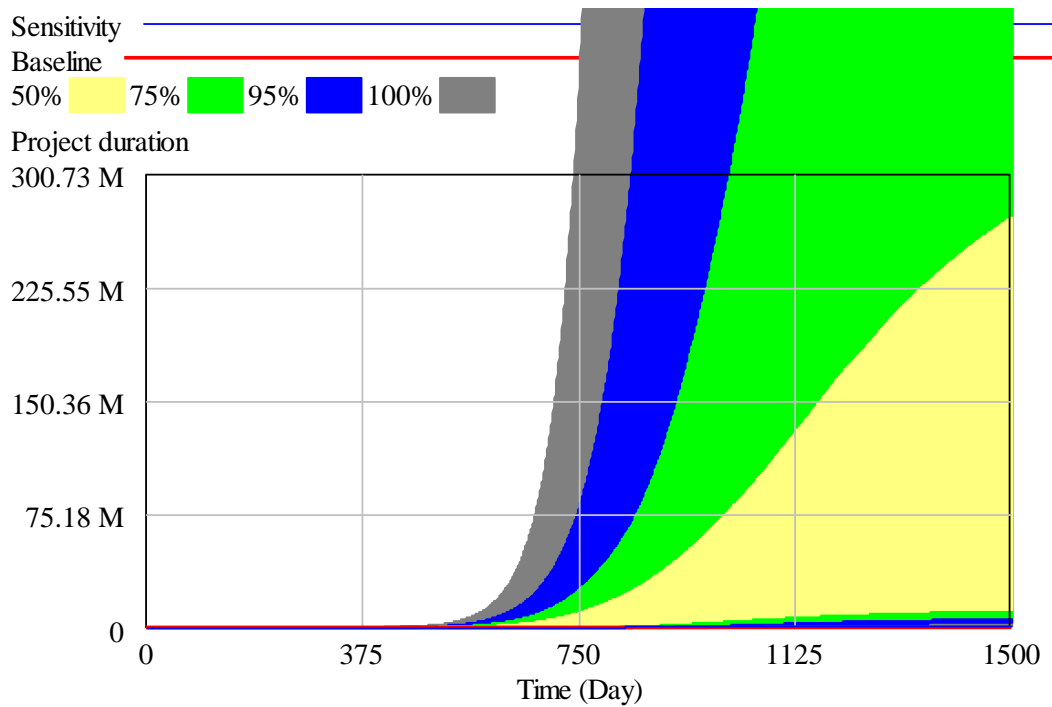


Figure 7-24 Sensitivity graph for project duration due to stakeholder related risk factors

### 7.3.3. Project Site related risk factors

The risk factors included in this category is poor site condition, land and property value and inadequate site information. The same sensitivity analysis setup was followed to vary the aggregated risk factors and study the effect on the project cost and time.

The range of project cost due to the change in site related risk factors lies between 243 to 383.5 million birr for 50% confidence interval. The increase in the confidence interval to 75% results in the range of the project costs to be between 136.7 to 452 million birr. There are 95% chances that the project cost ranges between 104.6 and 578 million birr.

The sensitivity of project duration due to site related risk factors are checked for three different confidence intervals. The range of project duration for 50% confidence interval is

1.425 to 4.11 million hours of work. The project duration lies between 1.325 and 5.815 million hours of work for 75% confidence interval. The high degree of confidence interval 95% results the range of the project duration between 1.287 to 8.127 million hours of work.

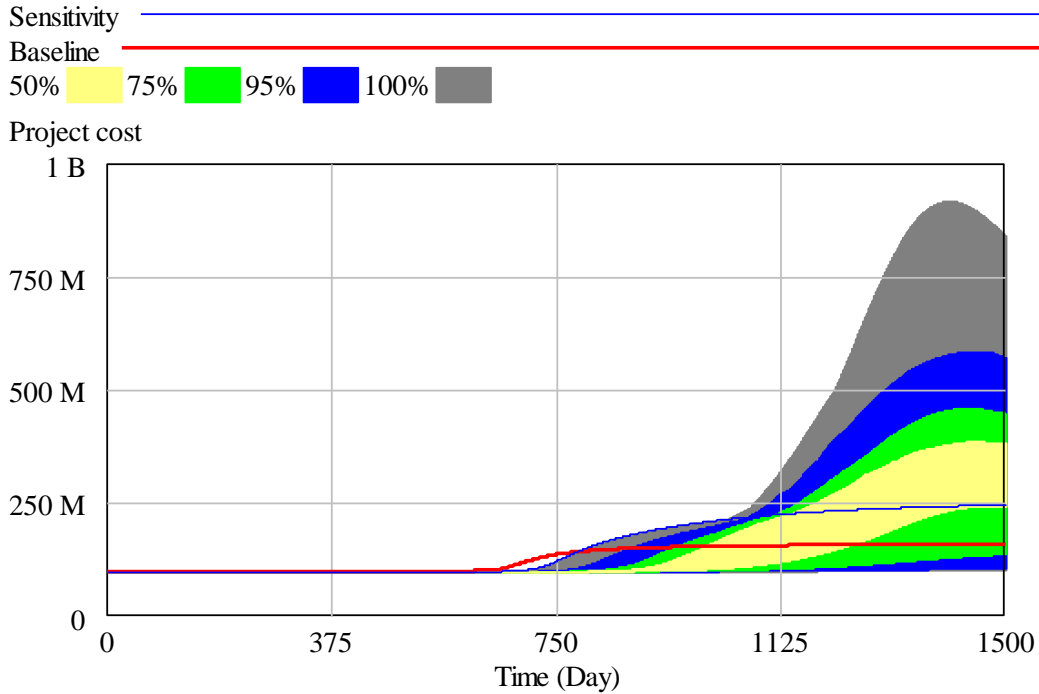


Figure 7-25 Sensitivity graph for project cost due to Project Site related risk factors

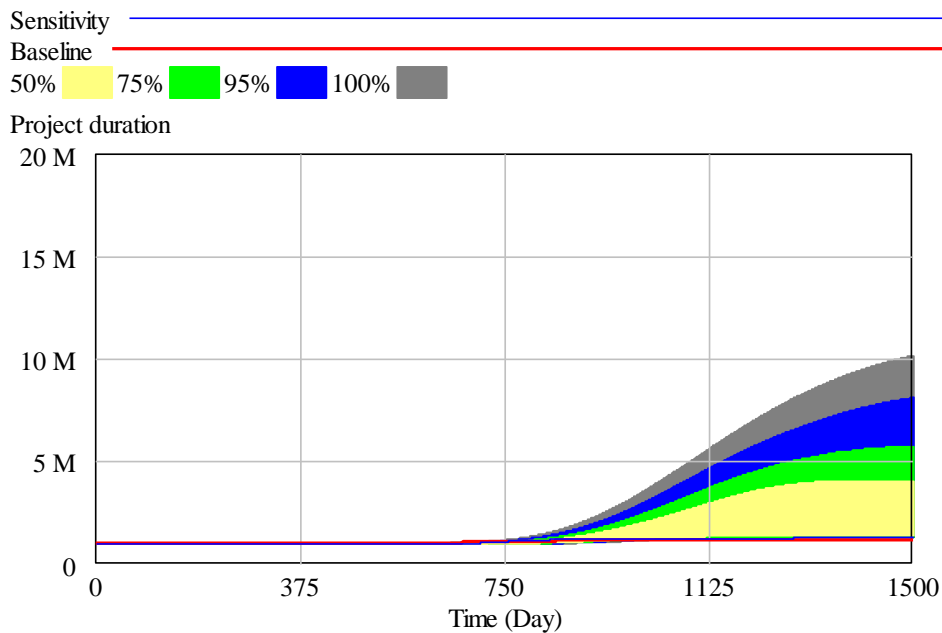
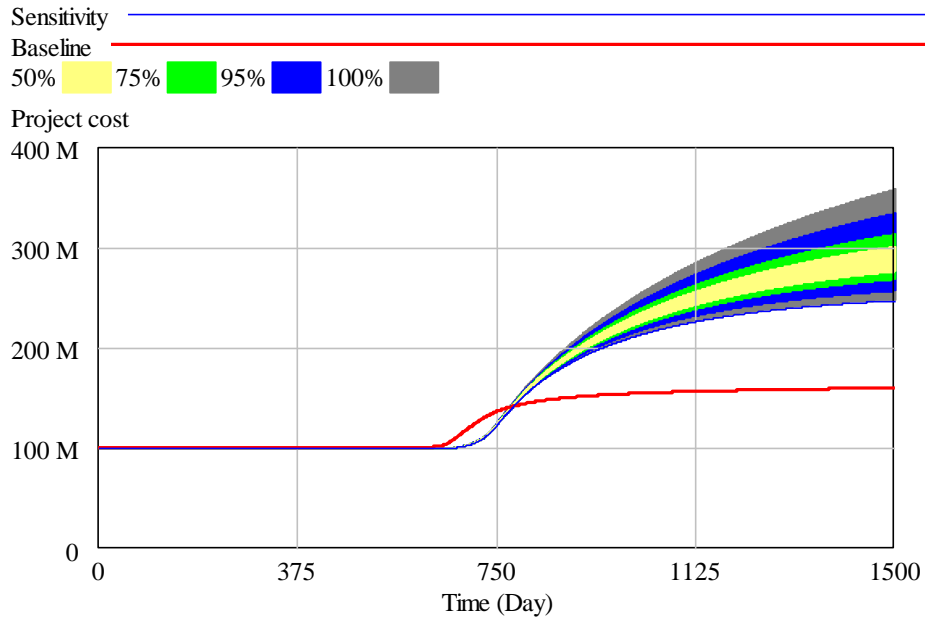


Figure 7-26 Sensitivity graph for project duration due to Project Site related risk factors

### 7.3.4. Economic related risk factors

Three risk factors namely low quality of material, import restriction and currency fluctuation are grouped into this category. The effects of the aggregation of risk factors on project cost and time are simulated and the results are illustrated in Figure 7-27 and Figure 7-28. The range of the risk aggregation is between 0 and 0.1 with the assumption of uniform distribution.

The project costs range between 275.95 and 301.02 million birr for 50% confidence interval. An increase in the confidence interval to 75% results the range of the project costs between 267.92 to 313.91 million birr. Likewise, the project costs will be between 256.76 and 334.63 million birr for 95% confidence interval as shown in Figure 6-27.



*Figure 7-27 Sensitivity graph for project cost due to Economic related risk factors*

Equally, the sensitivity analysis for project duration is shown in Figure 6-28 with three different confidence intervals. The overall results of the sensitivity are found to be not as significant as the other category of risk factors. The range of project duration due to 50% confidence interval is between 1.318 and 1.34 million hours. There is 75% degree of confidence for the project costs to lie between 1.311 and 1.349 million hours. Likewise, the range project costs for 95% confidence interval is between 1.3 and 1.365 million hours. Thus,

the result indicates that the economic related risk factors are less likely to affecting the project duration as compared to other categories of risk factors.

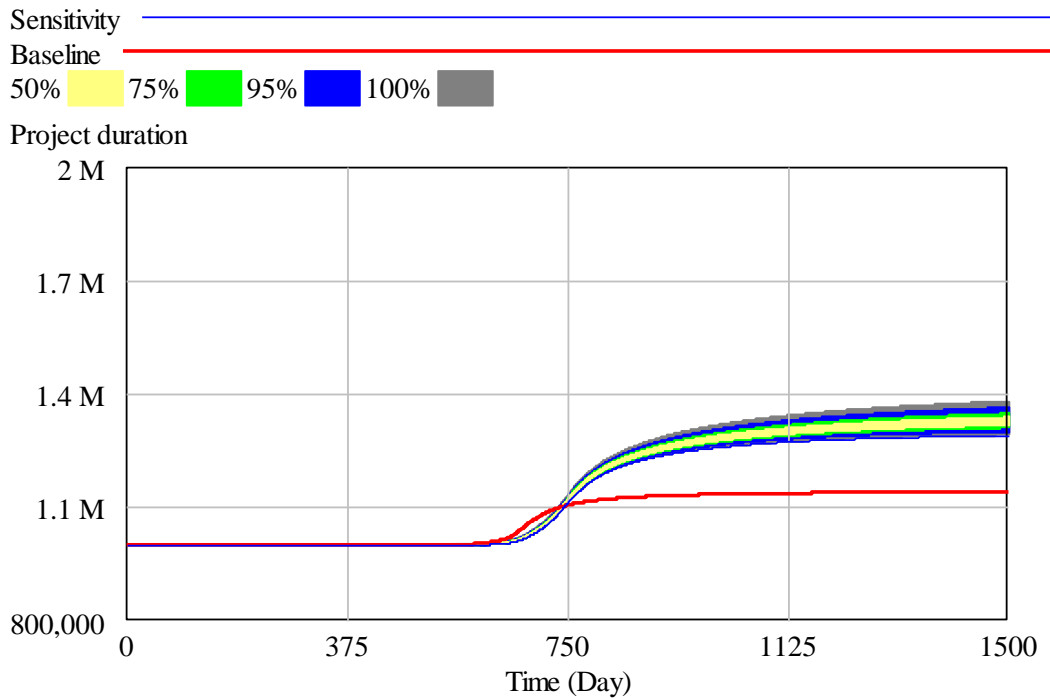


Figure 7-28 Sensitivity graph for project time due to Economic related risk factors

### 7.3.5. Contractor related risk factors

Four risk factors related to contractors are grouped under this category. These risk factors are shortage of plant and equipment, project planning and control, improper construction methods and improper quality control and testing. The same simulation setup is used like that of the other category of risks. The impacts of the contractor related risk factors on project cost and time are illustrated in Figure 7-29 and 7-30.

The range of project costs due to the change in the multivariate risk factors related to contractor with 50% confidence interval is between 270 and 294 million birr. Increasing the confidence interval to 75% results in the project cost ranging between 261 and 304 million birr. The project cost varies between 251 and 317 million birr for the 95% confidence interval as shown in Figure 7-29.

The change in the project duration due to the multivariate change in the magnitude of risk factors and three confidence intervals are plotted. The 50% confidence interval of the

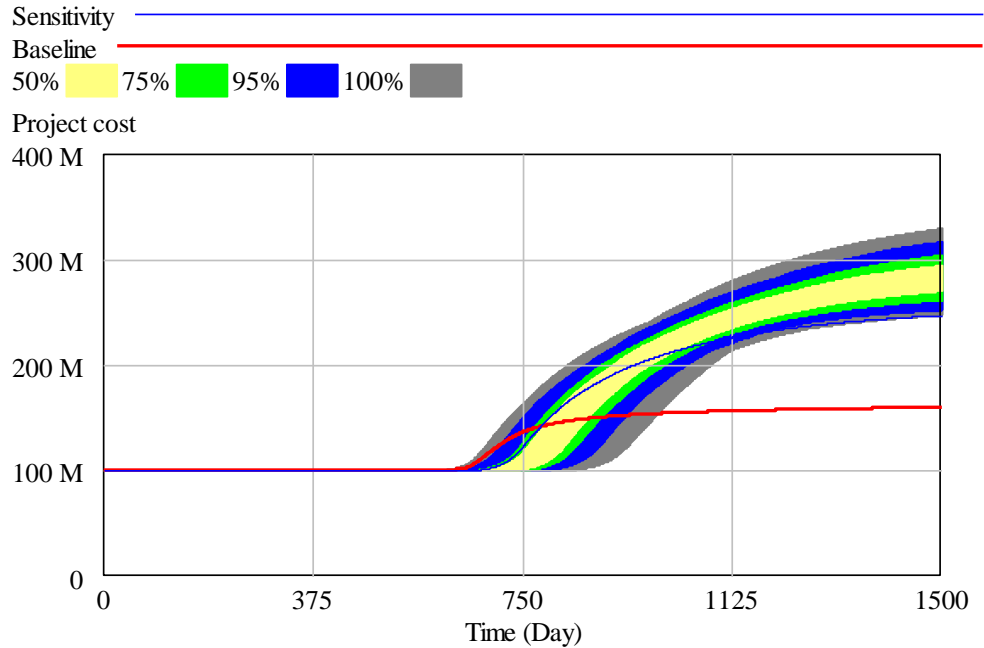


Figure 7-29 Sensitivity graph for project cost due to Contractor related risk factors

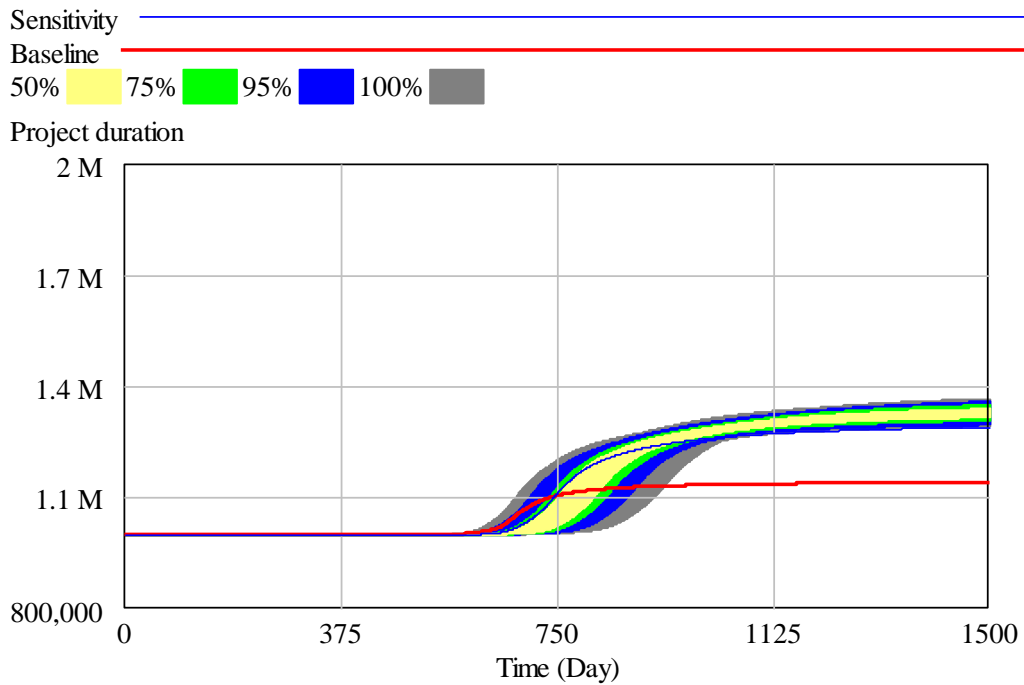


Figure 7-30 Sensitivity graph for project time due to Contractor related risk factors

contractor related risk factors result between 1.316 and 1.34 million of works for the project. Likewise, the project duration ranges between 1.307 and 1.351 million of works for 75%

confidence interval. The estimation of project duration ranges between 1.296 and 1.361 at the 95% confidence interval.

The range of project cost and duration result for both contractor related risk factors are less as compared to the forced majeure and site related risk factors.

## **7.4. Conclusion**

This chapter tries to present and discusses the results of system dynamics model and sensitivity analysis of the aggregated risk factors. The impact of six risk factors on the project cost and duration is presented by varying the magnitude of risk factors by 5 and 10% from the baseline i.e. 0. The result shows that government intervention has less impact than the other five risk factors on the project costs and also the change in the magnitude of the risk factor. On the contrary, inadequate site investigation has shown an overshoot on the project costs due to the change in the magnitude from 5% to 10%.

The project duration is highly affected by the change in the magnitude on the risk factor poor quality of design. Two risk factors (delay in contractor's payment certificate by the consultant and improper construction methods) have shown nearly the same impact on the project duration.

On the other hand, the sensitivity analysis of the risk factors is analysed by categorizing the risks into five based on the sources. The result revealed that stakeholder related risk factors are highly sensitive to the project duration but less sensitive to the project cost as compared to the other category of risks. Likewise, the site related risk factors are found to be highly sensitive to the project costs.

## Chapter Eight conclusions and recommendations

### 8.1. Conclusion

This research focuses on developing the relationship between different risk factors with the project cost and time overrun. The finding from the literature review indicates that there is no satisfactory theory or tools for assessing the aggregation of risk factors on project objective. Most of the research works have dealt with the effect of individual risk factors on the project cost and time. However, most of the risk factors have interrelationship where one risk factor can cause another risk and the effects of these is different from the individual risk. It is, therefore, essential to study the compounded effects of risk factors on the project cost and time. Moreover, there is no suitable methods proposed to anticipate and control the interrelationship between risk factors.

This research uses 51 risk factors identified from literature review and interview of experts. This risk factors are used for developing the interrelationship among each other and examine the impact on project cost and time.

This research uses the technique Interpretative Structural Modelling (ISM) to develop the interrelationship between risk factors from the pairwise relationship matrix developed from expert opinion. Thus, it enables to identify the transitivity of the risk factors and categorizes them into different levels. The research has grouped the identified risk factors into two (productivity and scope growth) based on the influence of risk factors. Each of these groups contain 33 risk factors where some are common to both groups. The result of the ISM shows that the risks are grouped into ten and seven levels for productivity and scope growth respectively. Moreover, contractual claim and productivity problems can occur due to the occurrences of any of the related risk factors among the group.

Another finding of this research is determination of the individual risk magnitude on project cost and time of the project. Although, most of the construction project risk assessment techniques are based on the statistical tools, the application of these tools may not give satisfactory results due to the incomplete risk data or the high level of uncertainty involved in the risk data available. Hence, fuzzy expert system based on interval arithmetic and  $\alpha$ -cut method is used to provide a systematic and structural approach to the complex process of risk assessment, which involves numerous objective and subjective criteria. The application of fuzzy expert

system enables this research to consider the unavailability of historical data, the need to consider expert judgements and the evaluation of risks towards prioritizing of top road construction risks. The result shows that the magnitude of risk factors based on the effect on project cost and time are ranked up to ten. The risk factors contractual claim and right of way problem are found to be the top-ranking risk factors for both project cost and time. Moreover, the finding shows that 46.93% of the risks have the same magnitude for both project cost and time.

On the other hand, the effect of compounded risk factors on the project cost and time are examined using system dynamics model. The model contains sixty-six key variables of both endogenous and exogenous with three model boundaries are developed. Based on the relationship with the model, six exogenous variables (risk factors) are used to study the effect on the project cost and time overrun. The result shows that poor quality of design risk factor has high impact on the project duration, whereas the risk factor inadequate site investigation affects the project cost significantly. Among the six risk factors, government intervention has low impact on project cost and time.

The compounded risk factors on the project cost and time are examined by categorizing the exogenous risk factors into five groups based on the sources of the risks. From the five categories, stakeholder related risks have high impact on project duration. Thus, the project duration is mainly affected to the risk factors caused by the stakeholders other than the contractors. Likewise, site related risk factors affect the project cost significantly as compared to the other categories of risks. The final project cost is highly determined by the project site related risks such as site condition, site information and land and property value at the site.

Finally, the results of this research revealed that the effects of the individual risk factors on the project cost and time are different from the compounded effects. Thus, this research has contributed the following:

- Identify the interrelationship between the risk factors using Interpretative Structural Modelling
- Examine the individual risk factors on the project cost and time using fuzzy expert system

- Examine the compounded effect of risk factors on the project cost and time using system dynamics

The application of this approach in the context of road construction project risk analysis system provides a dynamic analysis of risks and their impact on project cost and time. This model can be generalized and applied with some modifications to other construction projects to analyse the impact of risks on project cost and time.

## **8.2. Recommendations and Future Study**

Based on the results of the research, the following recommendations are forwarded

- This research uses literature review, questionnaire and experts' opinion as sources of data. This is due to the lack of complete records of risk factors and the additional cost and time incurred due to the risk factors. Thus, further research has to be done using live projects taking by accurately recording the risk magnitude in terms of project cost and time.
- This research deals with the comprehensive risk factors occurring in road construction projects in Ethiopia. It helps the construction project practitioners as a decision support on different risk factors encountered in project and will enable them focus on few critical risks that cause unintended effects on project objectives.
- The linear relationship was assumed between exogenous and endogenous risk factors. However, the non-linear behaviour of risk factors should also be studied. This enables the prediction of project cost and time using system dynamics model more precisely.
- Since risk is unavoidable in construction projects, proper risk mitigation response must be developed by all stakeholders before reaching implementation phase. Hence the identified risks, their respective magnitudes and the dynamic model of risks can be helpful to all involved parties as a starting point for proper response planning and control.
- Different risk response scenarios exist in practice. The dynamic behaviour of risk response strategies can be effectively modelled as an extension to develop SD model. Thus, this study strongly recommends future work on risk response decision support mechanism for the practitioner to select the optimum risk response strategy.

## References

1. A D IBRAHIM, A. D. F. P., A R J DAINTY 2006. The analysis and allocation of risks in public private partnerships in infrastructure projects in Nigeria. *Journal of Financial Management of Property and Construction*, Vol. 10 Iss 3 pp. 212-225.
2. ABDULAZIZ M. JARKAS, T. C. H. 2015. Major construction risk factors considered by general contractors in Qatar. *Journal of Engineering, Design and Technology*, Vol. 13 Iss 1 pp. 165 -194.
3. ABRHAM, T. H. 2004. *MODEL DEVELOPMENT for IMPROVING the PERFORMANCE of PROJECTS A Case Study on Ethiopian Roads Authority (ERA)*. aau.
4. ABUBEKER, J. 2015. *Factors Affecting Time and Cost Overrun in Road Construction Projects in Addis Ababa*. AAU.
5. ACKERMANN, F., EDEN, C., WILLIAMS, T. & HOWICK, S. 2007. Systemic risk assessment: a case study. *Journal of the Operational Research Society*, 58, 39-51.
6. ADAMS, F. K. 2006. Expert elicitation and Bayesian analysis of construction contract risks: an investigation. *Construction Management and Economics*, 24, 81-96.
7. ADAMS, F. K. 2008. Risk perception and Bayesian analysis of international construction contract risks: The case of payment delays in a developing economy. *International Journal of Project Management*, 26, 138-148.
8. ADDIS, M. 2014. *A Study on Construction Contract Risk Management Practices in Ethiopian Building Construction Projects 0*. AAU.
9. ADEDOKUN, O. A., OGUNSEMI, D. R., AJE, I. O., AWODELE, O. A. & DAIRO, D. O. 2013. Evaluation of qualitative risk analysis techniques in selected large construction companies in Nigeria. *Journal of Facilities Management*, 11, 123-135.
10. ADNAN ENSHASSI, J. A.-N., MOHAN KUMARASWAMY 2009a. Delays and cost overruns in the construction projects in the Gaza Strip. *Financial Management of Property and Construction*, Vol. 14 Iss 2 pp. 126 - 151.
11. ADNAN ENSHASSI, S. M., SALEH ABUSHABAN 2009b. FACTORS AFFECTING THE PERFORMANCE OF CONSTRUCTION PROJECTS IN THE GAZA STRIP. *OURNAL OF CIVIL ENGINEERING AND MANAGEMENT*, 15(3): 269–280.

12. AHMED, S. M., AHMAD, R., SARAM, D. & DARSHI, D. 1999. Risk management trends in the Hong Kong construction industry: a comparison of contractors and owners perceptions. *Engineering construction and Architectural management*, 6, 225-234.
13. AL-HUMAIDI, H. & HADIPRIONO TAN, F. 2010. A fuzzy logic approach to model delays in construction projects using rotational fuzzy fault tree models. *Civil Engineering and Environmental Systems*, 27, 329-351.
14. AL-TABTABAI, H. 2000. Modeling the Cost of Political Risk in International Construction Projects. *Project Management Journal*, 31, 4.
15. AL ZUBAIDI, H. & AL OTAIBI, S. 2008. An Empirical Approach for Identifying Critical Time-Overrun Risk Factors in Kuwait's Construction Projects. *Journal of Economic and Administrative Sciences*, 24, 35-53.
16. ALAGHBARI, W. E., KADIR, M. R. A., SALIM, A. & ERNAWATI 2007a. The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management*, 192-206.
17. ALAGHBARI, W. E., RAZALI A. KADIR, M., SALIM, A. & ERNAWATI 2007b. The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management*, 14, 192-206.
18. ALHOMIDAN, A. June 2013. Factors Affecting Cost Overrun in Road Construction Projects in Saudi Arabia. *International Journal of Civil & Environmental Engineering IJCEE-IJENS*, Vol:13 No:03.
19. AMEYAW, E. E. & CHAN, A. P. C. 2015. Risk ranking and analysis in PPP water supply infrastructure projects: An international survey of industry experts. *Facilities*, 33, 428-453.
20. ANDI 2006. The importance and allocation of risks in Indonesian construction projects. *Construction Management and Economics*, 24, 69-80.
21. ARAIN, F. M. & PHENG, L. S. 2007. Modeling for management of variations in building projects. *Engineering, Construction and Architectural Management*, 14, 420-433.
22. ARDITI, D., AKAN, G. T. & GURDAMAR, S. 1985. Reasons for delays in public projects in Turkey. *Construction Management and Economics*, 3, 171-181.
23. ASSOCIATION, I. P. M. 2006. ICB-IPMA competence baseline version 3.0. *International Project Management Association, Nijkerk*.

24. BAJAJ, D., OLUWOYE, J. & LENARD, D. 1997. An analysis of contractors' approaches to risk identification in New South Wales, Australia. *Construction Management & Economics*, 15, 363-369.
25. BALOI, D. & PRICE, A. D. F. 2003. Modelling global risk factors affecting construction cost performance. *International Journal of Project Management*, 21, 261-269.
26. BANAITIENĖ, N., BANAITIS, A. & NORKUS, A. 2011. Risk management in projects: peculiarities of Lithuanian construction companies. *International Journal of strategic property management*, 15, 60-73.
27. BEIDLEMAN, C. R., FLETCHER, D. & VESHOSKY, D. 1990. On Allocating Risk: The Essence of Project Finance. *Sloan Management Review*, 31, 47.
28. BESNER, C. & HOBBS, B. 2012. The paradox of risk management: a project management practice. *International Journal of Managing Projects in Business*, 230 - 247.
29. BING, L., TIONG, R. L.-K., FAN, W. W. & CHEW, D. A.-S. 1999. Risk management in international construction joint ventures. *Journal of construction engineering and management*, 125, 277-284.
30. BODEA, C.-N. & PURNUS, A. 2012. PROJECT RISK SIMULATION METHODS - A COMPARATIVE ANALYSIS. *Management & Marketing*, 7, 565-580.
31. BRYDE, D. J. & VOLM, J. M. 2009. Perceptions of owners in German construction projects: congruence with project risk theory. *Construction Management and Economics*, 27, 1059-1071.
32. BU-QAMMAZ, A. S., DIKMEN, I. & BIRGONUL, M. T. 2009. Risk assessment of international construction projects using the analytic network process. *Canadian Journal of Civil Engineering*, 36, 1170-1181.
33. BUDI, H., DEO, F. N. W. & HILYA, M. A. 2014. An empirically verified project risk maturity model: Evidence from Indonesian construction industry. *International Journal of Managing Projects in Business*, 7, 263-284.
34. CARR, V. & TAH, J. H. M. 2001. A fuzzy approach to construction project risk assessment and analysis: construction project risk management system. *Advances in Engineering Software*, 32, 847-857.
35. CARTER, B., HANCOCK, T., MORIN, J.-M. & ROBINS, N. 1996. *Introducing RISKMAN methodology: the European project risk management methodology*, HM Stationery Office.

36. CHAN, A. P., SCOTT, D. & CHAN, A. P. 2004. Factors affecting the success of a construction project. *Journal of construction engineering and management*, 130, 153-155.
37. CHAN, D. W. M. & KUMARASWAMY, M. M. 1997. A comparative study of causes of time overruns in Hong Kong construction projects. *International Journal of Project Management*, 15, 55-63.
38. CHAPMAN, C. 1997. Project risk analysis and management—PRAM the generic process. *International Journal of Project Management*, 15, 273-281.
39. CHAPMAN, C. & WARD, S. 2003. *Project Risk Management*, UK, John Wiley & Sons Ltd.
40. CHAPMAN, C. B. & WARD, S. C. 1997. *Project Risk Management Processes, Techniques and Insights*, Wiley.
41. CHAPMAN, R. J. 2001. The controlling influences on effective risk identification and assessment for construction design management. *International Journal of Project Management*, 19, 147-160.
42. CHARLES TEYE AMOATEY, Y. A. A., EBENEZER ADAKU, SAMUEL FAMIYEH 2015. Analysing delay causes and effects in Ghanaian state housing construction projects. *International Journal of Managing Projects in Business*, Vol. 8 Iss 1 pp. 198 - 214.
43. CHILESHE, N. & BOADUA YIRENKYI-FIANKO, A. 2012. An evaluation of risk factors impacting construction projects in Ghana. *Journal of Engineering, Design and Technology*, 10, 306-329.
44. CHILESHE, N. & JOHN KIKWASI, G. 2014. Critical success factors for implementation of risk assessment and management practices within the Tanzanian construction industry. *Engineering, Construction and Architectural Management*, 21, 291-319.
45. COOPER, D. 2004. The Australian and New Zealand standard on risk management, AS/NZS 4360: 2004. *Tutorial Notes: Broadleaf Capital International Pty Ltd*.
46. COOPER, K. G. 1980. Naval ship production: A claim settled and a framework built. *Interfaces*, 10, 20-36.
47. COYLE, R. G. 1996. *System dynamics modeling: a practical approach*, UK, Springer-Science+Business Media, B.Y.

48. DADA, J. O. & JAGBORO, G. 2007a. An evaluation of the impact of risk on project cost overrun in the Nigerian construction industry. *Journal of Financial Management of Property and Construction*, 12, 37-44.
49. DADA, J. O. & JAGBORO, G. O. 2007b. An evaluation of the impact of risk on project cost overrun in the Nigerian construction industry *Journal of Financial Management of Property and Construction*, 37-44.
50. DE MARCO, A. & RAFELE, C. Using system dynamics to understand project performance. Proc. of 1st ICEC&IPMA Global Congress on Project Management, 2009.
51. DENG, T. & ZHOU, X. 2010. Risk correlation analysis for China's construction projects based on stakeholder theory. *International Journal of Management Science and Engineering Management*, 5, 285-292.
52. DEY, P. K. & OGUNLANA, S. O. 2004. Selection and application of risk management tools and techniques for build-operate-transfer projects. *Industrial Management & Data Systems*, 104, 334-346.
53. DIKMEN, I., BIRGONUL, M. T. & HAN, S. 2007. Using fuzzy risk assessment to rate cost overrun risk in international construction projects. *International Journal of Project Management*, 25, 494-505.
54. DIKMEN, I., TALAT BIRGONUL, M., OZORHON, B. & EGILMEZER SAPCI, N. 2010. Using analytic network process to assess business failure risks of construction firms. *Engineering, Construction and Architectural Management*, 17, 369-386.
55. DOLOI, H. 2012a. Understanding impacts of time and cost related construction risks on operational performance of PPP projects. *International Journal of Strategic Property Management*, 16, 316-337.
56. DOLOI, H. 2012b. Understanding impacts of time and cost related construction risks on operational performance of PPP projects. *International Journal of Strategic Property Management*, Volume 16(3): 316–337.
57. DOLOI, H., SAWHNEY, A. & IYER, K. 2012. Structural equation model for investigating factors affecting delay in Indian construction projects. *Construction Management and Economics*, 30, 869-884.
58. DROUIN, N., BESNER, C., BESNER, C. & HOBBS, B. 2012. The paradox of risk management; a project management practice perspective. *International journal of managing projects in business*, 5, 230-247.

59. EDWARDS, P. & BOWEN, P. 1998. Risk and risk management in construction: a review and future directions for research. *Engineering, Construction and Architectural Management*, 5, 339-349.
60. EFFAH AMEYAW, E. & CHAN, A. P. 2013. Identifying public-private partnership (PPP) risks in managing water supply projects in Ghana. *Journal of Facilities Management*, 11, 152-182.
61. ENSHASSI, A., AL-NAJJAR, J. & KUMARASWAMY, M. 2009. Delays and cost overruns in the construction projects in the Gaza Strip. *Journal of Financial Management of Property and Construction*, 14, 126-151.
62. F.COOPER, D., GREY, S., RAYMOND, G. & WALKER, P. 2005. *Project Risk Management Guideline*, England, John Wiley & Sons,Ltd.
63. FAMA KIN, I., AJE, I. & OGUNSEMI, D. 2012. Assessment of success factors for joint venture construction projects in Nigeria. *Journal of Financial Management of Property and Construction*, 17, 153-165.
64. FANG, C. & MARLE, F. 2012. A simulation-based risk network model for decision support in project risk management. *Decision Support Systems*, 52, 635-644.
65. FANG, C. & MARLE, F. 2013. Dealing with project complexity by matrix-based propagation modelling for project risk analysis. *Journal of Engineering Design*, 24, 239-256.
66. FETHI HAMZAOFRANCK TAILLANDIER, R. M., DENYS BREYSSE, AMINE ALLAL 2015. Evolutive Risk Breakdown Structure for managing construction project risks: application to a railway project in Algeria. *European Journal of Environmental and Civil Engineering*, Vol. 19, No. 2, 238–262.
67. FIJNVANDRAAT, M. & BOUWMAN, H. 2010. Predicting the unpredictable: dealing with risk and uncertainty in broadband roll-out. *Foresight*, 3-19.
68. FLANAGAN, R., AND NORMAN, G. 1993. *Risk management and construction*, Victoria: Blackwell Science Pty Ltd.
69. FLANAGAN, R. & NORMAN, G. 1993. *Risk management and construction*, Wiley-Blackwell.
70. FLORICEL, S. & MILLER, R. 2001. Strategizing for anticipated risks and turbulence in large-scale engineering projects. *International Journal of Project Management*, 19, 445-455.

71. FORRESTER, J. W. 1961. *Industrial Dynamics*, MIT Press.
72. FOULADGAR, M., YAZDANI-CHAMZINI, A. & ZAVADSKAS, E. 2012. Risk evaluation of tunneling projects. *Archives of civil and mechanical engineering*, 12, 1-12.
73. GETACHEW, T. 2009. *Design Risk Management In Ethiopian Federal Road Projects*. aau.
74. GIMPELEVICH, D. 2011. Simulation-based excess return model for real estate development: A practical Monte Carlo simulation-based method for quantitative risk management and project valuation for real estate development projects illustrated with a high-rise office development case study. *Journal of Property Investment & Finance*, 29, 115-144.
75. GRIMSEY, D. & LEWIS, M. K. 2002. Evaluating the risks of public private partnerships for infrastructure projects. *International Journal of Project Management*, 20, 107-118.
76. HAMZAOU, F., TAILLANDIER, F., MEHDIZADEH, R., BREYSSE, D. & ALLAL, A. 2015. Evolutive Risk Breakdown Structure for managing construction project risks: application to a railway project in Algeria. *European Journal of Environmental and Civil Engineering*, 19, 238-262.
77. HASSANEIN, A. A. & AFIFY, H. M. 2007. Risk management practices of contractors: a case study of power station projects in Egypt. *Journal of Financial Management of Property and Construction*, 12, 164-179.
78. HAYES, R. W., PERRY, J. G., THOMPSON, P. A. & WILLMER, G. 1987. *Risk management in engineering construction Implications for project managers*, United Kingdom.
79. HEMANTA DOLOI, A. S., K.C. IYER 2012. Structural equation model for investigating factors affecting delay in Indian construction projects. *Construction Management and Economics*, 30, 869–884.
80. HERTZ, D. B. & THOMAS, H. 1983. *Risk analysis and its application*, Chichester, UK, John Wiley & Sons.
81. HILLSON, D. 2003. Using a risk breakdown structure in project management. *Journal of Facilities Management*, 2, 85-97.
82. HILLSON, D. 2004 *Effective Opportunity Management for Projects*, Marcel Dekker, Inc.

83. HLAING, N., SINGH, D., TIONG, R. & EHRLICH, M. 2008. Perceptions of Singapore construction contractors on construction risk identification. *Journal of Financial Management of Property and Construction*, 13, 85-95.
84. HOSSEN, M. M., KANG, S. & KIM, J. 2015. Construction schedule delay risk assessment by using combined AHP-RII methodology for an international NPP project. *Nuclear Engineering and Technology*, 47, 362-379.
85. HUANG, Y.-L., HUANG, P.-H. & HSIEH, C.-H. 2013. Management of unexpected project risk events by the icss and dummy garch model. *Journal of Information and Optimization Sciences*, 34, 261-279.
86. HWANG, B.-G., ZHAO, X. & SIYIN 2013. Identifying the critical factors affecting schedule performance of public housing. *Habitat International*, 214-221.
87. I. MAÑELELE, M. M. 2008. Risk identification on community-based construction projects in Zambia. *Journal of Engineering, Design and Technology*, Vol. 6 Iss 2 pp. 145 - 161.
88. IBRAHIM, A., PRICE, A. & DAINTY, A. 2006. The analysis and allocation of risks in public private partnerships in infrastructure projects in Nigeria. *Journal of Financial Management of Property and Construction*, 11, 149-164.
89. IEC, B. 62198: 2001 Project risk management-Application guidelines. *Both are available from the British Standards Institution*, 389.
90. IQBAL, S., CHOUDHRY, R. M., HOLSCHEMACHER, K., ALI, A. & TAMOŠAITIENĖ, J. 2015. Risk management in construction projects. *Technological and Economic Development of Economy*, 21, 65-78.
91. IRIMIA-DIÉGUEZ, A. I., SANCHEZ-CAZORLA, A. & ALFALLA-LUQUE, R. Risk Management in Megaprojects. *Procedia - Social and Behavioral Sciences* 2014 Seville. 407 – 416
92. ISOGUIDE73:2009 2009. *Risk management — Vocabulary*, ISO.
93. ISSA, U. H. 2013. Implementation of lean construction techniques for minimizing the risks effect on project construction time. *Alexandria Engineering Journal* (697–704).
94. J. H. M. TAH, V. C. 2000. A proposal for construction project risk assessment using fuzzy logic. *Construction Management and Economics*, 18, 491–500.
95. JARKAS, A. M. & HAUPT, T. C. 2015a. Major construction risk factors considered by general contractors in Qatar. *Journal of Engineering, Design and Technology*, 165-194.

96. JARKAS, A. M. & HAUPT, T. C. 2015b. Major construction risk factors considered by general contractors in Qatar. *Journal of Engineering, Design and Technology*, 13, 165-194.
97. JHA, K. N. & DEVAYA, M. N. 2008. Modelling the risks faced by Indian construction companies assessing international projects. *Construction Management and Economics*, 26, 337-348.
98. JOSHUA O DADA, G. O. J. 2007. An evaluation of the impact of risk on project cost overrun in the Nigerian construction industry. *Financial Management of Property and Construction*, Vol. 12 Iss 1 pp. 37 - 44.
99. KALIBA, C., MUYA, M. & MUMBA, K. 2009. Cost escalation and schedule delays in road construction projects in Zambia. *International Journal of Project Management*, 27, 522-531.
100. KAMALESH PANTHI, A. A., STEPHEN O. OGUNLANA 2009. Contingency Estimation for Construction Projects Through Risk Analysis. *International Journal of Construction Education and Research*, 5:79–94.
101. KARIMIAZARI, A., MOUSAVI, N., MOUSAVI, S. F. & HOSSEINI, S. 2011. Risk assessment model selection in construction industry. *Expert Systems with Applications*, 38, 9105-9111.
102. KE, Y., WANG, S., CHAN, A. P. & CHEUNG, E. 2011a. Understanding the risks in China's PPP projects: ranking of their probability and consequence. *Engineering, Construction and Architectural Management*, 18, 481-496.
103. KE, Y., WANG, S. & CHAN, A. P. C. 2011b. Equitable risks allocation of projects inside China: analyses from Delphi survey studies. *Chinese Management Studies*, 5, 298-310.
104. KEEY, R. 1998. Australia/New Zealand risk management standard. *Owning the future: Integrated risk management in practice*, 91-97.
105. KENDRICK, T. 2015. *Identifying and Managing Project Risk: Essential Tools for Failure-Proofing Your Project*, AMACOM.
106. KHODEIR, L. M. & MOHAMED, A. H. M. 2015. Identifying the latest risk probabilities affecting construction projects in Egypt according to political and economic variables. *HBRC Journal*, 129-135.
107. KHOSHGOFTAR, M., BAKAR, A. H. A. & OSMAN, O. 2010. Causes of delays in Iranian construction projects. *International Journal of Construction Management*, 10, 53-69.

108. KIM, S.-Y., VAN TUAN, N. & OGUNLANA, S. O. 2009. Quantifying schedule risk in construction projects using Bayesian belief networks. *International Journal of Project Management*, 27, 39-50.
109. KLOSS-GROTE, B. & MOSS, M. A. 2008. How to measure the effectiveness of risk management in engineering design projects? Presentation of RMPASS: a new method for assessing risk management performance and the impact of knowledge management—including a few results. *Research in engineering design*, 19, 71-100.
110. KOH, S., SAAD, S., AHMED, A., KAYIS, B. & AMORNSAWADWATANA, S. 2007. A review of techniques for risk management in projects. *Benchmarking: An International Journal*, 14, 22-36.
111. KOUSHKI, P. A., AL-RASHID, K. & KARTAM, N. 2005. Delays and cost increases in the construction of private residential projects in Kuwait. *Construction Management and Economics*, 23, 285-294.
112. KULULANGA, G. & KUOTCHA, W. 2010. Measuring project risk management process for construction contractors with statement indicators linked to numerical scores. *Engineering, Construction and Architectural Management*, 17, 336-351.
113. KUMARASWAMY, M., LING, F., FISCHER, K., LEIDEL, K., RIEMANN, A. & WILHELM ALFEN, H. 2010. An integrated risk management system (IRMS) for PPP projects. *Journal of Financial Management of Property and Construction*, 15, 260-282.
114. KUO, Y.-C. & LU, S.-T. 2013. Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. *International Journal of Project Management*, 31, 602-614.
115. LAILA MOHAMED KHODEIR, A. H. M. M. 2015. Identifying the latest risk probabilities affecting construction projects in Egypt according to political and economic variables. From January 2011 to January 2013. *Housing and Building National Research Cente*, 11, 129–135.
116. LI, P., WANG, J. & YUAN, H. Analysis of the Interactions between Risks Affecting Construction Project Cost. Proceedings of the 18th International Symposium on Advancement of Construction Management and Real Estate, 2014 Swiss. Springer-Verlag Berlin Heidelberg.
117. LIN, W., YAQI, L. & ENMAO, W. 2011. Research on risk management of railway engineering construction. *Systems Engineering Procedia*, 1, 174-180.

118. LIN, Z. & JIANPING, Y. 2011. Risk Assessment Based On Fuzzy Network (F-ANP) In New Campus Construction Project. *Systems Engineering Procedia*, 1, 162-168.
119. LINDLEY, D. V. & SINGPURWALLA, N. D. 1986. Reliability (and Fault Tree) Analysis Using Expert Opinions. *Journal of the American Statistical Association*, 81, 87-90.
120. LUNDIN, R. A., DR KJELL TRYGGESTAD, P., AMOATEY, C. T., AMEYAW, Y. A., ADAKU, E. & FAMIYEH, S. 2015. Analysing delay causes and effects in Ghanaian state housing construction projects. *International Journal of Managing Projects in Business*, 8, 198-214.
121. MACK, S. W. 1995. Risk analysis in construction: a paradigm shift from a hard to soft approach. *Construction management and economics*, 13, 385-392.
122. MAHAMID, I. 2011a. Risk matrix for factors affecting time delay in road construction projects: owners' perspective. *Engineering, Construction and Architectural Management*, 18, 609-617.
123. MAHAMID, I. 2011b. Risk matrix for factors affecting time delay in road construction projects: owners' perspective. *Engineering, Construction and Architectural Management*, Vol. 18 Iss 6 pp. 609 - 617.
124. MAHAMID, I. 2013. Common risks affecting time overrun in road construction projects in Palestine: Contractors. *Australasian Journal of Construction Economics and Building*, 45-53.
125. MAHAMID, I. 2014. Contractors' perception of risk factors affecting cost overrun in building projects in Palestine. *The IES Journal Part A: Civil & Structural Engineering*, 7, 38-50.
126. MAKUI, A., MOJTAHEDI, S. M. & MOUSAVI, S. M. 2010. Project risk identification and analysis based on group decision making methodology in a fuzzy environment. *International Journal of Management Science and Engineering Management*, 5, 108-118.
127. MANELELE, I. & MUYA, M. 2008. Risk identification on community-based construction projects in Zambia. *Journal of Engineering, Design and Technology*, 6, 145-161.
128. MARLE, F. 2014. A structured process to managing complex interactions between project risks. *International Journal of Project Organisation and Management*.
129. MARZOUK, M. M. & EL-RASAS, T. I. 2014. Analyzing delay causes in Egyptian construction projects. *Journal of Advanced Research* 49–55.

130. MEEAMPOL, S. & OGUNLAN, S. 2006. Factors affecting cost and time performance on highway construction projects: evidence from Thailand. *Journal of Financial Management of property and Construction*, 11, 3-20.
131. MEHDIZADEH RASOOL, T. F., BREYSSE DENYS AND NIANDOUHALIDOU June 2012. Methodology and tools for risk evaluation in construction projects using Risk Breakdown Structure. *European Journal of Environmental and Civil Engineering*, Vol. 16, s78-s98.
132. MEZHER, T. M. & TAWIL, W. 1998. Causes of delays in the construction industry in Lebanon. *Engineering, Construction and Architectural Management*, 5, 252-260.
133. MILLS, A. 2001. A systematic approach to risk management for construction. *Structural survey*, 19, 245-252.
134. MOTIAR RAHMAN, M. & KUMARASWAMY, M. 2002. Risk management trends in the construction industry: moving towards joint risk management. *Engineering, Construction and Architectural Management*, 9, 131-151.
135. MOUSAVI, S. M., TAVAKKOLI-MOGHADDAM, R., AZARON, A., MOJTAHEDI, S. & HASHEMI, H. 2011. Risk assessment for highway projects using jackknife technique. *Expert Systems with Applications*, 38, 5514-5524.
136. MUHWEZI, L., ACAI, J. & OTIM, G. 2014. An Assessment of the Factors Causing Delays on Building Construction Projects in Uganda *International Journal of Construction Engineering and Management*, 13-23.
137. NASIRZADEH, F., AFSHAR, A. & KHANZADI, M. 2008a. System dynamics approach for construction risk analysis. *international journal of civil engineering*, 6, 120-31.
138. NASIRZADEH, F., AFSHAR, A. & KHANZADI, M. 2008b. System dynamics approach for construction risk analysis. *International Journal of Civil Engineerng*, 120-131.
139. NASIRZADEH, F., AFSHAR, A., KHANZADI, M. & HOWICK, S. 2008c. Integrating system dynamics and fuzzy logic modelling for construction risk management. *Construction Management and Economics*, 26, 1197-1212.
140. NASIRZADEH, F., AFSHAR, A., KHANZADI, M. & HOWICK, S. 2008d. Integrating system dynamics and fuzzy logic modelling for construction risk management. *Construction Management and Economics*, 1197-1212, .

141. NASIRZADEH, F., KHANZADI, M. & REZAIE, M. 2014. Dynamic modeling of the quantitative risk allocation in construction projects. *International Journal of Project Management*, 32, 442-451.
142. NEGA, F. 2008. *Causes and effects of cost overrun on public building construction projects in Ethiopia*. Addis Ababa University.
143. NIETO-MOROTE, A. & RUZ-VILA, F. 2011. A fuzzy approach to construction project risk assessment. *International Journal of Project Management*, 29, 220-231.
144. NISHAT FAISAL, M., BANWET, D. K. & SHANKAR, R. 2006. Supply chain risk mitigation: modeling the enablers. *Business Process Management Journal*, 12, 535-552.
145. O.A. ADEDOKUN, D. R. O., I.O. AJE, O.A. AWODELE D.O. DAIRO 2013. Evaluation of qualitative risk analysis techniques in selected large construction companies in Nigeria. *Journal of Facilities Management*, Vol. 11 Iss 2 pp. 123 - 135.
146. ODECK, J. 2004. Cost overruns in road construction—what are their sizes and determinants? *Transport policy*, 11, 43-53.
147. PALOMO, J., RIOS INSUA, D. & RUGGERI, F. 2007. Modeling External Risks in Project Management. *Risk Analysis*, 27, 961-978.
148. PANTHI, K., AHMED, S. M. & OGUNLANA, S. O. 2009. Contingency Estimation for Construction Projects Through Risk Analysis. *International Journal of Construction Education and Research*, 5, 79-94.
149. PATRICK. X.W. ZOU, G. Z. 2009. Managing Risks in Construction Projects: Life Cycle and Stakeholder Perspectives. *International Journal of Construction International Journal of Construction*, 61-77.
150. PEDRYCZ, W. & GOMIDE, F. 2007. *Fuzzy systems engineering: toward human-centric computing*, John Wiley & Sons.
151. PERERA, B., DHANASINGHE, I. & RAMEEZDEEN, R. 2009. Risk management in road construction: the case of Sri Lanka. *International Journal of Strategic Property Management*, 13, 87-102.
152. PERERA, B., RAMEEZDEEN, R., CHILESHE, N. & HOSSEINI, M. R. 2014. Enhancing the effectiveness of risk management practices in Sri Lankan road construction projects: A Delphi approach. *International Journal of Construction Management*, 14, 1-14.
153. PERMINOVA, O., GUSTAFSSON & WIKSTROM 2007. Defining uncertainty in projects – a new perspective. *International Journal of Project Management*, 73-79.

154. PMI 2004. *A guide to the project management body of knowledge 3rd ed.*, USA, Project Management Institute Inc.,.
155. PMI, A. 2008. *guide to the project management body of knowledge* Project Management Institute. *Newton Square, PA*.
156. POLAT, G. & NEVAL BINGOL, B. 2013. A comparison of fuzzy logic and multiple regression analysis models in determining contingency in international construction projects. *Construction Innovation*, 13, 445-462.
157. POURROSTAM, T. & ISMAIL, A. 2012. Causes and Effects of Delay in Iranian Construction Projects *IACSIT International Journal of Engineering and Technology*.
158. PRUYT, E. 2013. *Small System Dynamics Models for Big Issues: Triple Jump towards Real-World Complexity*, The Netherlands, TU Delft Library
159. RAFTERY, J. 2003. *Risk analysis in project management*, Routledge.
160. RANASINGHE, M. & RUSSELL, A. D. 1992. Analytical approach for economic risk quantification of large engineering projects: validation. *Construction management and economics*, 10, 45-68.
161. RASOOL, M., FRANCK, T., DENYS, B. & HALIDOU, N. 2012a. Methodology and tools for risk evaluation in construction projects using Risk Breakdown Structure. *European Journal of Environmental and Civil Engineering*, 16, s78-s98.
162. RASOOL, M., FRANCK, T., DENYS, B. & HALIDOU, N. 2012b. Methodology and tools for risk evaluation in construction projects using Risk Breakdown Structure. *European Journal of Environmental and Civil Engineering*, 78-98.
163. RAVANSHADNIA, M. & RAJAIE, H. 2013. Semi-Ideal Bidding via a Fuzzy TOPSIS Project Evaluation Framework in Risky Environments. *Journal of Civil Engineering and Management*, 19, S106-S115.
164. ROSTAMI, A., SOMMERVILLE, J., WONG, I. L. & LEE, C. 2015. Risk management implementation in small and medium enterprises in the UK construction industry. *Engineering, Construction and Architectural Management*, 22, 91-107.
165. S.M. MOUSAVI, R. T.-M., A. AZARON, S.M.H. MOJTAHEDI, H. HASHEMI 2011. Risk assessment for highway projects using jackknife technique. *Expert Systems with Applications*, 38, 5514–5524.

166. SACHS, T., TIONG, R. & WAGNER, D. 2007. Political risk quantification using fuzzy set approach. *Journal of Financial Management of Property and Construction*, 12, 107-126.
167. SALAH, A. & MOSELHI, O. 2015. Contingency modelling for construction projects using fuzzy-set theory. *Engineering, Construction and Architectural Management*, 22, 214-241.
168. SAMBASIVAN, M. & SOON, Y. W. 2007a. Causes and effects of delays in Malaysian construction industry. *International Journal of Project Management*, 517-526.
169. SAMBASIVAN, M. & SOON, Y. W. 2007b. Causes and effects of delays in Malaysian construction industry. *International Journal of project management*, 25, 517-526.
170. SAN SANTOSO, D., OGUNLANA, S. O. & MINATO, T. 2003. Assessment of risks in high rise building construction in Jakarta. *Engineering, Construction and Architectural Management*, 10, 43-55.
171. SARKAR, D. 2012. Decision tree analysis for project risk mitigation options for underground metro rail project. *International Journal of Decision Sciences, Risk and Management*, 4, 25.
172. SARKAR, D. & PANCHAL, S. 2015. INTEGRATED INTERPRETIVE STRUCTURAL MODELING AND FUZZY APPROACH FOR PROJECT RISK MANAGEMENT OF PORTS. *International Journal of Construction Project Management*, 7, 17-31.
173. SHAHID IQBAL, R. M. C., KLAUS HOLSCHEMACHER, AHSAN ALI, JOLANTA TAMOŠAITIENĖ 2015. Risk management in construction projects. *Technological and Economic Development of Economy*, Volume 21(1): 65-78.
174. SHEARER, N., KHASAWNEH, M., JUN, Z., BOWLING, S. & RABADI, G. Sensitivity Analysis of a large-scale system dynamics immigration model. 2010 IEEE Systems and Information Engineering Design Symposium, 23-23 April 2010 2010. 78-81.
175. SHEHU, Z., HOLT, G. D., ENDUT, I. R. & AKINTOYE, A. 2015. Analysis of characteristics affecting completion time for Malaysian construction projects. *Built Environment Project and Asset Management*, 5, 52-68.
176. SICOTTE, H. & BOURGAULT, M. 2008. Dimensions of uncertainty and their moderating effect on new product development project performance. *R&D Management*, 468-479.

177. SID GHOSH, J. J. 2004. Identifying and assessing the critical risk factors in an underground rail project in Thailand: a factor analysis approach. *International Journal of Project Management*, 22, 633–643.
178. SINGPURWALLA, N. D. 1988. An Interactive PC-Based Procedure for Reliability Assessment Incorporating Expert Opinion and Survival Data. *Journal of the American Statistical Association*, 83, 43-51.
179. SMITH, P. G., MERRITT, G. M. & MERRITT, G. M. 2002. *Proactive risk management: Controlling uncertainty in product development*, Productivity Press New York.
180. ŠPAČKOVÁ, O., NOVOTNÁ, E., ŠEJNOHA, M. & ŠEJNOHA, J. 2013. Probabilistic models for tunnel construction risk assessment. *Advances in Engineering Software*, 62, 72-84.
181. STELLINGWERF, R. & ZANDHUIS, A. 2013. *ISO 21500 Guidance on project management—A Pocket Guide*, Van Haren.
182. STERMAN, J. D. 2000. *Business Dynamics Systems Thinking and Modeling for a Complex world*, USA, McGraw-Hill Companies, Inc.
183. SWEIS, G., SWEIS, R., HAMMAD, A. A. & SHBOUL, A. 2008. Delays in construction projects: The case of Jordan. *International Journal of Project Management*, 665–674.
184. TAFERE, Y. 2015. Causes of Cost and Time overrun on ERA road Construction Projects. Ethiopian Roads Authority.
185. TAH, J. & CARR, V. 2000a. A proposal for construction project risk assessment using fuzzy logic. *Construction Management & Economics*, 18, 491-500.
186. TAH, J. H. M. & CARR, V. 2000b. Information modelling for a construction project risk management system. *Engineering, Construction and Architectural Management*, 107 - 119.
187. TAH, J. H. M., THORPE, A. & MCCAFFER, R. 1993. Contractor project risks contingency allocation using linguistic approximation. *Computing Systems in Engineering*, 4, 281-293.
188. TAILLANDIER, F., TAILLANDIER, P., TEPELI, E., BREYSSE, D., MEHDIZADEH, R. & KHARTABIL, F. 2015. A multi-agent model to manage risks in construction project. *Automation in Construction*, 1–18.

189. TAREK ZAYED, M. A., JIAYIN PAN 2008. Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, 26, 408–419.
190. TAYLAN, O., BAFAIL, A. O., ABDULAAL, R. M. & KABLI, M. R. 2014. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. *Applied Soft Computing*, 17, 105-116.
191. THOMAS, A., KALIDINDI, S. N. & ANANTHANARAYANAN, K. 2003. Risk perception analysis of BOT road project participants in India. *Construction Management and Economics*, 21, 393-407.
192. THOMAS, A., KALIDINDI, S. N. & GANESH, L. 2006. Modelling and assessment of critical risks in BOT road projects. *Construction Management and Economics*, 24, 407-424.
193. TOURAN, A. & LOPEZ, R. 2006. Modeling cost escalation in large infrastructure projects. *Journal of construction engineering and management*, 132, 853-860.
194. TOURAN, A. & SUPHOT, L. 1997. Rank correlations in simulating construction costs. *Journal of Construction Engineering and Management*, 123, 297-301.
195. TURKEY, W. 2011. Risk factors leading to cost overrun in Ethiopian federal road construction projects and its consequences.
196. VAN THUYET, N., OGUNLANA, S. O. & DEY, P. K. 2007. Risk management in oil and gas construction projects in Vietnam. *International journal of energy sector management*, 1, 175-194.
197. VAUGHAN, E. J. & VAUGHAN, T. 2007. *Fundamentals of risk and insurance*, John Wiley & Sons.
198. WA'EL ALAGHBARI MOHD., R. A. K., AZIZAH SALIM ERNAWATI 2007. The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management*, Vol. 14 Iss 2 pp. 192 - 206.
199. WALKER, HARREMOES, ROTMANS & VON, K. 2003. Defining uncertainty: a conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, 5-17.
200. WANG, S. Q., DULAIMI, M. F. & AGURIA, M. Y. 2004a. Risk management framework for construction projects in developing countries. *Construction Management and Economics*, 237-252.

201. WANG, S. Q., DULAIMI, M. F. & AGURIA, M. Y. 2004b. Risk management framework for construction projects in developing countries. *Construction Management and Economics*, 22, 237-252.
202. WOLSTENHOLME, E. F. 1990. *System Enquiry: A System Dynamics Modelling Approach*, John Wiley & Sons.
203. WOODWARD, D. 1992. Risk management of BOOT projects. *Project, March*, 10-11.
204. XENIDIS, Y. & ANGELIDES, D. 2005. The financial risks in build-operate-transfer projects. *Construction Management and Economics*, 23, 431-441.
205. XU, Y., LU, Y., CHAN, A. P., SKIBNIEWSKI, M. J. & YEUNG, J. F. 2012. A computerized risk evaluation model for public-private partnership (PPP) projects and its application. *International Journal of Strategic Property Management*, 16, 277-297.
206. YANG, I. T. 2007. Risk Modeling of Dependence among Project Task Durations. *Computer-Aided Civil and Infrastructure Engineering*, 22, 419-429.
207. YAO-CHEN KUO, S.-T. L. 2013. Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. *International Journal of Project Management*, 31, 602-614.
208. YAZDANI-CHAMZINI, A., YAKHCHALI, S. H. & MAHMOODIAN, M. 2013. Risk ranking of tunnel construction projects by using the ELECTRE technique under a fuzzy environment. *International Journal of Management Science and Engineering Management*, 8, 1-14.
209. YELIN XU, Y. L., ALBERT P. C. CHAN, MIROSLAW J. SKIBNIEWSKI, JOHN F. Y. YEUNG 2012. A computerized risk evaluation model for public-private partnership (PPP) projects and its application. *International Journal of Strategic Property Management*, Volume 16(3): 277-297.
210. YILDIZ, A., DIKMEN, I., BIRGONUL, M., ERCOSKUN, K. & ALTEN, S. Risk mapping in construction projects. Engineering Project Organizations Conference Proceedings, Rheden, The Netherlands, 2012.
211. YILDIZ, A. E., DIKMEN, I. & BIRGONUL, M. T. 2014. Using Expert Opinion for Risk Assessment: A Case Study of a Construction Project Utilizing a Risk Mapping Tool. *Procedia-Social and Behavioral Sciences*, 119, 519-528.
212. ZAVADSKAS, E. K., TURSKIS, Z. & TAMOŠAITIENE, J. 2010. Risk assessment of construction projects. *Journal of civil engineering and management*, 16, 33-46.

213. ZAYED, T., AMER, M. & PAN, J. 2008. Assessing risk and uncertainty inherent in Chinese highway projects using AHP. *International Journal of Project Management*, 26, 408-419.
214. ZENG, J., AN, M. & SMITH, N. J. 2007. Application of a fuzzy based decision making methodology to construction project risk assessment. *International journal of project management*, 25, 589-600.
215. ZHEN-YU, Z. & LIN-LING, D. An integrated risk management model for construction projects. *Management of Engineering & Technology*, 2008. PICMET 2008. Portland International Conference on, 27-31 July 2008 2008. 1389-1394.
216. ZOU, P., ZHANG, G. & WANG, J. 2007a. Understanding the key risks in construction projects in China. *International Journal of Project Management* 601–614.
217. ZOU, P. X. & ZHANG, G. 2009. Managing risks in construction projects: life cycle and stakeholder perspectives. *International Journal of Construction Management*, 9, 61-77.
218. ZOU, P. X., ZHANG, G. & WANG, J. 2007b. Understanding the key risks in construction projects in China. *International Journal of Project Management*, 25, 601-614.

## APPENDIX I – Questionnaire

## APPENDIX II – Normalized membership values of risk factors and its impact on time and cost

*Table A-1 Normalized membership values for risk factors affecting project duration*

Risk Factor	1	2	3	4	5
Scope changes	0.5455	0.2727	0.9091	1.0000	1.0000
Payment delays	0.0000	0.6471	1.0000	0.3529	0.4118
Right of way problems	0.0000	0.0000	0.6316	0.5263	1.0000
Inadequate site investigation	0.1667	0.6667	1.0000	0.8333	0.7500
Schedule pressure by client	0.0667	0.7333	1.0000	0.6667	0.2667
Inappropriate intervention by client	0.1429	0.5714	0.8571	1.0000	0.3571
Design changes by client	0.1429	0.1429	1.0000	0.9286	0.7143
Slow decision-making	0.0000	0.6154	0.6923	1.0000	0.8462
Slow Site Handover	0.0833	1.0000	0.5833	0.9167	0.8333
Clients management ability	0.0000	0.1875	1.0000	0.9375	0.4375
Design errors	0.1429	0.4286	0.6429	0.7143	1.0000
Incomplete design	0.0000	0.3333	0.8000	1.0000	0.6000
Poor quality of design	0.0625	0.4375	0.6875	1.0000	0.3750
Consultants' lack of experience	0.4615	0.3846	1.0000	0.9231	0.3846
Inadequate site information (soil test and survey report)	0.3571	0.2143	1.0000	1.0000	0.3571
Inaccurate cost estimation	0.4286	0.3571	1.0000	0.7143	0.4286
Design Change	0.0000	0.1667	0.5556	1.0000	0.5556
Changes in material types and specifications during construction	0.5000	0.6667	0.7500	1.0000	0.5000
Delay in contractor's payment certification by the consultant	0.3125	0.5000	1.0000	0.5000	0.2500
Delay in consultant's response to requests for information	0.1538	0.6154	1.0000	0.8462	0.5385
Delay in design work	0.0000	0.2500	0.6875	1.0000	0.6250
Poor quality of construction	0.3333	0.2500	0.9167	0.9167	1.0000
Contractors' lack of experience	0.1429	0.2143	1.0000	0.8571	0.7143
Errors during construction	0.0000	0.5714	0.7857	0.5714	1.0000
Unskilled workers	0.0000	0.2000	1.0000	0.4000	0.4500
Poor labor productivity	0.0000	0.3125	0.6250	1.0000	0.6250
Contractors' poor management capacity	0.0000	0.2105	0.4211	0.5263	1.0000
Poor project planning & control	0.1429	0.1429	0.8571	1.0000	0.7857
Improper construction methods	0.1667	1.0000	1.0000	0.7500	0.5000
Improper Quality control & testing methods	0.1250	0.5625	0.4375	1.0000	0.4375

Shortage of plant and equipment	0.0000	0.0588	0.7647	0.5882	1.0000
Poor productivity of plant and equipment	0.1333	0.2667	0.5333	1.0000	0.8000
Poor site management and supervision	0.2667	0.0667	0.8667	1.0000	0.5333
Underestimation of construction costs	0.0000	0.5714	0.7143	1.0000	0.6429
Contractual claims, such as, extension of time with cost claims	0.0000	0.0625	0.6250	0.8750	1.0000
Low quality of materials	0.1765	1.0000	0.4706	0.3529	0.4118
Frequent damage of equipment	0.0588	0.2941	0.8235	1.0000	0.2353
Bribery and corruption	0.5000	0.3571	1.0000	0.3571	0.7143
Government intervention	0.2353	0.2941	1.0000	0.5882	0.2941
Land & property values	0.5000	1.0000	0.9167	0.5833	0.4167
Currency fluctuation	0.3333	0.9167	1.0000	0.5000	0.6667
Price inflation of construction materials	0.1176	0.2353	1.0000	0.4118	0.6471
Energy cost	0.1765	0.4706	1.0000	0.5294	0.2353
Shortage of construction materials in market	0.0000	0.0625	0.5625	0.9375	1.0000
Import and export restrictions	0.5455	0.9091	1.0000	0.8182	0.4545
Contract modifications (addition of new work to the project and change in specification)	0.0000	0.4375	0.6250	1.0000	0.5000
Mistakes and discrepancy in contract documents	0.4167	0.0833	1.0000	1.0000	0.9167
Heavy Flood, landslide, earthquake etc	0.9091	0.3636	1.0000	0.8182	0.6364
Weather conditions	0.4000	0.9000	1.0000	1.0000	0.8000
Poor site conditions (Location, ground, etc)	0.2000	0.4667	0.4667	1.0000	0.6000
Pollution caused by construction (water, air & noise)	0.5882	1.0000	0.4118	0.2941	0.1176

Table A-2 Normalized membership values for risk factors affecting project duration

<b>Risk Factors</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>
Scope changes	0.2353	0.1176	0.6471	1.0000	0.4118
Payment delays	0.2500	1.0000	0.8333	0.6667	0.6667
Right of way problems	0.0000	0.2778	0.6111	0.3889	1.0000
Inadequate site investigation	0.0000	0.4706	0.4118	1.0000	0.5294
Schedule pressure by client	0.0000	0.9231	1.0000	0.5385	0.6923
Inappropriate intervention by client	0.0000	0.5882	1.0000	0.4118	0.4118
Design changes by client	0.0667	0.2000	1.0000	0.6667	0.8000
Slow decision-making	0.1429	1.0000	0.7143	0.4286	0.6429
Slow Site Handover	0.2143	1.0000	0.5000	0.7143	0.5000
Clients management ability	0.0588	0.5294	1.0000	0.5882	0.2353
Design errors	0.2857	0.3571	0.7857	0.5000	1.0000
Incomplete design	0.0000	0.5000	0.3889	1.0000	0.3889
Poor quality of design	0.3333	0.9167	0.5833	1.0000	0.5833
Consultants' lack of experience	0.7500	0.4167	0.7500	1.0000	0.5000
Inadequate site information (soil test and survey report)	0.3529	0.0588	1.0000	0.5294	0.4706
Inaccurate cost estimation	0.2667	0.2667	0.5333	0.6667	1.0000
Design Change	0.0000	0.2857	0.6429	1.0000	1.0000
Changes in material types and specifications during construction	0.6364	0.7273	0.9091	1.0000	0.4545
Delay in contractor's payment certification by the consultant	0.9091	1.0000	1.0000	0.5455	0.2727
Delay in consultant's response to requests for information	0.1333	1.0000	0.6667	0.6667	0.2667
Delay in design work	0.0714	0.6429	1.0000	0.8571	0.3571
Poor quality of construction	0.1429	0.0714	1.0000	0.8571	0.8571
Contractors' lack of experience	0.0769	0.6154	1.0000	0.9231	0.5385
Errors during construction	0.0000	0.4118	0.5882	0.4118	1.0000
Unskilled workers	0.0000	0.5625	1.0000	0.5000	0.5000
Poor labor productivity	0.0000	0.8333	1.0000	1.0000	0.5833
Contractors' poor management capacity	0.0000	0.2941	0.4118	0.7059	1.0000
Poor project planning & control	0.1250	0.0625	1.0000	0.7500	0.6250
Improper construction methods	0.1333	0.5333	0.7333	1.0000	0.3333
Improper Quality control & testing methods	0.2500	0.9167	0.6667	1.0000	0.5833
Shortage of plant and equipment	0.0000	0.3333	1.0000	0.6667	0.7333
Poor productivity of plant and equipment	0.0625	0.3750	0.6250	1.0000	0.5000
Poor site management and supervision	0.2000	0.0500	1.0000	0.4500	0.3500
Underestimation of construction costs	0.0000	0.5333	0.4000	1.0000	0.8000

Contractual claims, such as, extension of time with cost claims	0.0000	0.0667	0.8667	0.8000	1.0000
Low quality of materials	0.1667	0.4167	0.9167	0.9167	1.0000
Frequent damage of equipment	0.0000	0.3889	1.0000	0.5556	0.3333
Bribery and corruption	0.9091	0.0000	1.0000	0.9091	0.9091
Government intervention	0.2308	0.9231	1.0000	0.9231	0.0769
Land & property values	1.0000	1.0000	0.7778	0.7778	1.0000
Currency fluctuation	0.2500	0.0625	0.5000	1.0000	0.7500
Price inflation of construction materials	0.0000	0.2000	0.3000	0.5500	1.0000
Energy cost	0.2857	0.4286	0.8571	1.0000	0.3571
Shortage of construction materials in market	0.0000	0.1765	0.6471	1.0000	0.5882
Import and export restrictions	0.5000	0.5714	1.0000	0.6429	0.2143
Contract modifications (addition of new work to the project and change in specification)	0.0000	0.5000	0.7143	1.0000	0.7143
Mistakes and discrepancy in contract documents	0.3846	0.1538	0.8462	1.0000	0.7692
Heavy Flood, landslide, earthquake etc	1.0000	0.5000	0.3333	0.9167	0.6667
Weather conditions	0.5000	1.0000	0.7500	0.6667	0.5000
Poor site conditions (Location, ground, etc)	0.2143	0.6429	0.7143	0.3571	1.0000
Pollution caused by construction (water, air & noise)	0.7692	1.0000	0.6923	0.5385	0.1538

## APPENDIX III – Error Calculation