

**DEVELOPMENT OF AN INTEGRATED MATHEMATICAL
MODEL BASED ON AHP AND MAUT TECHNIQUES FOR
ALLOCATING CONTINGENCY VALUE FOR BUILDING
PROJECTS IN SAUDI ARABIA**

BY

MOHAMMAD MOUTASEM ALSALTI

A Thesis Presented to the
DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

APRIL, 2020

**DEVELOPMENT OF AN INTEGRATED MATHEMATICAL
MODEL BASED ON AHP AND MAUT TECHNIQUES FOR
ALLOCATING CONTINGENCY VALUE FOR BUILDING PROJECTS
IN SAUDI ARABIA**

MOHAMMAD MOUTASEM MOHAMMAD ALSALTI

**CONSTRUCTION ENGINEERING AND MANAGEMENT
APRIL, 2020**

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

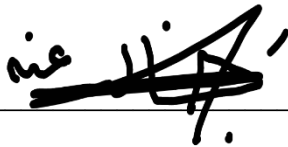
DHAHRAN-31261, SAUDI ARABIA

DEANSHIP OF GRADUATE STUDIES

This thesis, written by **MOHAMMAD MOUTASEM ALSALTI** under the direction of his thesis advisor and approved by his thesis committee, has been presented and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN CONSTRUCTION ENGINEERING AND MANAGEMENT**.



Dr. Khalaf Al-Ofi
Department Chairman



Prof. Dr. Salam A. Zummo
Dean of Graduate Studies

13/5/2020

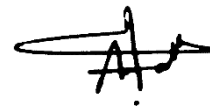
Date



Prof. Dr. Ali Shash
Advisor



Dr. Laith Al-Hadidi
Member



Dr. Adel Alshibani
Member



© MOHAMMAD MOUTASEM ALSALT

2020

DEDICATION

In the Name of Allah, the most Gracious, the most Merciful.

Praise be to Allah and blessing and peace be upon our Prophet Mohammed, his family and his companions.

This research is dedicated, in the first place, to Almighty Allah; “who has taught (the writing) by the Pen, has taught man that which he knew not” Qur’an [96: 4-5]. The first word revealed from Allah upon Prophet Mohammed peace be upon him was Iqra', which literally means read and which induces all people to learn, and seek knowledge to promote growth and prosperity on earth.

I would like to dedicate this modest work to my beloved parents, Fatima Osama Al-Salti and Moutasem Mohammad Al-Salti, who had spared no effort to support me and devoted their invaluable prayers for me. I am really indebted to them and no words can express my gratitude to them.

I put across my heartfelt thanks to my lovely sister and brother, Zena and Malek, for their endless support and encouragement. May Almighty Allah bless and protect all of them. I also dedicate this work to all my family members including my grandmother, Siham, brother-in-law, Mohammad Ghanem, and my nephew, Omar.

I also wish to express my deep profound gratitude to my affectionate deceased grandparents, Sobhia Yakoub and Osama Al-Salti. They granted me the love that made me who I am today. They are no longer among us but I still feel their souls with us. I also extend my dedication to my late aunt, Maha, and my late uncles, Samir and Samer, who unfortunately passed away during my studies. May Allah have mercy on all of them, grant them the eternal paradise and bring us together in the highest paradise with all our beloved ones.

All love goes to my prospective fiancée Inshallah, Tuba Çilenti, for her continual moral support.

Last but not the least I would like to convey my honest thanks to my cousins, Mohammad Mansour Al-Salti and Abdulghani Ghassan Al-Sooqi, and my friends, Ahmad Nazzal, Amro Al-Tayeb, Basel Al-Baghli, Jwad Salman, Moath Al-Rekabi, Mohammad Abo-Ramadan and Tarek Alaya, for their support and inspiring feelings.

I wish that this humble work contributes at least a little bit to the academic field and the industry.

“All the praises and thanks be to Allah, Who has guided us to this, and never could we have found guidance, were it not that Allah had guided us” Qur’an [7: 43].

ACKNOWLEDGMENTS

My first and sincere appreciation goes to my supervising teacher Dr. Ali Shash, Professor, Construction and Engineering Department (CEM), King Fahd University of Petroleum and Minerals (KFUPM), for all I have learned from him and for his continuous help and support in all stages of this thesis. I would also like to thank him for being open to ideas and for encouraging and helping me to shape my interest and ideas.

I would like to convey my honest thanks to Dr. Adel Alshibani, Assistance Professor, CEM, KFUPM, for his guidance and precious advices during my whole studies. I also communicate my words of special thanks to Dr. Laith Hadidi, Associate Professor, CEM, KFUPM, for his valuable inputs and suggestions throughout the research period.

I am very grateful for everyone individually who contributed in this research including participants in the survey and for anyone ever taught me a letter including my former teachers, Mr. Ahmad Jamil, Dr. Yasser El-Husseini, Dr. Mostafa Ismail, Prof. Jehad Alzabut, Dr. Bahaa-Eldin Abdalla, Dr. Ihab Katar, Eng. Mohammad Bani Mufarrej and so many to mention.

I am thankful to all my friends who have supported me throughout the tenure of the thesis. I would like to give my special thanks to Mohannad Zaaza, Basel Hasan, Marwan Dawood, Amin Abu Saa, Mohammad Hamida and Hamza Hamida. They assisted me in understanding some concepts and in data collection. They were like my brothers.

Acknowledgement is due to King Fahd University of Petroleum and Minerals and the Construction Engineering and Management department including Dr. Khalaf Al-Ofi and all members of the faculty and the office staff for providing such a rich environment for study and research.

TABLE OF CONTENTS

Acknowledgments.....	vi
List of Tables	x
List of Figures	xi
List of Abbreviations	xii
Abstract	xiv
Arabic Abstract	xvi
Chapter One: Introduction	1
1.1 Background	1
1.2 Problem Statement	2
1.3 Research Objectives	3
1.4 Significance of the Study	3
1.5 Scope and Limitations.....	5
Chapter Two: Literature Review	6
2.1 Definition of Risk.....	6
2.2 Definition of Uncertainty	7
2.3 Difference between Risk and Uncertainty	7
2.4 Risk Management.....	8
2.5 Behaviours towards Risk.....	10
2.6 Definition of Contingency.....	12
2.7 Sources of Risk.....	13
2.8 Contingency Allocation Approaches	21
2.8.1 Deterministic Approaches	23
2.8.2 Probabilistic Approaches.....	24
2.8.3 Modern Mathematical Models.....	30

Chapter Three: Research Methodology	33
3.1 Multi Attribute Utility Theory (MAUT)	35
3.2 Risk Identification	40
3.3 AHP Survey Design	41
3.3.1 Construction of the Hierarchal Structure.....	41
3.3.2 Pairwise Comparison.....	43
3.3.3 Consistency Check	44
3.4 MAUT Survey Design	45
3.4.1 Utility Functions Development	45
3.4.2 Expected Utility Value	51
3.4.3 Contingency Utility Function Development.....	52
3.5 Pilot Study	52
3.6 Population and Sampling	53
3.7 Data Collection.....	54
3.8 Data Analysis	54
3.9 Model Validation.....	56
3.10 Computer Implementation.....	56
3.10.1 Criteria for the Selection of Development Tools.....	56
3.10.2 Software System’s Architecture	57
3.10.3 Data Flow of the Proposed Model.....	59
Chapter Four: Results and Discussion	61
4.1 Demographic Information of Respondents	61
4.1.1 Educational Background of Respondents.....	62
4.1.2 Job Position of Respondents.....	63
4.1.3 Years of Work Experience of Respondents.....	64

4.1.4 Location of Organizations	65
4.1.5 Classification of Organizations	66
4.2 Risk Factors Affecting the Allocation of Cost Contingency.....	67
4.3 Model Development.....	82
4.3.1 Utility Function Development	82
4.3.2 Development of the Contingency Utility Function	93
4.4 Model Validation.....	97
4.4.1 Case Study 1:	99
4.4.2 Case Study 2:	103
4.5 Computer Implementation.....	107
4.5.1 Overview of the Computer Application	107
Chapter Five: Summary of the Study, Conclusion and Recommendations.....	110
5.1 Summary of the Study	110
5.2 Findings	111
5.2.1 Major Findings	111
5.2.2 Minor Findings	111
5.3 Conclusion.....	114
5.4 Recommendations	114
5.5 Future Studies.....	115
References.....	117
Appendix A.....	127
Appendix B	139
Appendix C	201
Vitae.....	212

LIST OF TABLES

Table 2.1: Risk Factors	15
Table 3.1: Risk Identification	40
Table 3.2: AHP Scale.....	43
Table 3.3: Random Index Values.....	45
Table 3.4: Illustrative Example of the Required Data	48
Table 3.5: Illustrative Example of the Required Data to Develop the Utility Functions.....	50
Table 3.6: Illustrative Example of the Required Three Coordinate Points	55
Table 4.1: Summary of the Computed Consistency Ratios	72
Table 4.2: Weights of Categories.....	75
Table 4.3: Ranking of Categories	75
Table 4.4: Local Weights of Risk Factors	76
Table 4.5: Local Ranking of Risk Factors	78
Table 4.6: Global Weights of Risk Factors.....	79
Table 4.7: Global Ranking of Risk Factors	81
Table 4.8: Financial Impact, Probability and Certainty Equivalent Values	85
Table 4.9: Shape of Utility Functions	90
Table 4.10: Coordinate Points and Risk Attitude	90
Table 4.11: Utility Functions of Risk Factors.....	92
Table 4.12: Scale Conversion	95
Table 4.13: Project Cost Contingency Percentages	96
Table 4.14: Coordinate Points of the Contingency Utility Function	96
Table 4.15: Impact-Probability Matrix	98
Table 4.16: Summary of the User's Input and Calculations	100
Table 4.17: Summary of the Developed Contingency Utility Functions and Results	101
Table 4.18: Summary of the User's Input and Calculations	104
Table 4.19: Summary of the Developed Contingency Utility Functions and Results	105

LIST OF FIGURES

Figure 2.1: Cost Contingency Allocation Methods	22
Figure 3.1: Research Methodology	34
Figure 3.2: Risk Attitudes Utility Functions	36
Figure 3.3: AHP Hierarchy Structure	42
Figure 3.4: Risk Factor Utility Function	48
Figure 3.5: System Layout	58
Figure 3.6: Contingency Value Prediction Process	60
Figure 4.1: Educational Background	62
Figure 4.2: Years of Work Experience	64
Figure 4.3: Organization Address	65
Figure 4.4: Organization Classification	66
Figure 5.1: Dialog Window of Risk Factors Evaluation	108
Figure 5.2: Dialog Window of Selecting Risk Attitude	109

LIST OF ABBREVIATIONS

AACE	:	The Association for the Advancement of Cost Engineering
AHP	:	Analytical Hierarchy Process
ANN	:	Artificial Neural Network
BOQ	:	Bill of Quantities
CE	:	Certainty Equivalent
CI	:	Consistency Index
CR	:	Consistency Ratio
DBB	:	Design Bid Build Delivery System
DTA	:	Decision Tree Analysis
EMV	:	Expected Monetary Value
ERA	:	Estimating Using Risk Analysis
EV	:	Expected Value
FIDIC	:	The International Federation of Consulting Engineers
FOSM	:	First-Order, Second-Moment
GDP	:	Gross Domestic Product
MAUT	:	Multi Attribute Utility Theory
MCDM	:	Multi-Criteria Decision Making
MCS	:	Monte Carlo Simulation
ORF	:	Overall Risk Factor
PDF	:	Probability Density Function
PERT	:	Program Evaluation and Review Technique
PMF	:	Probability Mass Function

PMI	:	Project Management Institute
RD	:	Risk Discrimination
RF	:	Risk Factor
RI	:	Random Index
RI	:	Risk Impact
RP	:	Risk Probability
UCPW	:	Unified Contract for Public Works

ABSTRACT

Full Name : [MOHAMMAD MOUTASEM AL SALTI]
Thesis Title : [DEVELOPMENT OF AN INTEGRATED MATHEMATICAL
MODEL BASED ON AHP AND MAUT TECHNIQUES FOR
ALLOCATING CONTINGENCY VALUE FOR BUILDING
PROJECTS IN SAUDI ARABIA]
Major Field : [MASTER OF SCIENCE IN CONSTRUCTION ENGINEERING
AND MANAGEMENT]
Date of Degree : [APRIL, 2020]

The construction industry is by nature one of the riskiest businesses because of its viability to be influenced by numerous factors and the unique circumstances of each project. Poor management of risk and uncertainty can prevent the delivery of project expected outcomes and objectives. Cost contingency allocation has for decades been a common strategy for addressing risk and uncertainty in construction projects. Nevertheless, subjective judgement of and decisions regarding the amount of cost contingency have regularly proven inefficient and imprecise. Cost contingency allocation requires a delicate and systematic estimation of where it should be implemented within the framework of risk management. Prediction of the optimum cost contingency percentage that balances business competitiveness with the achievement of project objectives is the most desirable outcome. However, the literature has revealed a lack of research in the field of cost contingency prediction models, especially in Saudi Arabian building contract firms. Therefore, the objective of this research was to develop a model for predicting the required cost contingency percentage for local contractors engaging in domestic construction projects in the Eastern Province of Saudi Arabia. To this end, an analytical hierarchical process was integrated with multi-attribute utility theory. Initially, an extensive literature review was performed to identify the risk factors influencing decisions regarding cost contingency. The Unified Contract for Public Works was

closely examined to extrapolate risk factors in which the responsibility falls on the contractor to determine the most common risk treatment strategies under unit price/lump sum contracts in design-bid-build delivery systems. The hierarchical structure identified 18 risk factors. A total of 17 experts were interviewed to evaluate these risk factors in terms of financial impact, probability of occurrence, and relative importance. This research revealed that unrealistic construction schedules, escalations in prices, and inadequate designs were the most influential on project cost. Utility functions were then established using MATLAB software and subsequently coded using Java to develop a user-friendly interface prototype software. Users of the model input the expected impact and likelihood level of each risk factor and selected the risk behavior desired based on specific project conditions. The capabilities of the model were tested by applying it to two construction projects. The model was able to match 90% of the actual expended cost contingency. Use of the proposed model in the actual cases would have resulted in savings of more than SR 3.5 million. The model developed here is a powerful tool reflecting the basic dimensions of risk where they are implicitly embedded and explicitly appear. Moreover, consideration of the risk attitudes presented in the model provides contractors with the opportunity to choose which strategy to adopt based on specific project conditions. The model is believed to outperform the current practice of allocating cost contingency because it reduces subjectivity, enhances competitive advantage, and maintains fair profit margins. This work greatly contributes to the overall industry because it augments a project's expected outcomes and ensures more efficient utilization of government and private resources. This model can also be used to assist in establishing government budgets and determining the required funding for proposed projects.

ARABIC ABSTRACT

ملخص الرسالة

الاسم الكامل: [محمد معتصم محمد السلطي]

عنوان الرسالة: [تطوير نموذج رياضي قائم على أساس الدمج بين تقنيات عملية التحليل الهرمي ونظرية المنفعة المتعددة الخصائص للتنبؤ بتكاليف المخاطر في مشاريع المباني في المملكة العربية السعودية]

التخصص: [ماجستير العلوم في هندسة وإدارة التشييد]

تاريخ الدرجة العلمية: [رمضان، ١٤٤١]

تعد صناعة البناء، في طبيعتها، واحدة من أكثر الأعمال خطورةً بسبب قابليتها للتأثر بعوامل عديدة وبسبب الظروف الفريدة لكل مشروع. تؤدي الإدارة السيئة للمخاطر إلى الفشل في تحقيق النتائج والأهداف المتوقعة للمشروع. ولقد كانت استراتيجية تخصيص تكاليف المخاطر هي الممارسة السائدة التي يتم اتباعها للتعامل مع المخاطر في مشاريع البناء لفترة طويلة. ومع ذلك، أثبتت الأحكام والقرارات الذاتية بشأن تحديد تكلفة المخاطر عدم كفاءتها وعدم دقتها. في حين أن تقدير تكلفة المخاطر يتطلب حساباً دقيقاً حيث يجب تنفيذه بشكل منهجي في إطار إدارة المخاطر. وإن توقع تكلفة المخاطر المثلى، التي توازن بين الحفاظ على القدرة التنافسية للأعمال وتحقيق أهداف المشروع، كنسبة مئوية من إجمالي قيمة المشروع هو المسعى الأكثر رغبة. وبالرغم من أهمية مرحلة تقدير تكاليف المخاطر، يوجد ندرة للمراجع العلمية في مجال نماذج التنبؤ بتكاليف المخاطر في المملكة العربية السعودية وخصوصاً لمشاريع المباني. لذلك، كان الهدف من هذا البحث هو تطوير نموذج بهدف توقع تكلفة المخاطر المطلوبة التي سيتم تخصيصها من قبل المقاولين المحليين لمشاريع البناء المحلية في المنطقة الشرقية بالمملكة العربية السعودية من خلال الدمج بين تقنية عملية التحليل الهرمي (AHP) وتقنية نظرية المنفعة المتعددة الخصائص (MAUT). في البداية، تم إجراء مراجعة موسعة للدراسات السابقة لتحديد عوامل الخطر التي تؤثر على القرار بشأن تحديد تكلفة المخاطر. تم فحص العقد الموحد للأشغال العامة عن كثب لإستقراء عوامل الخطر التي تقع مسؤوليتها على المقاول وتم تحديد استراتيجية معالجة المخاطر الأكثر شيوعاً لكل عامل خطر محدد بموجب عقد سعر الوحدة مع منهجية التصميم - المناقصة - التشييد. تم تحديد ١٨ عامل خطر لدراساتهم وتحليلهم بالتفصيل. كما تمت مقابلة ما مجموعه ١٧ خبيراً في مجال تقدير التكاليف لتقييم عوامل الخطر من حيث الآثار المالية واحتمالية الحدوث والأهمية. ولقد كشف البحث، على التوالي، أن عدم واقعية الجدول الزمني وارتفاع الأسعار وعدم كفاءة التصميم هي أكثر عوامل الخطر تأثيراً على تكلفة المشروع. ثم تم إنشاء دوال المنفعة باستخدام برنامج MATLAB ثم تم ترميزها باستخدام

لغة البرمجة JAVA لتطوير نموذج أولي سهل الاستخدام. . يتطلب البرنامج من المستخدمين إدخال مستوى التأثير والإحتمالية المُتَوَقَّعين لعوامل الخطر بالإضافة إلى تحديد السلوك المرغوب اتجاه المخاطر بناءً على ظروف المشروع المعني. أخيراً، تم اختبار قدرات النموذج المطور من خلال تطبيقه على مشروعي بناء. ولقد كان النموذج قادراً على المطابقة مع ٩٠ ٪ من تكاليف المخاطر الفعلية المستهلكة. ولقد كان من الممكن أن يؤدي النموذج المقترح إلى توفير أكثر من ٣,٥ مليون ريال سعودي لو تم استخدامه بالفعل على المشاريع المعروضة في هذه الدراسة. النموذج المطور هو أداة قوية لأنه يعكس الأبعاد الأساسية للمخاطر حيث تم اعتبارها بشكل ضمني في تطوير النموذج وكذلك بشكل صريح عند الاستخدام. إلى جانب ذلك، أتاح أخذ سلوك المقاولين اتجاه المخاطر في عين الاعتبار في النموذج فرصة للمقاولين لتحديد الاستراتيجية التي سيتبنونها وفقاً لظروف المشروع المحددة. يُعتقد أن النموذج المطور يتفوق على الممارسات الحالية في تقدير تكاليف المخاطر والذي من شأنه أن يساعد في تعزيز ميزة الشركات التنافسية والحفاظ على هوامش ربح عادلة. بالإضافة إلى مساهمته بشكل كبير في تطوير صناعة البناء ككل لأنه يزيد من فرصة تحقيق النتائج المتوقعة للمشروع ويضمن الاستخدام الأكثر كفاءة للموارد الحكومية والخاصة. كما يمكن استخدام النموذج المطور أيضاً للمساعدة في وضع الميزانيات الحكومية وتحديد مقدار التمويل المطلوب للمشاريع المقترحة.

CHAPTER ONE

INTRODUCTION

1.1 Background

The construction industry has always been a significant contributor to economic prosperity and is a reflection of a nation's social progress. In Saudi Arabia, the construction sector contributes about 4.3% to the overall gross domestic product and employs over 25% of the total workforce, or about 3.5 million workers (General Authority for Statistics, 2018). A significant portion of government expenditures go to the construction industry for various strategic projects, including (but not limited to) infrastructure, healthcare, energy, education, and housing endeavors. The success of these various construction projects has a crucial impact on people's lives, as well as on the country's economic standing. Nevertheless, the industry experiences recurrent obstacles to achieving project objectives. Improper implementation of risk management is one key problem that often leads to project failure. Risk and uncertainty are deeply inherent in the nature of the construction industry. The viability of a project can be influenced by numerous factors that are difficult to prepare for because each development project is unique. For decades, cost contingency allocation has been adopted to address risk and uncertainty in construction projects (Chen and Hartman, 2000). The Association for the Advancement of Cost Engineering (AACE) defined contingency as "an amount added to an estimate to allow for items, conditions, or events for which the state, occurrence, or effect is uncertain and that experience shows will likely result, in aggregate, in additional costs" (AACE, 2019). Yet multiple studies have demonstrated that the subjective judgement and arbitrary decisions resulting from the cost contingency strategy result in inefficiency and imprecision (Baccarini, 2004; Akinradewo and Awodele, 2016). Cost contingency allocation requires delicate estimations that should be implemented systematically

within a larger risk management framework. Prediction of the optimum cost contingency percentage, one that balances business competitiveness and the achievement of project objectives, is essential. Therefore, the objective of this research was to develop a model for predicting the cost contingency percentages to be allocated by local contractors in domestic construction projects in the Eastern Province of Saudi Arabia. To this end, the analytical hierarchy process (AHP) was integrated with multi-attribute utility theory (MAUT). The resulting model predicts the cost contingency required for design-bid-build projects under unit price/lump sum contracts.

1.2 Problem Statement

Contingency is a monetary amount added to an estimated bid cost to cover unforeseen events. In the construction industry, contracts are commonly awarded on a highly competitive bidding basis. According to Smith and Bohn (1999), overestimating the amount of contingency may lead to business loss and an increase in opportunity cost. Conversely, underestimating the amount of contingency may mean that the risks and uncertainties inherent in construction work are not being properly considered, which can lead to paramount issues such as cost overruns, schedule delays, poor quality, and legal disputes, all serious obstacles to development and progress. Contingency allocation has always been a major concern and controversial issue among cost estimators and project management teams due to its complexity; it is affected by numerous factors and conditions. One common practice worldwide for allocating contingency is adding a certain percentage to the total estimated cost of construction (Chen and Hartman, 2000). In Saudi Arabia, contractors often rely on expert judgment to determine contingency values, and then allocate a certain percentage to the total estimated price (Abdo, 2015). One study found substantial variations between estimated contingency values and the actual amounts expended, and further revealed that this variation could be attributed to a set of factors including “adequacy of schedule requirements” and “risk involved

in investment.” Such variations can lead either to bid failure or project financial loss. In fact, despite the critical nature of contingency allocation, related decisions are often wholly subjective (Burroughs and Juntima, 2004). Moreover, the dynamic nature of the construction industry and surrounding circumstances mean that the environment is constantly changing and varies considerably from one country to another. Consequently, construction professionals often face great difficulties when attempting to adopt a suitable approach that considers the various risk factors affecting accurate contingency allocation.

1.3 Research Objectives

The primary purpose of this research was the integration of AHP with MAUT to develop of a robust model for determining the optimum amount of contingency cost to be allocated by local contractors in domestic construction projects in the Kingdom of Saudi Arabia.

This study had the following secondary objectives:

- Identification of sources of risk and uncertainty in the Saudi construction market.
- Determination of the most significant risk factors to consider when allocating contingency in the Saudi construction market.

1.4 Significance of the Study

The Kingdom of Saudi Arabia is one of the most rapidly developing countries worldwide. The government has ambitiously launched Vision 2030 in pursuit of comprehensive improvements to the economy and society, with goals including (but not limited to) three Saudi cities being ranked in the top 100 in the world, enhancing the quality of life of its citizens, and advancing the housing sector (Saudi Council of Economic and Development Affairs, 2016). Accordingly, the government is launching a tremendous number of projects to achieve these goals and investing heavily in the

economy. Consequently, the construction industry has experienced an immense boom and is expected to be a major contributor to achieving this government vision and the Saudi peoples' ambitions. Therefore, project success is mandatory, particularly in the coming years. The accurate allocation of contingency amounts to construction projects is a critical factor in achieving project goals related to cost, time, quality, safety, and the environment. If not accurately assigned, contingency allocations may result in substantial losses, especially in larger projects representing billions of dollars. Contractor failure is also a possibility if contingency allocation is underestimated and does not account for all possible risks.

Thus, the significance of this study is as follows:

- The literature lacks research on cost contingency estimation models for the Kingdom of Saudi Arabia, especially for building contractors.
- The model developed here considers the various risk attitudes of contractors.
- The model also reflects the basic dimensions of risk and provides weighted scores for each.

The primary benefit of this research is it enables contractors to more accurately estimate the optimum contingency value as a percentage of the total estimated bid cost, facilitating preparation for unforeseen events. The secondary benefits of this research are as follows:

- Identification of current sources of risk and uncertainty that contractors must take into consideration when assigning contingencies.
- Determination of the most significant sources of risk and uncertainty that contractors must take into consideration when assigning contingencies in the Saudi market.

1.5 Scope and Limitations

The scope of this research includes an approach using AHP and MAUT techniques to determine the amount of contingency to be allocated by local contractors for domestic construction projects in the Eastern Province of the Kingdom of Saudi Arabia. In addition, it addresses the most significant sources of risk and uncertainty that local contractors must take into consideration when assigning contingencies in the Saudi market. The results of this research rely heavily on the accuracy of the actual data provided by participants in this study. In order to obtain reasonable and logical results, this research was limited as follows:

- This study was conducted solely from the contractors' point of view.
- This research was limited to domestic construction projects in the Eastern Province of the Kingdom of Saudi Arabia, under its market environment's regulations and circumstances.
- This research targeted classified building contractors of Grades 1 or 2.
- Since the responsibilities and conditions vary from one project delivery system and contract to another, the design-bid-build project delivery system with a unit price/lump sum contract under the Unified Contract for Public Works (UCPW) was deemed the focus of this research.

CHAPTER TWO

LITERATURE REVIEW

This chapter reviews existing literatures related to the subject matter. The discussions are divided into eight sections. The first three sections aims to define both risk and uncertainty and differentiate between them. The fourth and fifth sections discuss the basics of risk management and risk behaviors. The sixth section presents a discussion of the definition of contingency. Furthermore, the seventh section aims to explore the literature to identify all source of risks and uncertainties. Finally, the last section presents various contingency allocation methods.

2.1 Definition of Risk

Risk and uncertainty are involved in almost every aspect and field in life. There have been various attempts to define risk conceptually and mathematically by several researchers and organizations (Šotić and Rajić, 2015). Risk has been defined as "unpredictable events that might occur in the future whose exact likelihood and outcome is uncertain but could potentially affect their interests/objectives in some way" by Loosemore et al. (2006). According to Loch et al. (2006), risk is the multiplication of the likelihood of occurrence of an event and the severity of its impact. However, it is noticeable that there has been no consensus of opinion about the definition of risk due to the various perceptions of risk from different perspectives and to what and whom it is being applied (Adams, 2014; Aven, 2011). In addition, the terminology risk is being mistakenly associated with negative impacts and downsides only, while, in contrast, risk could be considered as a great opportunity with several positive impacts and upsides presented as profit or gain (Al-Bahar and Crandall, 1990). Understanding the concept of risk has shed the light on several business opportunities for investments like the one in the insurance industry. In the context of construction

industry, risk can be defined as an event, if it occurs, that affects project objectives and deliverables of cost, time and quality (Akintoye and MacLeod, 1997).

2.2 Definition of Uncertainty

According to Winch (2010), uncertainty is the lack of information at the time of making critical decisions. Given the background, uncertainty, in construction, could be defined as the difference between the required information and the available information at the bidding stage. Uncertainty causes vagueness and ambiguity for cost estimators and other decision makers which in result leads to immense variation among bids (Jayasena, 2005).

2.3 Difference between Risk and Uncertainty

Risk and Uncertainty terms are often hardly distinguished from each other and one might be interpreted as the other (Saunders, 2016). The distinction between risk and uncertainty has been described by Willows and Connell (2003) and as defined earlier as that risk requires two dimensions to be defined which are:

- (1) The magnitude of the consequence or outcome of the risk source.
- (2) The probability of occurrence of a consequence.

Whereas, uncertainty represents the ambiguity associated with the determination of the above-mentioned risk dimensions. As the amount of information about a potential source of risk increases, risk can be no longer considered a risk since it can be accounted for at the time of making decisions with a reasonable percentage of certainty. It can be said that all risks are a result of uncertainty and lack of information that is necessary for assessing and quantifying risks (Olsson, 2007).

2.4 Risk Management

In accordance with the (Institute of Risk Management), risk management is a systematic framework that basically aims to enhance the decision-making process of organizations about risks with the purpose of achieving organizational objectives. In general, several research studies have found that risk management process mainly involves numerous stages which are identifying, analysing, evaluating, responding to risk and monitoring (Snow, 2010; Khaliluddin, 2010). Responding to risk is one of the most important stages of the process of risk management in which a critical decision about the most appropriate risk treatment strategy must be made. Risk treatment strategies essentially endeavour to have control over risks and to reduce the effect of risks on project objectives as much as possible (Al-Bahar and Crandall, 1990). There have been several risk treatment strategies discussed by Al-Bahar and Crandall (1990) and these can assume one of the following forms:

- 1) Risk Avoidance: This strategy prefers to avert taking risks from the very beginning and not even be engaged in a risky situation. By way of illustration, a contractor might decide not to bid in a country that is not politically and economically stable in a try to avoid the risks associated with country's status. However, as defined earlier that risk might have a positive impact, the contractor by default loses the potential gains from taking the risk by adopting this treatment strategy.
- 2) Risk Reduction: This strategy basically seeks to control the two risk dimensions mentioned previously. Particularly, reducing the likelihood of occurrence of a certain risk and mitigating the negative impacts of the consequences of a certain risk are the core concept of this action.

- 3) Risk Retention: By adopting this treatment strategy, a contractor accepts taking risks and being responsible to affording the potential impacts of risk.
- 4) Risk Transfer: This strategy implies that risks are to be borne or afforded by another party through contractual arrangements and negotiations. For instance, a contractor and an owner might agree upon a construction contract in which there is a clause stating that the owner shall be responsible for any price escalations in any kind of materials such as steel or concrete. However, the amount of endurance of a certain risk by a certain party, other than the one who is seeking to transfer risk, can be either partially or completely transferred, depending on the provisions and conventions between stakeholders.
- 5) Insurance: This strategy represents the practice of purchasing a commercial insurance by contractors, such that, an insurance firm shall undertake to bear the financial impacts of risks if they occurred.

(Rajendhran and Sundar, 2011; Rehacek, 2017) have found two more treatment strategies as follows:

- 6) Risk Exploit: This strategy focuses on taking advantage of the favourable aspects of risks by eliminating the uncertainty associated with risks.
- 7) Risk Enhance: Similar to risk exploit, it focuses on maximizing the benefits from potential positive risks by increasing the probability of occurrence of potential positive risks or increasing the magnitude of their impacts.

As a matter of fact, adopting a risk treatment strategy in response to risks can be considered the most significant stage among other risk management stages. Moreover, deciding the most appropriate response to risk is influenced by several considerations and factors. Consequently, adopting a risk treatment strategy varies from one business market to another, from one contractor

to another and from one project to another as well. In general, the chief principle that contractors shall base their decisions upon is to adopt a treatment strategy that provides the least possible exposure to financial losses and at the same time the one that minimizes the likelihood of risk occurrence. Hence, a single risk treatment strategy or a combination of alternatives could be adopted to deal with a certain risk (Al-Bahar and Crandall, 1990). According to Fisk and Reynolds (2010), there are two methods to handle risks when a risk retention strategy is adopted as follows:

- 1) Contingency Allocation.
- 2) Risk Control.

2.5 Behaviours towards Risk

Risk and uncertainty are deeply embodied in the nature of the construction business and therefore contractors realize the fact that in most cases they have to accept risks associated with projects. As mentioned previously that there are two approaches to deal with risks under the assumption that the risk retention treatment strategy is adopted. However, the emphasis in this research shall be on contingency allocation approach to deal with potential risks and uncertainties. In fact, risk behaviours of decision makers have a significant role in decision making situation (Han et al., 2005). Moreover, studying the risk attitudes of contractors is crucial in the decision-making process of the amount of contingency to be allocated to construction projects under uncertainty situations. In particular, contingency assignment is significantly dependable in the first place on decision makers' beliefs and attitudes in which each decision maker could react to a certain risky situation in a different manner even if the situations have analogous circumstances (Akintoye and MacLeod, 1997). Furthermore, Han et al. (2005) developed an experiment to explore the risk behaviours of contractors when deciding on bidding on international projects. On the other hand, Wang and Yuan (2011) pointed out to several factors that could have a substantial influence on

contractors' attitudes toward risk, other than personal beliefs and perceptions, in construction projects in China. Through a comprehensive literature review and semi structured interviews with Chinese contractors, the study discovered 26 factors including "consequences of decision making", "engineering experience", and "completeness of project information" ranked as the most important influencing factors among others. In addition, two more important factors have been revealed namely, "Company's economic strength" and "External economic environment" to be critical factors among the only critical 16 factors out of 26 and were ranked in the tenth and sixteenth places respectively. In fact, it is more logical to determine the shape of the utility function -as explained in section 3.1 - based on variables whose relationships are identifiable and measurable rather than basing it on subjective factors. Therefore, for the sake of simplicity and generalization purposes, it can be assumed based on study conducted by Laryea and Hughes (2008) about the relationship between risk and price that contractors' attitudes and behaviours towards risk are based on the factors mentioned below. However, risk attitudes are described in section 3.1.

- a) Market Status: Basically, this can be explained by the concept of supply and demand, and determined by the level of competition exists on bids. To illustrate that, an interview study with 12 contractors in the United States of America conducted by Smith and Bohn (1999) revealed that contractors give no consideration to risk management when they are thirsty for work and where competition is high. While on the other hand, a research has found that contractors rise bids prices by approximately 3% of the total value of a project to reimburse for their lack of enthusiasm for work and risk (Neufville and King, 1991).
- b) Company Financial Standing: This refers to "Company's economic strength" mentioned previously in the research conducted by Wang and Yuan (2011). Moreover, Slovic et al. (1984) has demonstrated the relationship between decision makers' risk attitudes and

companies' financial strength. It has been found that contractors' propensity to take risk increases along with the increases in companies' financial strength.

2.6 Definition of Contingency

According to Cambridge dictionary, the term contingency refers to “something that might possibly happen in the future, usually causing problems or making further arrangements necessary”. In the context of construction industry, it is classified as an approach to deal with risk and uncertainty under the risk management framework in which a monetary allowance is allocated to the total project value in order to overcome project cost overruns that might be caused by risk and uncertainty (Laryea et al., 2007). However, a research conducted on 48 road construction projects in Australia revealed that the average contingency cost was 5.24% while the average actual variation or cost overrun was 9.92% with an increase of approximately 89% (Baccarini, 2004). In addition, an analysis has been undertaken by Akinradewo and Awodele (2016) on 53 construction projects in Ondo State, Nigeria. The analysis has revealed that the average amount of cost contingency considered by contractors was about 5% while actually the average cost overrun was about 18%. Furthermore, a research carried out by Shash (1998) showed that specialist contractors in USA usually add 5-10% to the total bid price when working with general contractors with whom they have never worked before. Undoubtedly, contingency cost is not supposed to cover all sources of risk and uncertainty. In agreement with Smith and Bohn (1999), contingency cost shall cover all sources of risk and uncertainty except those covered by other risk treatment strategies and approaches such as risk transfer. In addition, Al-Bahar and Crandall (1990) have suggested various risk treatment strategies to handle each identified risk. For instance, it was proposed to adopt a risk transfer and insurance strategies to handle political and environmental risks such as changes in laws and war. Hence, it is noticeable that the amount of cost contingency vastly depends on several

factors including the project delivery system and the procurement method used. Therefore, in this research, a unit price/lump sum contract shall be assumed. For instance, a larger number of risk factors are handled through a risk transfer treatment strategy in a cost plus contract comparing to a unit price contract.

2.7 Sources of Risk

As stated earlier, identifying potential sources of risk and uncertainty is the first and most important stage of the process of risk management (Rehacek, 2017). As a matter of fact, failure to explore all sources of risk may lead to catastrophic consequences in which unpredictable events might occur and would need corrective actions that are, in most cases, more costly than planned actions of adopting a risk treatment strategy because they were not recognized at first (Al-Bahar and Crandall, 1990). Moreover, given that the determination of cost contingency is a decision-making problem, sources of risk and uncertainty can be considered as criteria influencing the amount of cost contingency apportion. An extensive literature review was performed to identify risk factors that influence the decision on the amount of cost contingency as shown in table 2.1. Risk factors were adopted to best conform with the research scope such that international risk factors were excluded, since this research is devoted to predicting the amount of cost contingency to be assigned by local contractors in domestic construction projects in the Kingdom of Saudi Arabia. By way of illustration, a study was conducted in Palestine by Enshassi et al. (2008) to investigate risk factors influencing the achievement of construction projects objectives revealed extraordinary risk factors such as borders closure and invasions, and thereby such factors shall not be taken into consideration. In addition, some researchers (Sonmez et al., 2007) have identified several risk factors such as the level of quality specified in documents or schedule requirements. While in contrast, those factors have been criticized by other researchers (Zou et al., 2007) for being

considered as risk factors because contractors must account for such factors as direct costs in the bid price in which schedule requirements can be dealt with by increasing manpower or other strategies, and quality requirements should be solved by adopting the cost of material and skilled manpower to comply with the specified quality.

Table 2.1: Risk Factors

Number	Risk Factors	Brief Description	References
1	Payments Delay	The contractor does not receive payments from the owner on the agreed dates which might results in schedule and cost issues.	(Kangari, 1995), (Wiguna and Scott, 2005), (Enshassi et al., 2008), (Polat and Bingol, 2011), (Goh and Abdul-Rahman, 2013), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
2	Unrealistic Construction Schedules	Project Schedules that are not achievable regardless of management or resources.	(El-Sayegh, 2008), (Polat and Bingol, 2011), (Goh and Abdul-Rahman, 2013), (Jarkas and Haupt, 2015) and (Jayasudha and Vidivelli, 2016).
3	Vagueness of Scope of Work	The statement of the project scope is not clear or vague, which might lead to misunderstandings. Scope of work should define the requirements including supply, installation, testing and commissioning.	(Ghosh and Jintanapakanont, 2004), (Sonmez et al., 2007), (Polat and Bingol, 2011), (Iqbal et al., 2015) and (Amoudi et al., 2015).

4	Changes in Scope	Late changes in the proposed project scope which requires, in certain times, to rework multiple work items that may lead to eventually claims and disputes.	(Wiguna and Scott, 2005), (El-Sayegh, 2008), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
5	Inadequate Design	Insufficient supplementary design documents of the project. It also implies the risk of improper coordination between various engineering drawings. Construction projects might require the design of temporary structures including shoring, underpinning and scaffolding.	(Al-Bahar and Crandall, 1990), (Wiguna and Scott, 2005), (Enshassi et al., 2008), (Polat and Bingol, 2011), (Iqbal et al., 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
6	Drawing and Approval Delays	Represents delays in obtaining approvals or feedback for requests for information, shop drawings, material approvals and so on.	(Wiguna and Scott, 2005), (Sonmez et al., 2007), (Iqbal et al., 2015) and (Jarkas and Haupt, 2015).
7	Quality of Drawings and Details	Insufficient information and detailing of drawings and specifications might lead to misunderstanding and raising inquiries which in result will require time and cost.	(Al-Bahar and Crandall, 1990), (Sonmez et al., 2007) and (Jarkas and Haupt, 2015).
8	Defective Work	Refers to the cost of rework or repair caused by mistakes or nonconforming material.	(Al-Bahar and Crandall, 1990), (Wiguna and Scott, 2005) and (Jarkas and Haupt, 2015).

9	Poor Productivity of Manpower and Equipment	Poor productivity can affect project schedule and as a result may lead to cost overrun. Several factors could cause Poor productivity.	(Sonmez et al., 2007), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
10	Labor Injuries and Accidents	Undesired accident occurrence in the construction site due to several factors. Such as, crane falls or fire.	(Al-Bahar and Crandall, 1990), (Jannadi, 2008), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
11	Damage to Material, Equipment and Facilities	Any damage occurs to materials, equipment and facilities during installation, in storage, or in transit. For instance, risk is embodied in the downtime cost of equipment such as cranes, bar bending and cutting machines, concrete pumps and so on.	(Al-Bahar and Crandall, 1990) and (Jayasudha and Vidivelli, 2016).
12	Subcontractors Issues	Poor Performance of subcontractors in terms of quality and time.	(Al-Bahar and Crandall, 1990), (Ghosh and Jintanapakanont, 2004), (Polat and Bingol, 2011), (Iqbal et al., 2015), (Jarkas and Haupt, 2015) and (Amoudi et al., 2015).
13	Suppliers Issues	Represents late delivery of material, nonconforming material and so on.	(Al-Bahar and Crandall, 1990), (Ghosh and Jintanapakanont, 2004), (Polat and Bingol, 2011), (Iqbal et al., 2015), (Jarkas and Haupt, 2015) and (Amoudi et al., 2015).

14	War and Civil Disorder	The state of instability in the nation which may pause, interrupt or hinder the current work progress.	(Al-Bahar and Crandall, 1990), (Iqbal et al., 2015) and (Amoudi et al., 2015).
15	Labor Disputes and Strikes	The unpredicted actions of labors during the project construction which may result in schedule changes.	(Al-Bahar and Crandall, 1990), (Iqbal et al., 2015) and (Jayasudha and Vidivelli, 2016).
16	Changes in Laws and Regulations	Modification of governmental rules that have direct effect on construction items prices.	(Al-Bahar and Crandall, 1990), (Sonmez et al., 2007), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
17	Permit Delays	Delaying various construction permits such as work permits and lack of well-known systematic procedures can lead to schedule issues and as a result may affect project cost.	(Iqbal et al., 2015), (Jarkas and Haupt, 2015) and (Jayasudha and Vidivelli, 2016).

18	Security and Theft	The loss of equipment, materials or any other items.	(Al-Bahar and Crandall, 1990), (Iqbal et al., 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
19	Adverse Weather Conditions	Undesirable weather conditions that can hinder the progress of a certain work item/activity involved in the construction that have not been neither predicted nor accounted for in the cost.	(Al-Bahar and Crandall, 1990), (Wiguna and Scott, 2005), (Sonmez et al., 2007), (Polat and Bingol, 2011), (Goh and Abdul-Rahman, 2013), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
20	Subsurface Conditions	The unforeseen conditions that have not been discovered neither in site investigations nor in soil reports.	(Al-Bahar and Crandall, 1990), (Wiguna and Scott, 2005), (Sonmez et al., 2007), (Jannadi, 2008), (Jarkas and Haupt, 2015) and (Amoudi et al., 2015).
21	Natural Disaster	Acts of god that cannot be controlled such as; flood, earthquake, collapse and landslide design.	(Al-Bahar and Crandall, 1990), (Sonmez et al., 2007), (Iqbal et al., 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).

22	Escalation in Prices	The increase or decrease associated with construction items such as material prices, equipment prices and so on due several causes such as inflation, embargoes or other economical phenomena.	(Al-Bahar and Crandall, 1990), (Wiguna and Scott, 2005), (Sonmez et al., 2007), (El-Sayegh, 2008), (Polat and Bingol, 2011), (Goh and Abdul-Rahman, 2013), (Iqbal et al., 2015), (Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
23	Accuracy of Quantities Estimation	The degree to which calculated quantities in BOQs and drawings conforms to the actual quantities to be executed on site.	(Iqbal et al., 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
24	Site Accessibility	Several conditions such as traffic and permits could hinder employees, goods or equipment access to site. Placement of cranes and concrete pumps are well illustrative examples.	(Jarkas and Haupt, 2015), (Amoudi et al., 2015) and (Jayasudha and Vidivelli, 2016).
25	Stringent Inspections by Engineers	Refers to inspectors' strictness beyond requirements and standards.	(Jarkas and Haupt, 2015).

2.8 Contingency Allocation Approaches

According to several studies, it has been found that unsystematic approaches are being used by contractors for predicting cost contingency amounts. In general, those approaches depend on a contractor's intuition and judgment (Laryea et al., 2007). Consequently, tremendous efforts and several attempts have been made to develop more formularized models to assist contractors in assessing risks and predicting cost contingency in construction projects. Bakhshi and Touran (2014) classified cost contingency allocation approaches into three main categories namely, deterministic methods, probabilistic methods and modern mathematical models. Further classifications of the main categories to sub categories and groups have been introduced as shown in Figure 1. However, a single approach or a combination of methods could be used as shown below.

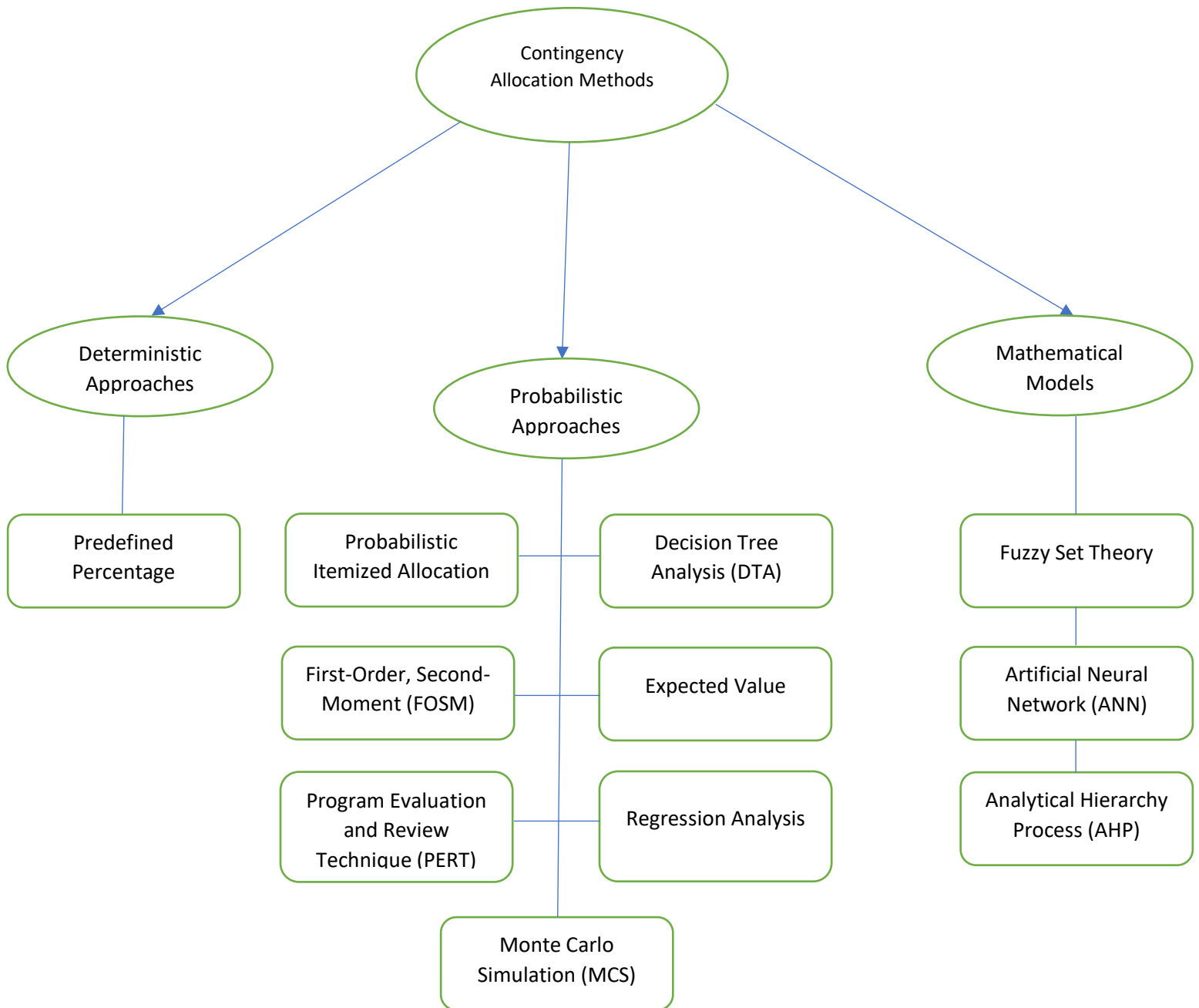


Figure 2.1: Cost Contingency Allocation Methods

Source: (Bakhshi and Touran, 2014)

2.8.1 Deterministic Approaches

According to Rey (2001), a deterministic model assumes no randomness in predicting a dependent variable value. It implies that the model provides a certain unique value for the amount of cost contingency. Moreover, deterministic methods are the most common used approaches by contractors and it could be in one of the following forms in subsection 2.8.1.1.

2.8.1.1 Predefined Percentage

In this method, contractors base their decision on the amount of cost contingency on their intuitions and past experience (Bello and Odusami, 2008). It could be applied in two different ways, either by adding a fixed percentage to the total project value which has been called "across the board" by Baccarini (2004) or by adding a certain percentage to the individual project work packages (Moselhi, 1997; Ahmad, 1992). The total project contingency is then calculated as a weighted average as shown in equation 2.1. However, Percentages that represent cost contingency are typically between 1% and 5%, and rarely exceeds 10%.

$$PT = \frac{1}{TC} \sum_i^n T_i \times C_i \quad (2.1)$$

Where;

PT: Total project contingency

TC; Project estimated cost

T_i: Work package estimated contingency percent

C_i: Work package estimated cost

n: Total number of work packages

2.8.2 Probabilistic Approaches

Probabilistic models are distinguished from deterministic models in the existence of randomness in predicting a dependent variable value. Probabilistic models become quite essential when dealing with situations involving variation in nature and where the outcome variable shall be preferably presented by a probability distribution instead of representing it by a point estimate for the dependent variable (Rey, 2015). Moreover, Moselhi (1997) has showed that an inverse relationship does exist between risk and cost contingency amount. Bakhshi and Touran (2014) have classified multiple methods under the probabilistic methods category as follows.

2.8.2.1 Probabilistic Itemized Allocation:

According to Moselhi (1997), this method is similar to the predefined percentage method except that it considers the basic definition of risk. Furthermore, the total project contingency is estimated in a way similar to the one in equation 1 except considering significant or critical work packages only in accordance with Pareto's law that states that 20% of the work packages cause 80% of the risk and cost overruns.

2.8.2.2 Decision Tree Analysis (DTA)

DTA is an analytical tool that represents various available alternatives or solutions graphically in order to help in making decisions upon alternatives. Dey (2002) has incorporated the use of DTA with another analytical tool which is analytical hierarchy process (AHP) in order to develop a risk management model for construction projects. The emphasis in the study was on the determination of the two main dimensions of risk which are; the probability of risk occurrence and the severity of consequences for each work package. The likelihoods of occurrence of the identified risks were obtained via pairwise comparisons performed by experts for each work package. The severity of

the identified risks for each work package were determined by guess estimation. Subsequently, several plans and responses for mitigating the identified risks were obtained for each work package and the costs of implementing those responses were estimated for the various project work packages. DTA was employed to determine the best response on the basis of the concept of expected monetary value (EMV). The developed model was validated through a case study and showed considerable effectiveness and accuracy.

2.8.2.3 First-Order, Second-Moment (FOSM)

It is an approximation method used to calculate statistical parameters for stochastic distributions and complex functions (Bakhshi and Touran, 2014). A moment simply represents the expected value of a random variable to various powers. There are two types of moment namely, raw moment and central moment. Raw moment is the moment about origin which can be considered to be zero while the central moment is the one about a certain value which can be considered to be about the mean. In fact, moments can be calculated for discrete and continuous variables. Moreover, a discrete random variable is represented by probability mass function (PMF) while a continuous random variable is represented by probability density function (PDF). The expected value of random variable or the mean is the first raw moment and can be calculated by equation 2.2 or equation 2.4 depending on the type of variable. Similarly, the variance is represented by the second central moment and can be calculated by equation 2.3 or equation 2.5. Furthermore, Dey (2002) has used this concept to determine the expected time and cost overruns as well as the standard deviations.

For discrete random variables:

$$\mu'_k = E(x^k) = \sum_{j=1}^n x_j^k \times PMF \quad (2.2)$$

$$\mu'_k = E(x - \mu)^k = \sum_{j=1}^n (x_j - \mu)^k \times PMF \quad (2.3)$$

For continuous random variables:

$$\mu'_k = E(x^k) = \int_{-\infty}^{+\infty} (x)^k \times PDF \, dx \quad (2.4)$$

$$\mu'_k = E(x - \mu)^k = \int_{-\infty}^{+\infty} (x - \mu)^k \times PDF \, dx \quad (2.5)$$

Where;

μ'_k : The $K - th$ moment

n : Total number of outcomes for the random variable

x : Random Variable

k : The power of moment

$E(x)$: Expected value

μ : Mean

2.8.2.4 Expected Value

Mak (1998) conducted a research in an attempt to compare estimating using risk analysis (ERA) that the Hong Kong government has adopted in public projects with non-ERA projects. ERA is a methodology for estimating projects costs with taking uncertainty and risk events in consideration based on the expected value principal. Firstly, potential risk and uncertainty factors were identified by the project team. These factors were then categorized into either fixed risk or variable risk. Fixed risk factors are those which either occur in total or not at all while variable risk factors are those which occur partially and the extent of occurrence is unknown. For each categorized risk factor, an average allowance and a maximum allowance were determined. Maximum allowance is the maximum cost that a risk can cause if occurred, and it was assumed that there is only a 10% chance that the actual cost of risk will exceed the maximum allowance. On the other hand, the average allowance is the multiplication of the probability of risk occurrence and the maximum cost that a risk can cause if happened. Similarly, an assumption was made that there is only a 50% chance that the actual cost of risk will exceed the average allowance. After all, the amount of contingency was calculated by summing all the average allowances for all risk factors. By studying and analyzing data from 91 building projects, this approach has shown more accurate contingency estimates than traditional and non-ERA approaches.

2.8.2.5 Program Evaluation and Review Technique (PERT)

It is a statistical project management tool which was widely known to be used for estimating construction project time and can be applied for estimating project cost considering uncertainty associated with projects (Ahuja et al., 1994). The idea behind this method is to estimate the cost of each cost item or work package based on three estimates; minimum, maximum and most likely value. These estimates can either be obtained quantitatively from previous projects data or qualitatively by expert judgement (Moselhi, 1997). Assuming the cost of each work package follows a beta distribution, an expected value, which represents the mean for the beta distribution, and the variance were then calculated as in equation 2.6 and 2.7.

$$\text{Expected Value} = \frac{\text{Maximum} + 4 \times \text{Most Likely} + \text{Minimum}}{6} \quad (2.6)$$

$$\text{Variance} = \left(\frac{\text{Maximum} - \text{Minimum}}{6} \right)^2 \quad (2.7)$$

At the overall project level, the total project cost was assumed to follow a normal distribution based on the central limit theory, whose mean equals the summation of the expected values for all cost items. Likewise, the overall project variance was calculated by summing all the variances for all cost items. After that, the project cost can be calculated such that the probability of exceeding it equals 0, which indicates that no risk has been accepted and the determined project cost shall not be exceeded (Nasser, 2002).

2.8.2.6 Regression Analysis

It is a statistical tool used to examine the relationship between various variables and the influence of several independent variables on a certain dependent variable of interest. Cook (2006) conducted a study on 243 construction projects with the aim of estimating the amount of contingency fund using multiple linear regression analysis. In the study, three main categories namely, project characteristics, design phase performance and the contract award process, served as the independent variables in the model to estimate the dependent variable which is the amount of contingency fund required to cover project cost overruns. The model has shown accurate results in which it reduced the average contingency error from -11.2% to -0.3%.

2.8.2.7 Monte Carlo Simulation (MCS)

MCS is a commonly used technique that helps in making decisions on situations involving risk and uncertainty. Basically, the concept is similar to the one used in PERT except the use of a computerized software that generates random numbers for each cost item based on the assumed statistical distribution for each cost item or work package. In fact, each cost item can assume a different probability distribution such as triangular, lognormal, uniform and so. These random numbers are used to generate many cost values for each cost item within a range specified by management. Similar to PERT, a probability distribution function is then developed for the project as a whole, in which it allows management to estimate contingency based on the required confidence level.

2.8.3 Modern Mathematical Models

2.8.3.1 Fuzzy Set Theory

It is an effective mathematical tool used to quantify qualitative data in which linguistic terms and subjective judgment such as severe impact or high probability can be assessed quantitatively and converted into numbers. Nieto-Morote and Ruz-Vila (2011) have incorporated fuzzy logic and AHP to prioritize various identified risks. The identified risks were categorized into four groups which are engineering, execution, suppliers and project management risks. Risk factors were ranked based on a developed equation of three parameters as shown in equation in 2.8.

$$\text{Overall Risk Factor (ORF)} = \frac{\text{Risk Impact (RI)} \times \text{Risk Probability (RP)}}{\text{Risk Discrimination (RD)}} \quad (2.8)$$

A linguistic scale was developed to quantify and measure the input from experts in which various fuzzy sets were assigned to each linguistic input for each parameter. For instance, this fuzzy set (0.8, 0.9, 1, and 1) was used to indicate that the expert has considered the impact of a certain risk factor as critical. Risk impact and risk probability were evaluated by four experts and an aggregated value was calculated using the fuzzy arithmetic average for each risk factor as in formula 2.9. Likewise, risk discrimination was determined after applying pairwise comparisons among the hierarchy levels of the AHP by four experts. The defuzzification process took place after all ORF fuzzy sets are determined in order to rank the identified risk factors.

$$\text{Arithmetic Average} = \frac{1}{m} \times \sum_{n=1}^m \text{Risk Parameter}_n^i \quad (2.9)$$

Where;

m: Number of experts

Risk Parameter: RI, RP or RD

i: Risk factor

2.8.3.2 Artificial Neural Network (ANN)

In contrast with regression analysis technique, ANN has better abilities in dealing with nonlinear complex relationships (Chan and Hartman, 2000). Furthermore, Polat (2012) developed a neural network model that enables Turkish contractors to predict the required amount of cost contingency when bidding on international construction projects using MATLAB software. Six risk groups, where each risk group contains several risk factors, were used as the input data for the neural network model. On the other hand, the amount of cost contingency was considered to serve as the output data for the model. Through a survey, 195 data sets from international construction projects were used to train and test the model. The author has shown the effect of the number of neurons in the hidden layer on model performance. The use of 4 neurons in the hidden layer was found to be the most appropriate and showed more accurate results. The developed model has shown robust performance in estimating the amount of cost contingency.

2.8.3.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is an analytical tool that addresses multi-criteria decision making problems and allows decision makers to set priorities through a series of pairwise comparisons. AHP was firstly introduced by Thomas Saaty in 1980. According to Darko et al. (2018), AHP was found to be effective in the area of risk management. Mohamed et al. (2009)

have utilized the use of AHP to develop a model that predicts time contingency in construction projects. Through a comprehensive literature review, several criteria or risk factors that are believed to affect project time were determined. First of all, a hierarchal structure, consisting of 3 major criteria and several sub-criteria under each major criterion placed at the second and third level of the hierarchy respectively, was developed. As a part of the AHP process, pairwise comparison matrices were established and filled out by 16 construction management teams in Canada in order to determine the weight of each identified criterion or factor that might have an influence on project schedule. After all, time contingency was calculated as the summation of the multiplication of each risk factor weight, probability of occurrence and impact. However, probability of occurrence and impact were obtained via a survey with developed scales for each one. Authors have concluded that contractors should approximately consider 36% of the total project duration as time contingency. In the same manner, El-Touny et al. (2014) conducted a research to estimate the amount of cost contingency required for highway construction projects in Egypt. However, the developed model was validated using a case study. The average cost overrun of five different projects was found to be 5.97% whereas the developed model predicted a contingency of 5.75%.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter presents the steps that will be followed to achieve the objective of this research. The first section presents a brief introduction about MAUT technique and two studies that applied AHP and MAUT for prediction purposes. In the rest part of this chapter, the process of developing the desired model for predicting the amount of cost contingency for construction projects is presented as illustrated in figure 3.1.

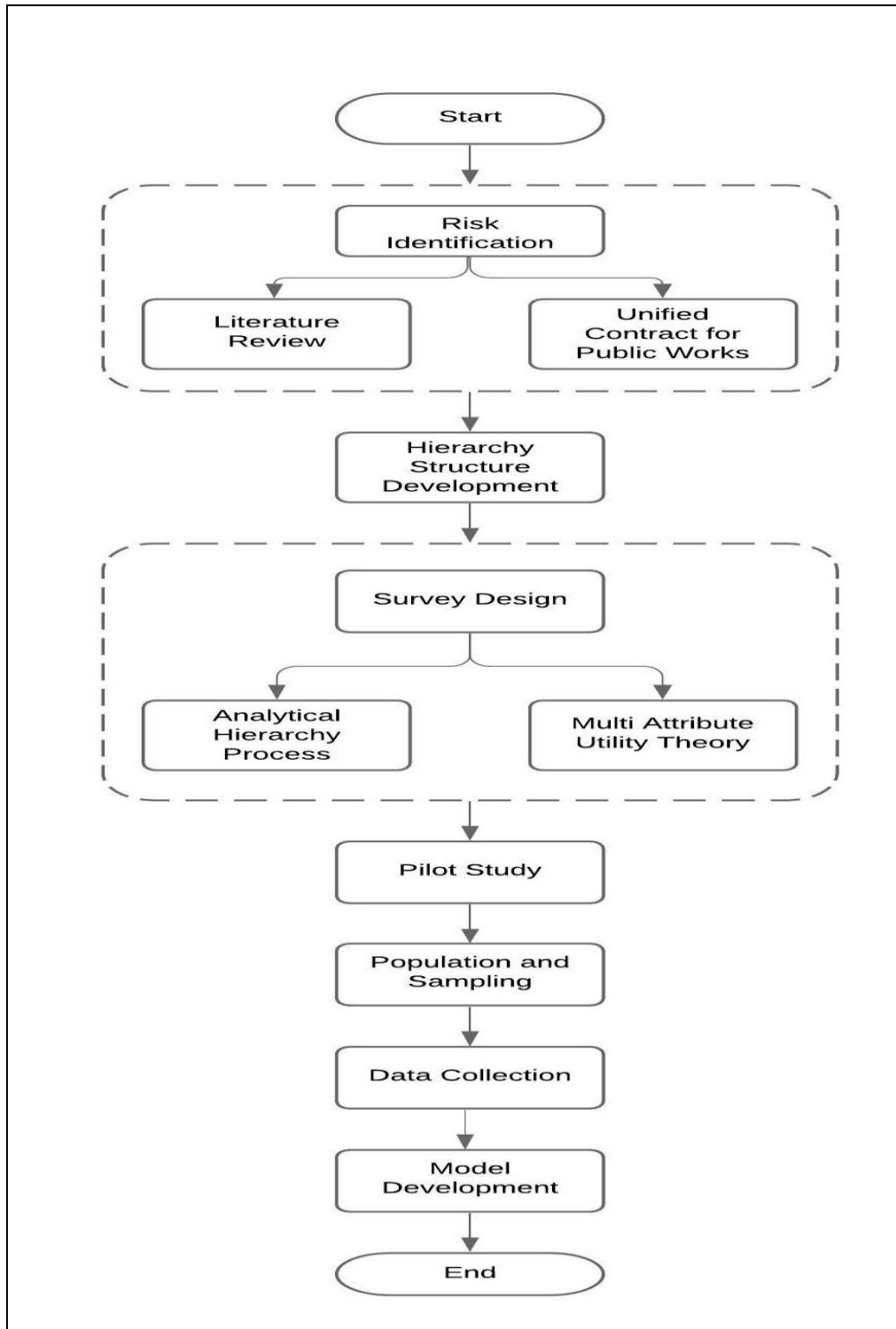


Figure 3.1: Research Methodology

3.1 Multi Attribute Utility Theory (MAUT)

MAUT is a technique that assists in making decision on problems involving several factors (so-called attributes) that are of a decision-maker's interest or influence the decision to be taken. In fact, what makes taking decisions a complicated issue is the multitude of attributes and the existence of natural conflict among attributes. For example, a decision has to be made on purchasing a certain product among various available options, where the price is the only considered attribute. In this case, making decision is quite trivial, in which most people would prefer to choose the option with the least price. In other cases where there are various important factors or attributes to be considered, the case would not be trivial as described in the previous example. However, different people may have different preferences especially when uncertainty conditions exist. For this reason, utility functions were introduced to quantify decisions makers' preferences in terms of satisfaction over various available options of a certain attribute or factor. An example of a simple decision-making problem under uncertainty conditions is a situation with a single attribute that proposes two options with one option offering a lottery with 30% chance to win 3 million, while the other option offering 1 million with 70% chance as well. In fact, there are two ways to deal with such problems. First, a probabilistic theory called the expected value which proposes that the option with higher expected value should be considered implying the selection of the first option. The expected value is calculated by multiplying the lottery value by its associated probability. In reality, the expected value theory makes no sense for many people's intuition and it fails to quantify people's preferences. Second, the expected utility theory can better explain people's preferences under risky situations. According to the expected utility theory, the option with highest utility value should be considered. However, utility function is just the degree of satisfaction against a certain attribute with any preferred units. Furthermore, utility values and

people's preferences may vary according to their attitudes towards risk. In fact, there are three defined risk attitudes: risk aversion, risk neutrality and risk seeking. The utility functions of the various risk attitudes are represented by a concave function, straight line function and convex function respectively. The charts a, b and c in figure 3.2 represent risk aversion, risk neutrality and risk seeking attitudes respectively. Risk aversion is the willingness to give up an amount of money to have something for certain. At this point, a new term called certainty equivalent (CE) shall be introduced. CE is the amount of payoff that is acceptable for decision makers to be indifferent between two options. For a risk averse decision maker, CE is lower than the expected gain from an uncertain situation, which means that two different values will have the same degree of satisfaction for a decision maker. Risk neutrality is the state of being indifferent between taking and avoiding risk. Risk seeking is the state of preferring an uncertain situation with the hope of potential gain rather than accepting something lower than the potential gain for certain. In this case, the CE, which a risk seeking decision maker would accept for not entering an uncertain situation, would be higher than the expected gain.

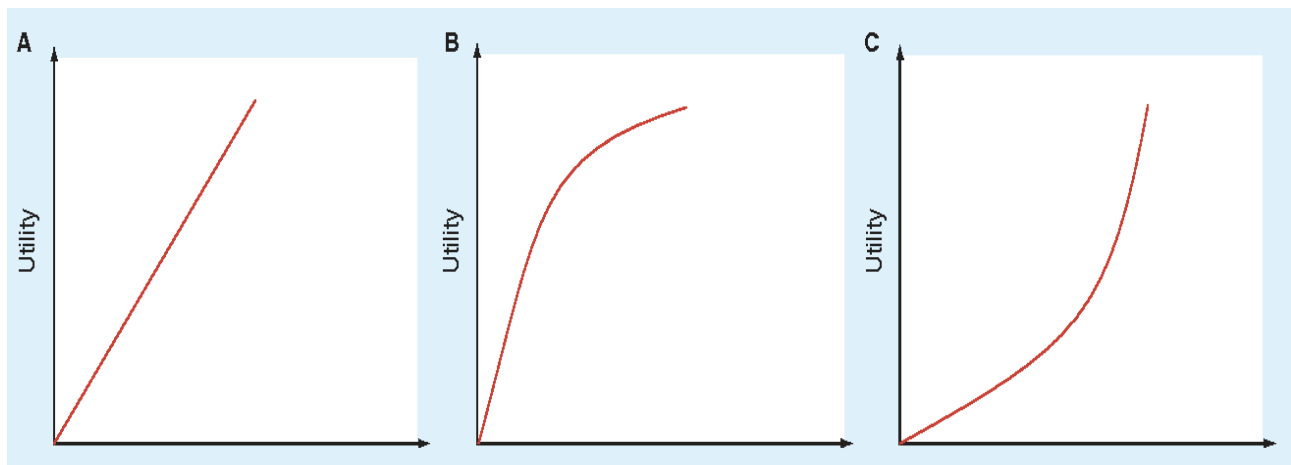


Figure 3.2: Risk Attitudes Utility Functions

Source: (Moffett and Suarez-Almazor, 2005)

In fact, the literature lacks researches that used the utility theory to predict the amount of cost contingency in construction projects. However, two studies incorporated the use of AHP and MAUT to estimate bids markup in construction projects. The first study conducted by Dozzi et al. (1996), 21 criteria that affect bidding decision have been identified, grouped and structured in a hierarchy format. A utility function was developed for each single criterion using two points, threshold point which corresponds to the lowest utility and the most preferred point which corresponds to the highest utility, with a straight line relationship. The developed utility functions were used to evaluate a decision maker's input for any project under consideration. Those utility values were then transformed to a common utility scale with the help of the criteria weights obtained from AHP. The summation of all transformed utility values represents an expected utility value (E_u), which is based on related information about any project being studied. Furthermore, a utility function was similarly established for the markup by determining the largest and smallest acceptable markup percentage by the decision maker. The markup utility function was established by computing three expected utility values, the worst-case scenario (E_{u_w}), the threshold (E_{u_t}) and the best-case scenario (E_{u_b}). The expected utility value of the best-case scenario was computed in a similar way to the method of calculating (E_u), but with assuming that every criterion will occur in the most preferred conditions. The research was tested using a case study. Percentages of 15%, 5% and 0.5% were assigned to the expected utility value of the worst-case scenario, threshold and the best-case scenario respectively to form three coordinate points. After the project was evaluated according to its specific information and conditions and the expected utility was determined 28.3, the project bid markup was found to be 3.9% using the markup utility graph. However, Dozzi et al. (1996) stated that utility functions can be developed using a straight line relationship as in equation 2.10 or as an exponential relationship as in equation 2.11.

$$u(x_i) = A_i x_i + B_i \quad (2.10)$$

$$u(x_i) = A_i e^{B_i x_i} + C_i \quad (2.11)$$

Where;

$u(x_i)$: The utility value of option x for attribute i

A_i, B_i and C_i : Function constants for attribute i

x_b and x_w : The best and worst options for a certain attribute

In case of considering the utility function to be a straight line relationship, (A_i and B_i) can be obtained by solving two equations with two unknowns by setting:

$$u(x_b)_i = 1 \text{ And } u(x_w)_i = 0$$

If the exponential relationship is considered, another option with its corresponding utility score has to be specified by the decision maker in order to be able to form and solve three equations with three unknowns (A_i, B_i and C_i).

Moreover, the second study was an extension to the first one with few modifications. Marzouk and Moselhi (2003) have developed utility functions in a different way in which three points have been considered instead of two points using predefined equations. Risk averse, risk prone and risk neutral attitudes are defined in equation 2.12, 2.13 and 2.14 respectively. However, risk averse and risk prone attitudes can be expressed using a piecewise function or exponential function as shown in 2.15 and 2.16. The main issue in this approach is the blurriness in the mechanism of determining the certainty equivalent of the various attributes. For instance, the decision maker would face difficulties in determining the certainty equivalent for attributes such as project location. Considering various risk attitudes is an advantage unlike that referred to above.

$$u(x) = ae^{bx} + c \quad (2.12)$$

$$u(x) = a \times \ln(x + b) + c \quad (2.13)$$

$$u(x) = ax \quad (2.14)$$

$$u_1(x) = ax \quad (2.15)$$

$$u_2(x) = bx + c \quad (2.16)$$

3.2 Risk Identification

Further investigations were needed to determine risk factors that shall be handled with a contingency treatment strategy. For this purpose, the Unified Contract for Public Works (UCPW) in Saudi Arabia was closely examined to extrapolate risk factors whose responsibility falls on the contractor and determine the most common practiced risk treatment strategy for each identified risk factor in a unit price/lump sum contract with design-bid-build delivery system as shown in table 3.1. The identification process ended up with 18 risk factors to be considered in the research.

Table 3.1: Risk Identification

Risk Factor	Responsible Party	Contract Article
Payments Delay	Owner	• Section 1/Article 6 • Section 2/Article 59
Unrealistic Construction Schedules	Contractor	Section 1/Article 3
Vagueness of Scope of Work	Contractor	Section 2/Article 12/Item 1
Changes in Scope	Owner	• Section 2/Article 43 • Section 2/Article 8
Inadequate Design	Contractor	Section 2/Article 10/Item 2
Quality of Drawings and Details	Contractor	Section 2/Article 10/Item 2
Defective Work	Contractor	Section 2/Article 31
Poor Productivity of Manpower and Equipment	Contractor	Section 2/Article 38
Labor Injuries and Accidents	Insurance Company	• Section 2/Article 12/Item 5 • Section 2/Article 17
Damage to Material, Equipment and Facilities	Contractor	Section 2/Article 18
Subcontractors Issues	Contractor	Section 2/Article 4
Suppliers Issues	Contractor	Section 2/Article 4
War and Civil Disorder	Owner	• Section 2/Article 55 • Section 2/Article 56

Changes in Laws and Regulations	Owner	Article 60
Security and Theft	Insurance Company	• Section 2/Article 12/Item 5 • Section 2/Article 17
Adverse Weather Conditions	Contractor	Section 2/Article 32
Subsurface Conditions	Contractor	Section 2/Article 10/Item 1
Natural Disaster	Insurance Company	• Section 2/Article 12/Item 5 • Section 2/Article 17
Escalation in Prices	Owner	Section 2/Article 11
Currency Fluctuation	Owner	Section 2/Article 11
Accuracy of Quantities Estimation	Owner	• Section 2/Article 8 • Section 2/Article 46
Site Accessibility	Contractor	Section 2/Article 34
Stringent Inspections by Engineers	Contractor	Section 2/Article 2
Drawing and Approval Delays	Undecided	
Labor Disputes and Strikes	Undecided	
Permit Delays	Undecided	

3.3 AHP Survey Design

3.3.1 Construction of the Hierarchal Structure

After having all risk factors identified, risk factors that have common features are clustered into groups (so-called criteria). Different classifications have been introduced to categorize various types of risk. In this research, each risk factor was classified according to its primary source under one of the following groups: bidding, construction, environmental, legal, and economic. The hierarchal structure was then developed in which the goal is kept at the first level, criteria were kept at the second level and risk factors were kept at the third level. The developed hierarchal structure including all levels is shown in figure 3.3.

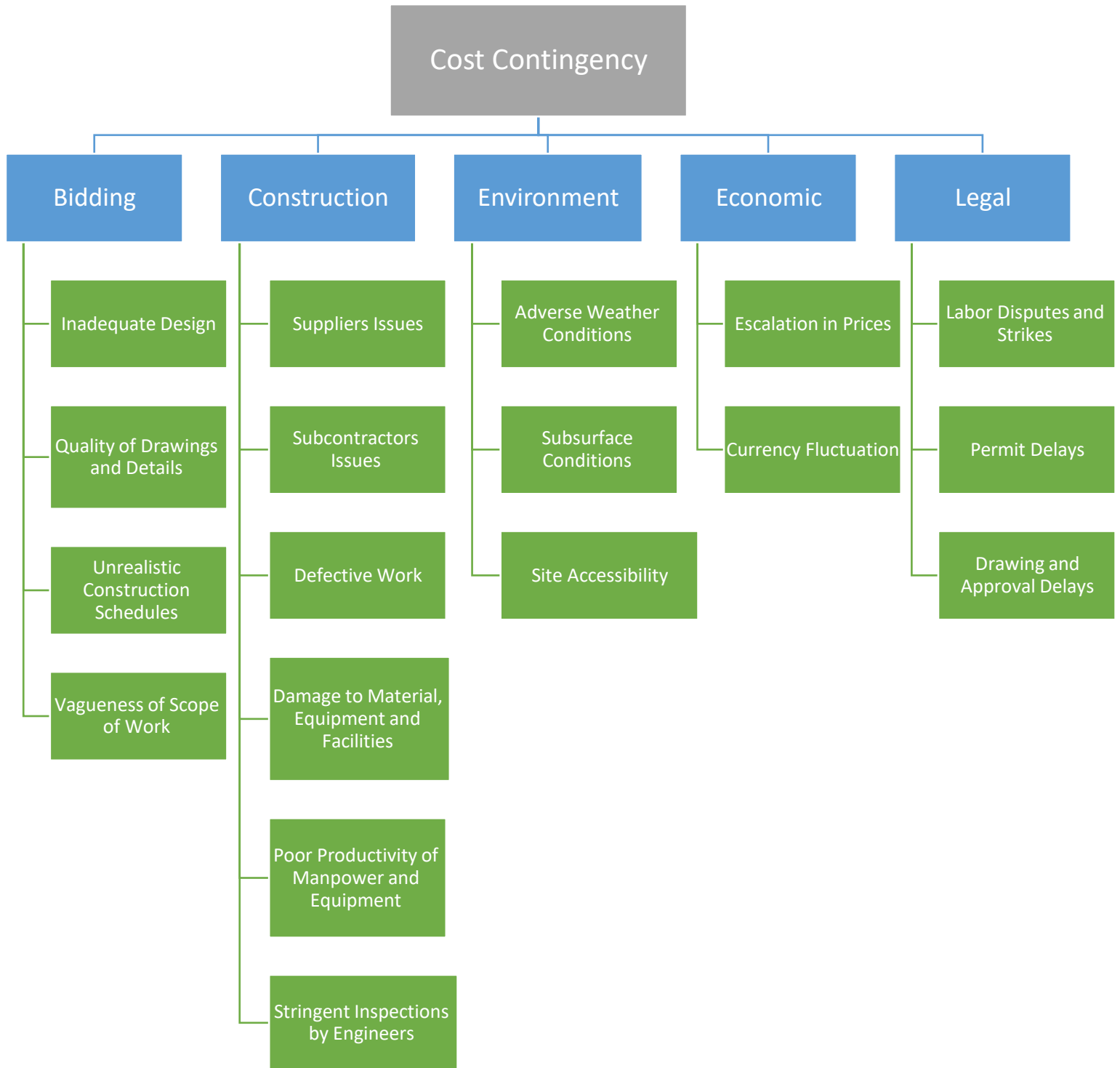


Figure 3.3: AHP Hierarchy Structure

3.3.2 Pairwise Comparison

This stage aims to provide importance scores or weights for each identified risk factor based on decision makers' judgments. These importance scores were used later on in the model development. However, in a pairwise comparison matrix, the decision maker was only requested to evaluate criteria or attributes against each other. In other words, determining how important a particular attribute with respect to another one. However, pairwise comparisons were performed for all criteria and attributes at all hierarchal levels. Pairwise comparisons were created in the form of a square matrix with size of n , where n is the number of criteria or attributes being considered. This can be performed with the aid of a numerical scale ranging from 1 to 9 as shown in table 3.2.

Table 3.2: AHP Scale

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2, 4, 6 and 8	Intermediate Values
Reciprocals of the above numbers	When assigning an importance intensity value between two elements (i) and (j), the reciprocal of that importance intensity value is assigned when comparing between (j) and (i).

Pairwise comparison matrices were established based on the developed hierarchal structure. Furthermore, relative importance scores (so-called local weights) are obtained by either computing the eigenvector of the matrix or through the normalization process. Local weights of attributes describe the relative importance scores under their parent criterion. On the other hand, global weights (W_i) describe attributes' relative importance within the whole context of the hierarchy. Global weights were calculated by multiplying each attribute's weight by the weight of each parent criterion under which the attribute is categorized. In addition, the summation of local weights in any pairwise comparison matrix at any hierarchal level must equal to 1. The pairwise comparison matrices are shown in Appendix A, section 2.

3.3.3 Consistency Check

The consistency ratio (CR) was used to measure the discrepancy of the pairwise comparisons' evaluations made by decision makers. An inconsistent judgement indicates that unreliable or contradicting information has been committed. The consistency ratio of a pairwise comparison matrix should exactly equal 0 for a perfect consistent decision maker. However, an evaluation was considered acceptable if the consistency ratio is less than or equal 0.1. The consistency ratio (CR) and consistency index (CI) can be computed using equation 3.1 and 3.2 respectively. However, the random index (RI) can assume different values depending on the matrix size as shown in table 3.3. However, λ represents the maximum eigenvalue of the matrix being considered. However, the computational process was carried out using AHP-OS package which is an online tool that supports the calculations of the eigenvector and the eigenvalue. The tool was developed by Goepel (2018) and has been used in several studies (Gładysz, 2019; Mesaros et al., 2020).

$$\text{Consistency Ratio (CR)} = \frac{\text{Consistency Index (CI)}}{\text{Random Index (RI)}} \quad (3.1)$$

$$CI = \frac{\lambda_{max} - n}{n - 1} \quad (3.2)$$

Table 3.3: Random Index Values

n	2	3	4	5	6	7	8	9	10
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.51

3.4 MAUT Survey Design

3.4.1 Utility Functions Development

Utility functions were used to transform various attributes values into a dimensionless utility scores in order to be able to combine all dimensioned attributes with a unified unit. A utility function for each risk factor or attribute should be established. As stated previously, utility functions were created by assigning a utility score of (1) to the most preferred option (x_b) for a particular attribute, and assigning (0) to the least preferred option (x_w). In other words, the utility value of the best option for a particular attribute is equal to (1), whereas the utility value of the worst option is equal to (0). The best and worst options were determined by the decision maker with help of the established scale above.

The literature revealed different approaches in developing utility functions and measuring decision makers' risk behaviors. For instance, Filip (2002) has suggested an approach to develop utility functions based on the certainty equivalent concept. At first, five coordinate points are required to proceed with the methodology. The determination of these points is achieved through a designed

lottery which examines decision makers' risk attitudes and preferences. Using Mathcad software, more coordinate points can be produced to express the function graphically. Of the five points, two points represent the maximum and the minimum possible gain. The decision maker is asked to specify the certainty equivalent of the lottery. The certainty equivalent is the amount at which the decision maker would renounce the lottery. The utility of the specified certainty equivalent is equal to the summation of the utility value of the maximum gain multiplied by the probability of its occurrence and the utility value of the minimum gain multiplied by the probability of its occurrence. Likewise, the other two points can be determined by defining two new lotteries. In one lottery, the certainty equivalent is considered to be the minimum possible gain with the initial maximum possible gain. On the other hand, the certainty equivalent is considered to be the maximum possible gain with the initial minimum possible gain (Lixăndroiu, 2014).

If this approach were to be considered to address the issue of cost contingency in this study, it would be applicable with some adaptations. Unlike a lottery, which represents an opportunity, a risk factor represents a threat. In an inverse manner, a risk can be expressed by the maximum and the minimum amount of loss that can cause as a percentage of the total contract value, with a corresponding probability of occurrence to each value. Three other points are to be determined as described earlier. In this case, the certainty equivalent would represent the amount of money that a decision maker is willing to pay in order to eliminate a particular risk. The maximum and minimum values define risk factors' boundaries or limits. In view of this, it should be noted that the maximum amount of loss corresponds to the lowest utility value because it is the least desirable scenario, whereas the minimum amount of loss corresponds to the highest utility value because it is the most preferred scenario. Unlike other methods which assume specified formulas to describe decision makers' risk attitudes, this method automatically considers decision makers' risk attitudes

with a reasonable accuracy through the determined five points. In addition, this approach reflects the basic definition of risk as it considers the two dimensions of risk: magnitude and probability. On the other hand, the difficulty of collecting data is a major disadvantage of this approach. In addition, performing this approach requires a deep understanding of several mathematical concepts. The following example demonstrates the approach by applying it on the (adverse weather conditions) risk factor as shown in table 3.4. In box (A), the decision maker is required to approximately specify the maximum monetary loss as a percentage of the total contract value that the considered risk factor can cause based on previous experience. Box (C) shows the probability of losing the specified amount in box (A) which should be specified by the decision maker as well. On the other hand, the value in box (B) represents the minimum amount of monetary loss as a percentage of the total contract value which is at least zero, since the positive impact of risk can be neglected. It should be noted that the probability associated with the value in box (B) is denoted by (C') and it is the complement of the value in box (C). Those two extreme points, as a whole, form threat number (1). Accordingly, the decision maker is requested to specify the certainty equivalent of this threat in box (D1), which is the amount that the decision maker would pay to insure that the threat is eliminated. Similarly, threat (2) is composed of two extreme points. The first point is the value previously defined in box (A) with its associated probability of occurrence (C). The second one is the certainty equivalent of threat (1) that was specified earlier in box (D1). The probability associated with the certainty equivalent is the complement of (C). Upon establishing threat (2), the decision maker is requested to specify the certainty equivalent of threat (2) in box (D2). Likewise, threat (3) is defined by two points. The first point is the value previously defined in box (B) with its associated probability of occurrence (C'). The second one is the certainty equivalent of threat (1) that was specified earlier in box (D1). Upon identifying the required five

coordinate points, the utility function of each risk factor can be graphed. According to the previous example in table 3.4, the utility function of the (adverse weather condition) risk factor is shown in figure 3.4.

Table 3.4: Illustrative Example of the Required Data

Risk Factor	Point Number	Cost	Probability	Certainty Equivalent
Adverse Weather Conditions	1	(A) (7%)	(C) (0.5)	(D1) (2.5%)
		(B) (0%)	(C') (0.5)	
	2	(7%)	(0.5)	(D2) (3.5%)
		(2.5%)	(0.5)	
	3	(0)	(0.5)	(D3) (0.4%)
		(2.5%)	(0.5)	

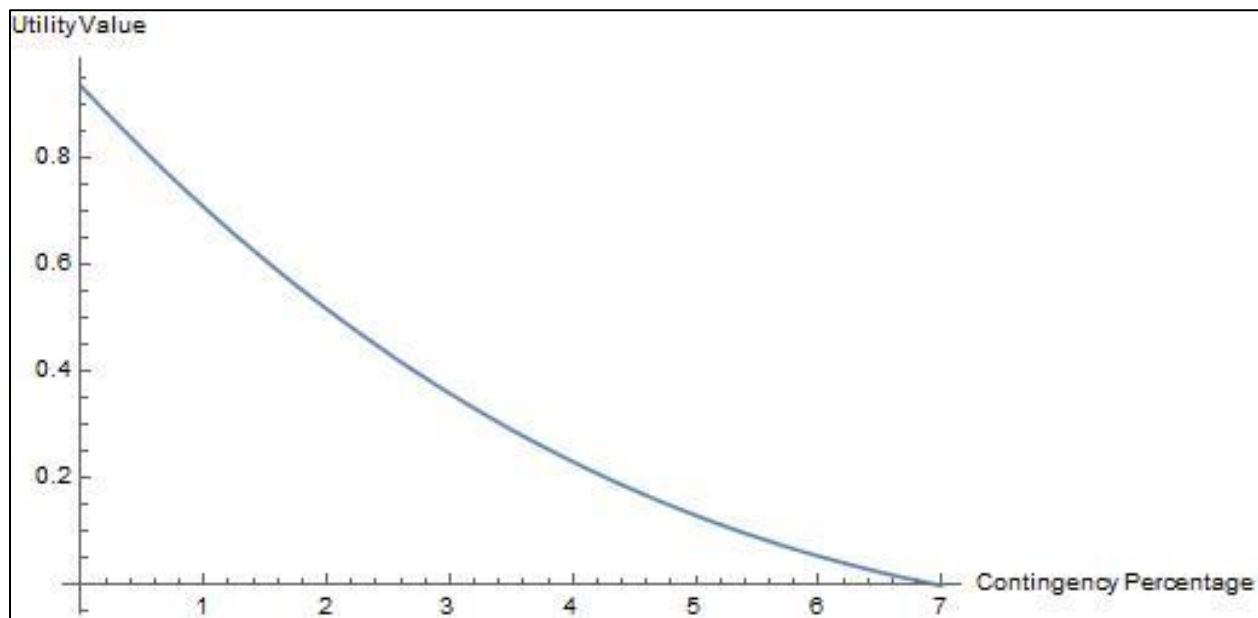


Figure 3.4: Risk Factor Utility Function

The followed approach in this research is similar to the one presented by Marzouk and Moselhi (2003). The utility function for each risk factor was established using three coordinate points: (1) the maximum monetary loss as a percentage of the total contract value; (2) the minimum amount of monetary loss as a percentage of the total contract value; (3) the certainty equivalent. The maximum percentage loss corresponds to the lowest utility value on the y-axis, which is zero, because it is the least desirable scenario, whereas the minimum percentage loss corresponds to the highest utility value, which is one, because it is the most preferred scenario. Respondents were requested to specify the probability of occurrence associated with the maximum percentage loss and the probability of occurrence associated with the minimum percentage loss. Upon identifying and establishing the three coordinate points, decision makers' risk attitudes were then determined by comparing the certainty equivalent with the expected value. The certainty equivalent was provided by the respondent while the expected value is the summation of the multiplication of the maximum percentage loss value by its associated probability and the minimum percentage loss value by its associated probability. In a gain situation, the certainty equivalent should be less than the expected value for a risk averse decision maker. For a risk seeking investor, the certainty equivalent should be greater than the expected value. Finally, the certainty equivalent should exactly equal the expected value for a risk neutral investor. In this research, the situation is inverted because risk represents a threat and therefore represents a loss situation. The certainty equivalent should be greater than the expected value for a risk averse decision maker. For a risk seeking investor, the certainty equivalent should be less than the expected value. Lastly, the certainty equivalent should exactly equal the expected value for a risk neutral investor. The utility functions of the three risk behaviors including risk aversion, risk seeking and risk neutrality were defined using equations 3.3, 3.4 and 3.5 respectively.

$$u(x) = ae^{bx} + c \quad (3.3)$$

$$u(x) = a \times \ln(x + b) + c \quad (3.4)$$

$$u(x) = ax \quad (3.5)$$

Furthermore, a preliminary survey was designed to collect data in order to construct the utility function for each risk factor. Respondents were requested to provide the maximum amount of money as a percentage of the total contract that the risk factor can cause in box (A) and its associated probability of occurrence in box (C). Likewise, the minimum value were determined in box (B) and its associated probability of occurrence in box (C'). Based on that, respondents were then asked to determine the certainty equivalent in box (D). Table 3.5 were provided to decision makers for each risk factor. The complete survey is shown Appendix A, section 3.

Table 3.5: Illustrative Example of the Required Data to Develop the Utility Functions

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
	Maximum Loss Percentage	(A) (7%)	(C) (0.6)	(D) (2.5%)
	Minimum Loss Percentage	(B) (0%)	(C') (0.4)	

3.4.2 Expected Utility Value

In this stage, the decision maker shall evaluate each attribute for a certain project of interest according to that project specific information and conditions. At this point, utility functions become essential to determine the utility values of the options input by the decision maker. The determination of utility values were simply carried out by substituting the attribute value in the utility function or using the utility function curve. Furthermore, the combination of those utility values of all attributes forms an expected utility value for any project being considered (EU_p). The project expected utility can be seen as an overall project evaluation. Lifson and Shaifer (1982) suggested that the transformation of utility value to attribute expected value (EU_a) can be achieved using the relative importance scores. Dozzi et al. (1996) have used the scaling factor of each attribute obtained from AHP to transform each attribute's utility function to a common scale utility function. The expected value of any attribute and the project expected value were computed using equation 3.6 and equation 3.7 respectively (Keeney and Raiffa, 1993).

$$EU_{a_i} = W_i \times u(x_i) \quad (3.6)$$

$$EU_p = \sum_{i=1}^n W_i \times u(x_i) \quad (3.7)$$

Where;

W_i : Global weigh of attribute i

n : Total number of attributes in the heirarchy

3.4.3 Contingency Utility Function Development

The contingency utility function was used to determine the cost contingency percentage corresponding to the computed project expected utility. However, in a similar manner to the establishment of utility function for each attribute, the contingency utility functions were developed. Respondents were asked firstly to provide the largest contingency percentage acceptable to the company and that which ensures and maintains competitiveness. This percentage should correspond to the worst case scenario because it implies that risks are extreme and therefore a considerable amount of contingency must be added. Secondly, the smallest contingency percentage acceptable to the company in situations where risks are at the minimum was identified as well. Lastly, the most common contingency percentage that the company considers in projects. Accordingly, those values were used to establish the contingency utility function using the predefined equations in section 3.4.1. However, the contingency percentage combining all risk factors was calculated using three different utility shapes in order to be able to observe the effect of risk behaviors on contingency percentage.

3.5 Pilot Study

A pilot interview was conducted with the aim of testing and evaluating the understandability of the designed survey and the time required to complete the survey. The pilot interview was performed with experts prior to survey distribution to the entire sample size in order to improve and modify any deficiencies. However, there were no major modifications on the survey content except the need to notify participants of the assumptions being considered in the research such as the type of project delivery system and contracting method being under consideration.

3.6 Population and Sampling

According to Schmidt et al. (2015) and Darko et al. (2018), there is no standardized method or common rule to calculate the sample size in AHP technique. Nevertheless, there has been a unanimity that AHP could lead to robust results even with small sample size. However, for this research, the population size was obtained from the statistical reports issued by the Ministry of Municipal and Rural Affairs in the Kingdom of Saudi Arabia. According to the reports published in 2017, the population size was found to be 48 classified building contractors in the Eastern Province with both 1 and 2 grades. Furthermore, the required sample size was calculated using Kish's (1995) formulas as shown in equation 3.8 and 3.9.

$$n_o = \frac{p \times q}{E^2} \quad (3.8)$$

$$n = \frac{n_o}{1 + \frac{n_o}{N}} \quad (3.9)$$

Where;

n_o : The initial estimate of the sample size

p : The planning value of the sample proportion

q : The complement of p

E : Desired margin of error

n : The final estimate of the sample size

In this research, the maximum allowed percentage of error was set to be 10%. Moreover, the planning values of the sample population were considered 0.5 in order to maximize the sample size. Subsequently, the required sample size was found to be 17.

3.7 Data Collection

In general, the main informants in this research were decision makers such as cost estimators and top management who have the authority to decide on bids price and contingency amounts in contracting companies. Furthermore, the required data to achieve the objectives of this research was collected through interviews with decision makers using a structured questionnaire as shown in Appendix A. The questionnaire was divided into three sections. The first section contains general information about respondents and organizations. The second section is the AHP which aims to provide importance scores for each identified risk factor. In this section, the decision makers were requested to evaluate the identified risks against each other. In other words, determining how important a particular attribute with respect to another one. The last section is the MAUT which aims to combine and transfer all risk factors into a contingency utility function. In this section, respondents were asked to provide the maximum and the minimum monetary loss that the risk is expected to cause as a percentage of the total contract value. In addition, the decision makers were asked to provide the probability associated with each value.

3.8 Data Analysis

The final weight of attributes was based on the simple average of all respondents' results such that the average value of all obtained global weights from respondents for each attribute or risk factor were considered. However, inconsistent results were reevaluated or eliminated. On the other hand, the utility function of each attribute was established based on the average of each point's values provided by all respondents. In view of the example in section 3.4.1 in table 3.4, the required three coordinate points were derived from the MAUT survey for each attribute as shown in table 3.6. As mentioned earlier, the first two points are the primary points that were initially defined by the decision maker. The third point was derived from the first two points by determining the certainty equivalent and computing its utility score. The utility score of the certainty equivalent was computed using equation 3.10. Upon establishing the three coordinate

points and determining the function that is going to represent the decision makers' behavior towards risk, obtaining the coefficients values (a, b and c) was accomplished to end up with a utility function for each risk factor. The coefficients values (a, b and c) were determined by substituting the obtained coordinate points in table 3.6 in one of the predefined functions depending on the risk attitude. By this, three equations with three unknowns were formed and solved. Furthermore, MATLAB Software was used to solve and graph complex exponential and logarithmic equations.

$$u(x) = P(x_n) \times u(x_n) + P(x_m) \times u(x_m) \quad (3.10)$$

Where;

$u(x)$: The utility of any considered point

$P(x)$: The probability of occurrence of any point

n and m : The points numbers from which the considered point is derived

Table 3.6: Illustrative Example of the Required Three Coordinate Points

Risk Factor		
Parameters	Contingency Percentage (X-axis)	Utility Value (Y-axis)
Maximum Loss Percentage	7%	0
Certainty Equivalent	2.5%	0.4
Minimum Loss Percentage	0%	1

3.9 Model Validation

Two case studies were analyzed to validate the developed model. All case studies were a construction project in Eastern Province, the Kingdom of Saudi Arabia. In the project, each identified attribute in the hierarchal structure was evaluated by the decision maker in the contracting company. Consequently, the project expected utility was computed and the contingency percentage was obtained using the established contingency utility function. Finally, the obtained contingency percentage was compared to the actual variation occurred in the bid estimate. The variation was calculated as the difference between the total estimated bid cost and the total cost upon project completion.

3.10 Computer Implementation

The proposed model was implemented into a prototype software. JAVA programming language was used to code the proposed model. It was intended to operate on Windows system. The prototype software has only one function which is predicting the optimum contingency value for building contracting firms. Furthermore, the software was not intended to store any data after obtaining the results.

3.10.1 Criteria for the Selection of Development Tools

The decision on selection of the development tool was made on the basis of certain criteria that assure the best implementation to serve the desired objective of the model. Alshibani (2008) suggested the consideration of criteria such as the integrability of the tool with other software systems, the availability of the tool, the capability of the tool to carry out complex computation and its ability to deliver a user-friendly interface. The concentration in this research is on the capability of the tool to carry out complex calculations in a fast running time as the proposed model

involves relatively complex calculations. In addition, the ease of use is another important criterion to be considered. JAVA programming language combines all the necessary requirements for the development of the prototype software.

3.10.2 Software System's Architecture

As mentioned earlier, the proposed model has one objective which is predicting the optimum contingency value. This simplifies the architecture of the system. The system requires two levels input from the user: (1) Evaluation of multiple provided risk factors; and (2) Selection of the preferred risk attitude depending on the nature and objective of project. The breakdown structure of the developed system is shown in figure 3.5.

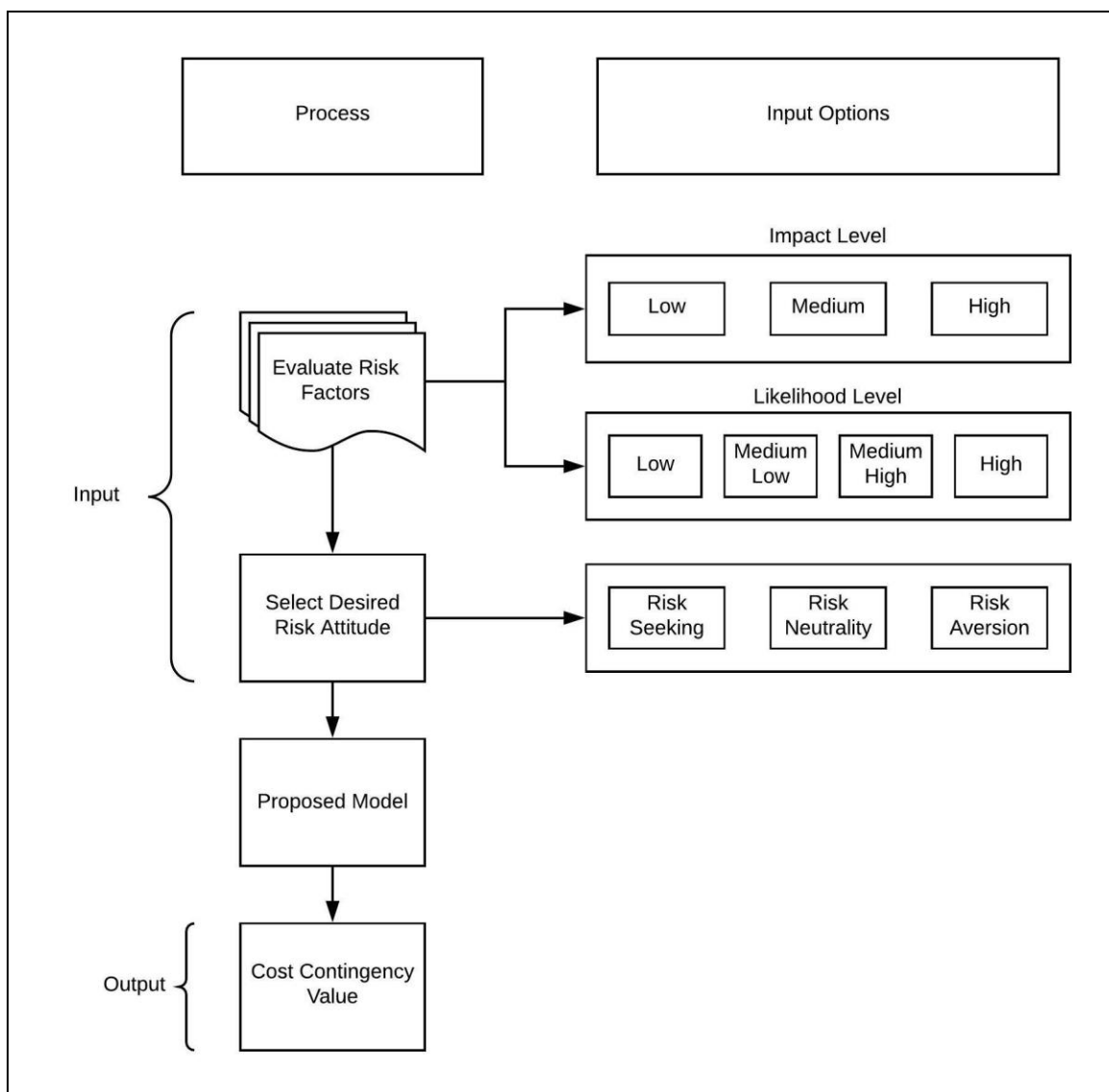


Figure 3.5: System Layout

3.10.3 Data Flow of the Proposed Model

The proposed system commences once the user firstly evaluates the provided risk factors in terms of impact and likelihood of occurrence. The evaluations are entered through a set of dialog boxes. Users are also requested to select the desired risk attitude depending on the nature and objective of project. The model starts by transferring the input evaluations into a scale whose limits were obtained from the MAUT survey which are defined by the maximum and the minimum financial impacts of each risk factor. The transferred evaluations are then substituted in the developed utility functions of risk factors to obtain the utility value of the considered evaluations for each risk factor. The calculated utility values are then integrated with AHP importance scores to obtain the expected utility for each risk factor. After that, a project expected utility is formed by summing all the computed expected utilities. The contingency utility function associated with selected desired risk attitude by the user is set equal to the project expected utility to obtain the normalized score. The normalized score is then converted to a cost contingency percentage. The contingency value prediction process is shown in figure 3.6.

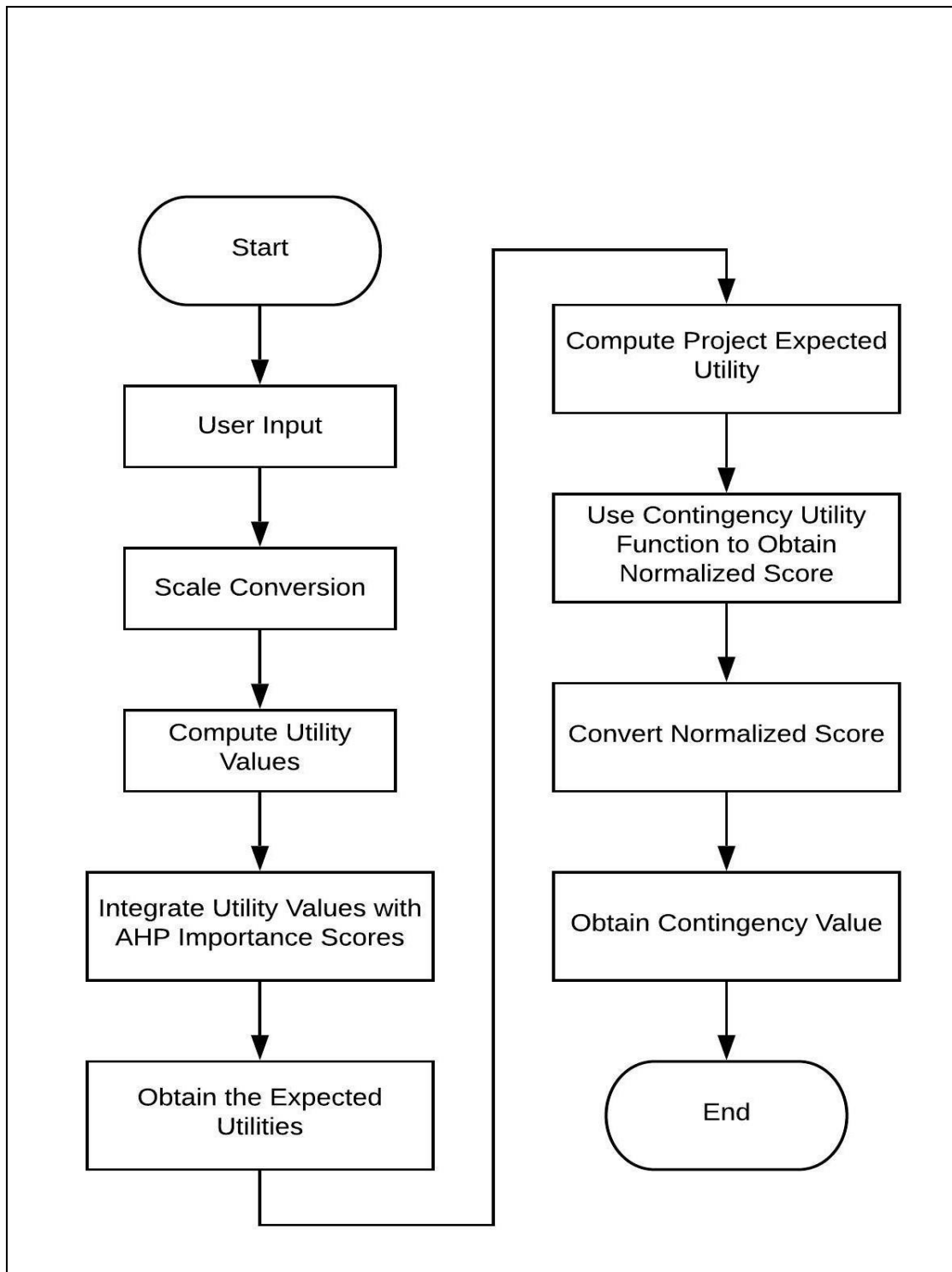


Figure 3.6: Contingency Value Prediction Process

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter aims to analyse and present the findings of this research. The first section discusses the profile of respondents and organization. The second section addresses the secondary objectives of this study that were achieved as the first step in the model development. The importance of the secondary objectives lies in identifying and determining the most significant risk factors that affect the allocation of cost contingency to building construction projects in the construction industry of Saudi Arabia from contractors' point of view. In the rest part of this chapter, the process of developing the desired model is presented and after that case studies are applied to validate the developed model.

4.1 Demographic Information of Respondents

A total of 28 experts working in firms and projects that conform to the scope of this research were contacted in person in the last quarter of 2019 to participate in the study by filling in the developed questionnaire in an interview setting. However, due to time constraints, 14 experts preferred to complete the survey on their own. The researcher provided such participants with a brief explanation over the whole survey and the method for completing the questionnaire. Out of these 14 experts, 3 experts submitted properly completed questionnaires, 4 experts submitted completed questionnaires, however, with major errors and thus eliminated, and 7 experts did not respond at all despite the researcher's continuous reminders through emails and telephone calls. Moreover, complete 14 one-on-one interviews were conducted with the remaining of the contacted experts. The interview length ranged between 60 and 90 minutes. Therefore, a total of 17 experts participated in the study which is considered acceptable. AHP technique can be performed with small sample size and still yield sound results. Multiple studies have applied AHP with sample

size ranging from 4 to 9 (Dalal et al., 2010; Akadiri et al., 2013). In addition, as per Kish's equation, 17 participants are believed to represent the population.

4.1.1 Educational Background of Respondents

Figure 4.1 depicts the educational background of experts participated in this research. The results indicated that the participants are well educated with college degrees. The vast majority of respondents have civil engineering degrees and the rest of experts have different engineering disciplines such as electrical and building engineering.

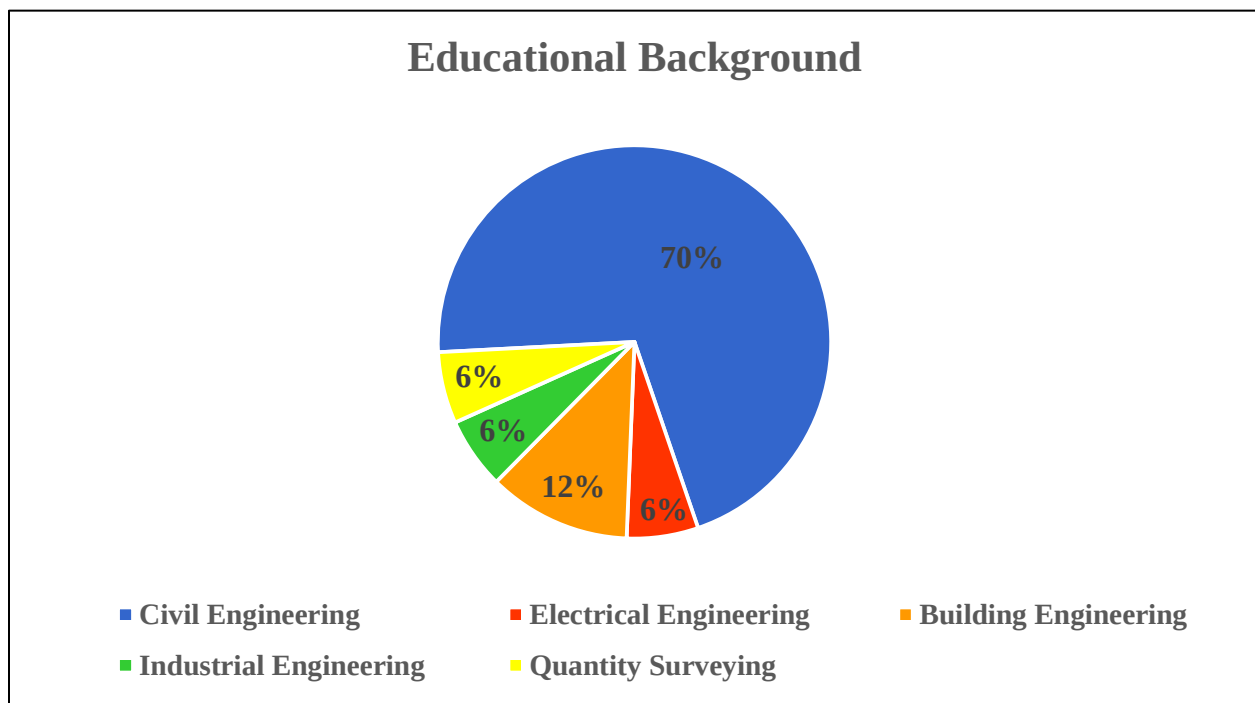


Figure 4.1: Educational Background

4.1.2 Job Position of Respondents

Job position of experts varied greatly between top managerial roles and non-managerial roles. Despite the job title of respondents, all of them have affirmed that they have experience and authority to decide on bids price and contingency percentages. Five experts were directly working under cost estimation departments either as cost control engineer, cost estimator or quantity surveyor. Two experts were holding top-level managerial roles with one serving as a general manager and the other as a commercial manager while five experts had middle-level managerial roles such as quality control manager, project manager and construction manager. The rest were working either at site such as site and project engineers or departments such as procurement engineers and technical senior engineers.

4.1.3 Years of Work Experience of Respondents

Figure 4.2 illustrates the work experience of experts participated in this research. Years of work experience was divided into four categories with each representing a period of 5 years. The analysis showed that the majority of experts had from 11 to 15 years of experience in bids pricing and tendering while the rest was nearly equally distributed across the other classifications. Furthermore, more than 53% of participants had work experience more than 11 years which supports the reliability of the provided data.

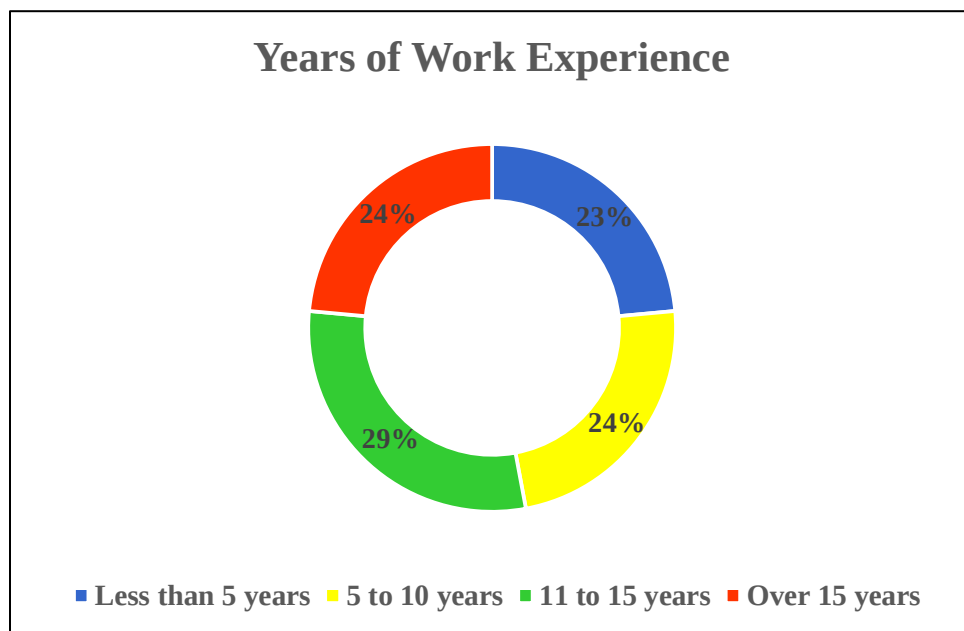


Figure 4.2: Years of Work Experience

4.1.4 Location of Organizations

The Eastern Province consists of 8 main cities including Dammam, Jubail, Khobar, Dhahran, Qatif, Khafji, Nuayriyah and Ras Tanura (Asharqia Chamber, 2019). The collected data were mainly from two main cities, Dammam and Khobar. Dammam is the capital and the largest city of the Eastern Province. It hosts most of the Eastern Province population and all governmental departments as well as industrial facilities. The city of Khobar represents a commercial center and a foremost tourist destination in the Eastern Province. Figure 4.3 displays the distribution of contracting firms who participated in this research. Most of the contracting firms were located in Dammam with a percentage of 59%.

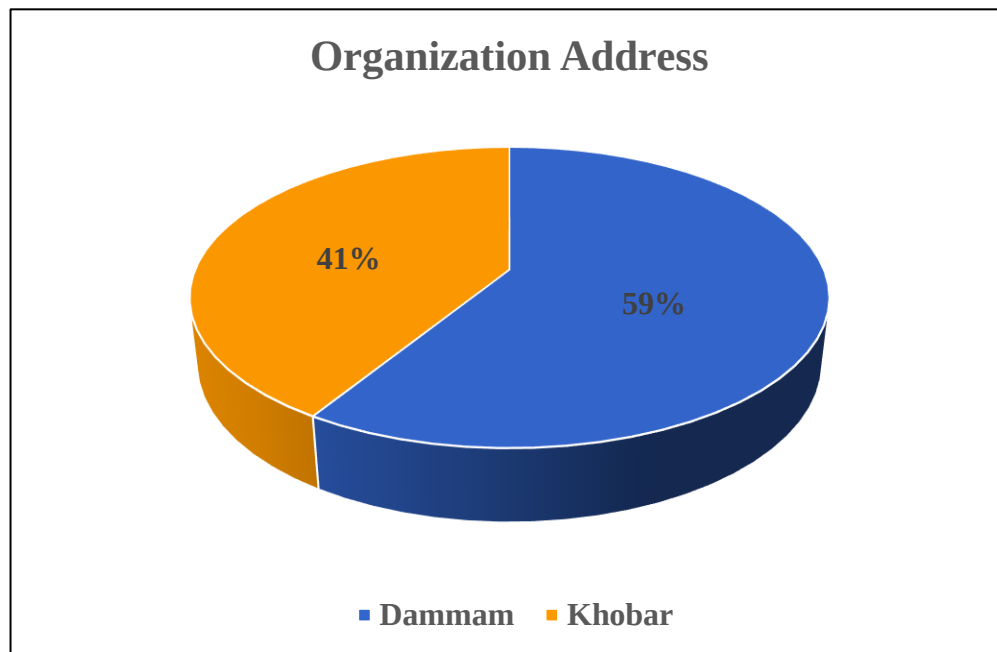


Figure 4.3: Organization Address

4.1.5 Classification of Organizations

The Ministry of Municipal and Rural Affairs in Saudi Arabia classifies contractors into 5 grades according to certain financial and technical criteria. Classified grade 1 and 2 building contractors were the main interest in this research. Figure 4.4 depicts the frequency of contracting firms participated in the study.

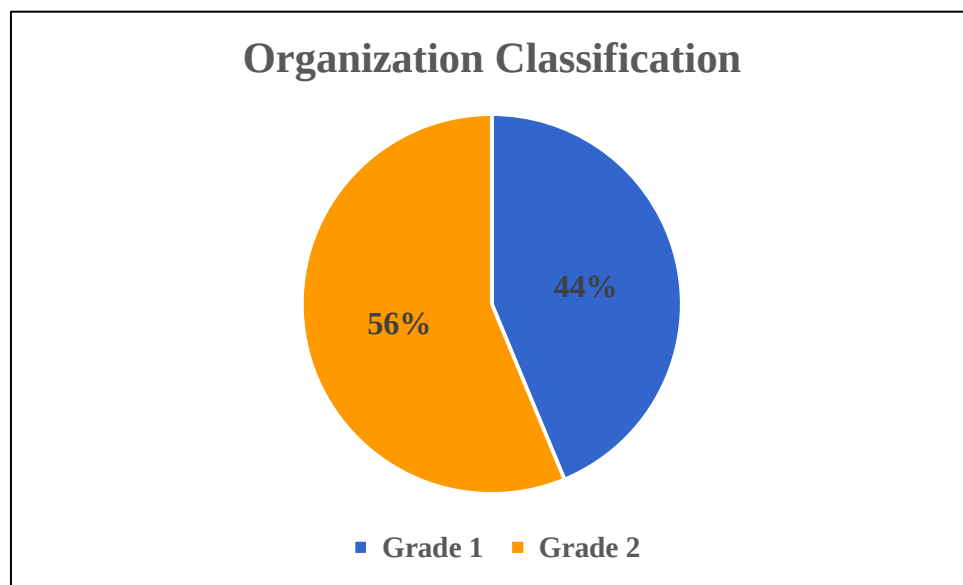


Figure 4.4: Organization Classification

4.2 Risk Factors Affecting the Allocation of Cost Contingency

AHP was used to prioritize 18 risk factors. The pairwise comparisons made are shown in Appendix B, Section 2, along with the consistency ratios computed. The consistency ratios were calculated using the AHP-OS package developed by Goepel (2018). In accordance with Saaty (1980), only evaluations and responses with consistency ratios lower than 0.1 were considered reliable. There have been numerous studies discussing the relationship between the reliability of evaluations and consistency ratios (Franek and Kresta, 2014). For instance, acceptance of evaluations with consistency ratios higher than 0.1 and up to 0.2 has been suggested (Goepel, 2019). This research entirely eliminated evaluations with consistency ratios greater than 0.2, revaluated responses with consistency ratios between 0.1 and 0.2, and accepted evaluations with consistency ratios less than 0.1. This strategy resulted in 15 consistent evaluations out of the 17 responses collected. As mentioned above, the 17 responses were the product of 14 one-on-one interviews and three completed surveys. A summary of the consistency ratios computed for the six pairwise comparisons developed for all respondents is shown in Table 4.1.

Pairwise comparisons were used to demonstrate the importance of risk factors on three different levels. The first level weighted the main categories of bidding, construction, economics, environment, and legal into a hierarchy. This prioritization provided an overall indication of the categories contractors emphasized. Table 4.2 presents the respective weights of the main categories and average weights obtained from analysing only consistent responses. The categories were ranked according to the average weights, with the highest average weight corresponding to Rank 1, and so on (see Table 4.3). A second or local-level prioritization provided weights for risk factors in each main category of the hierarchical structure. This assisted with understanding which risk factors had the greatest impact on cost contingency as compared to other risk factors in the

same category. The local weights obtained for these risk factors from all 15 consistent respondents are shown in Table 4.4. Table 4.5 demonstrates the ranking of risk factors at the local level. The final prioritization was performed on a global level to determine the most significant risk factors compared to all other risk factors in all categories. Tables 4.6 and 4.7 present the global weights of the risk factors for all respondents and ranking of those risk factors on a global level. The computation process was accomplished via the AHP-OS package developed by Goepel (2018). Respondents' evaluations are shown in Appendix B, Section 2, along with the weights obtained. It should be noted that the sum of each category's weight and the local weights of risk factors had to equal 1. Moreover, the global weights of the risk factors falling in a certain category had to add up to the weight of the category itself.

The analysis showed that bidding-related risks were the most significant, with a weight score of 0.313. This category was comprised of risks such as unrealistic construction schedules and inadequate design. Experts stated that poor planning for various elements of the bidding process could affect the whole project, unlike risks in other categories. The effects of such risks may not be realized until advanced stages of the project. Corrective action for bidding-related risks is usually more costly and may require the implementation of radical changes. Construction-related risks ranked second, with a weight score of 0.255. Construction-related risks can have an instant impact but may not affect a project in the longer term; these risks are also more likely to occur than risks in other categories.

Prioritization at the local level highlighted the most significant risk factors within each category. This prioritization was helpful for focusing concentration on specific risks related to issues expected to emerge from a particular category. The analysis showed that the most significant risk factor in the bidding process was unrealistic schedules, while the least significant risk factor was

the quality of the drawings and other details. Contractors are sometimes vulnerable to being forced to work under schedule pressure, either to keep a project on track from the beginning or if they bid on a project according to an unrealistic construction schedule in order to satisfy the client's requirements. One contractor stated that his firm had recently bid on a project knowing that the proposed duration was not achievable by any means. The firm tackled this issue by allocating a 10% contingency, which was the delay penalty stipulated in the UCPW. The risk of working in such an environment may yield not only a delay penalty, but adversely impact other project objectives such as quality and productivity. This inference agrees with the findings of Nepal et al. (2006), whose study analyzed the effects of tight construction schedules on project performance in Singapore. Negative effects can take the form of work defects from cutting corners and lost motivation. Through an empirical investigation of 38 construction projects, it was shown that the desired results and advantages of compressed schedules were offset by losses in quality and productivity. Certainly, contracting firms realize that these negative outcomes will be at their own expense, especially without the owner's recognition of such factors. Therefore, unrealistic construction schedules were the most serious risk at the bidding stage and even at the global level (see Tables 4.5 and 4.7).

The most serious risk in the construction phase was related to subcontractors, while the least risk was from damage to equipment and materials. Subcontracting is an essential and indispensable practice in the construction industry. Studies have found that up to 80% of the work in building projects in Hong Kong is sublet to subcontractors (Chiang, 2009). In Saudi Arabia, it was found that 20% of the contract value of industrial projects is undertaken by subcontractors (Ganiyu, 2010). Subcontractor failure implies bargaining for the sublet work. Subcontractors may then fail to deliver quality on-time work. The experts stated that subcontractors are difficult to fully control.

When comparing the impact of subcontractors' issues with that of suppliers (which ranked second in the construction category), it was found that the relationship between general contractors and subcontractors tends to be much more multifaceted and complex than that of general contractors and suppliers. General contractors have the upper hand in imposing conditions and exerting pressure on suppliers because they have the ability to replace them with minimal impact. However, subcontractors are much more difficult to replace in the case of construction failure. This explains why contractors in the US usually add 5% to 10% to the total bid price when working with contractors with whom they have never worked before (Shash, 1998). General contractors usually allocate a lower contingency percentage if the subcontractor is reputable.

Finally, the risk factors were ranked on a global level to show their relative significance. The analysis revealed that in descending order, unrealistic construction schedules, escalations in prices, and inadequate designs had the greatest impacts on project costs. These results comport with those of Zou et al. (2007), which investigated the key risks in the Chinese construction market. The risks were prioritized according to the significance of their effect on project objectives. A significance index score was used because it is a function of the impact of a risk's consequences and likelihood of its occurrence. The top four risks in descending rank were as follows: variations in the order, price escalation, design variation, and tight project schedule. However, the first-ranked risk was not deemed a risk within the research scope. It is evident that risk factors with significant impact and a high probability of occurrence should be ranked nearest the top. The construction industry in Saudi Arabia has faced serious vicissitudes in the last few years. For instance, building materials and labor wages have fluctuated dramatically for a variety of reasons. The market has also faced a workforce shortage that has caused a significant increase in labor cost (approximately 47%), due in part to substantial changes in government regulations. Furthermore, raw building materials have

increased in price. Concrete, for instance, increased by approximately 29% per meter cube. The precedence of some risk factors such as approval and drawing delays over poor productivity and supplier issues is an interesting topic for discussion. However, experts have stated that supplier issues and poor productivity are more controllable than approval and drawing delays, implying that risks being under direct contractor control reduces the impact of their consequences. Thus, contractors attribute greater significance to risk factors over which they have little control.

Table 4.1: Summary of the Computed Consistency Ratios

Respondents	Pairwise Comparison	Consistency Ratio
Expert 1	Parent Criteria	0.065
	Bidding Criterion	0.004
	Construction Criterion	0.082
	Environment Criterion	0.056
	Economic Criterion	0
	Legal Criterion	0.098
Expert 2	Parent Criteria	0.04
	Bidding Criterion	0.089
	Construction Criterion	0.1
	Environment Criterion	0.019
	Economic Criterion	0
	Legal Criterion	0
Expert 3	Parent Criteria	0.085
	Bidding Criterion	0.096
	Construction Criterion	0.077
	Environment Criterion	0.074
	Economic Criterion	0
	Legal Criterion	0.09
Expert 4	Parent Criteria	0.091
	Bidding Criterion	0.097
	Construction Criterion	0.093
	Environment Criterion	0.098
	Economic Criterion	0
	Legal Criterion	0.077
Expert 5	Parent Criteria	0.091
	Bidding Criterion	0.092
	Construction Criterion	0.079
	Environment Criterion	0.09
	Economic Criterion	0
	Legal Criterion	0.002
Expert 6	Parent Criteria	0.054
	Bidding Criterion	0.078
	Construction Criterion	0.044
	Environment Criterion	0.006
	Economic Criterion	0
	Legal Criterion	0.01

Expert 7	Parent Criteria	0.685
	Bidding Criterion	0.287
	Construction Criterion	0.874
	Environment Criterion	0.327
	Economic Criterion	0
	Legal Criterion	0.384
Expert 8	Parent Criteria	0.098
	Bidding Criterion	0.1
	Construction Criterion	0.099
	Environment Criterion	0.056
	Economic Criterion	0
	Legal Criterion	0.056
Expert 9	Parent Criteria	0.099
	Bidding Criterion	0.096
	Construction Criterion	0.091
	Environment Criterion	0
	Economic Criterion	0
	Legal Criterion	0.056
Expert 10	Parent Criteria	0.044
	Bidding Criterion	0.038
	Construction Criterion	0.077
	Environment Criterion	0.056
	Economic Criterion	0
	Legal Criterion	0.056
Expert 11	Parent Criteria	0.09
	Bidding Criterion	0.034
	Construction Criterion	0.087
	Environment Criterion	0.077
	Economic Criterion	0
	Legal Criterion	0.089
Expert 12	Parent Criteria	0.099
	Bidding Criterion	0.097
	Construction Criterion	0.098
	Environment Criterion	0.098
	Economic Criterion	0
	Legal Criterion	0.084

Expert 13	Parent Criteria	0.084
	Bidding Criterion	0.086
	Construction Criterion	0.088
	Environment Criterion	0.098
	Economic Criterion	0
	Legal Criterion	0.056
Expert 14	Parent Criteria	0.094
	Bidding Criterion	0.092
	Construction Criterion	0.1
	Environment Criterion	0.074
	Economic Criterion	0
	Legal Criterion	0.068
Expert 15	Parent Criteria	0.019
	Bidding Criterion	0.044
	Construction Criterion	0.029
	Environment Criterion	0.019
	Economic Criterion	0
	Legal Criterion	0
Expert 16	Parent Criteria	0.22
	Bidding Criterion	0.271
	Construction Criterion	0.47
	Environment Criterion	0
	Economic Criterion	0
	Legal Criterion	0.455
Expert 17	Parent Criteria	0.098
	Bidding Criterion	0.09
	Construction Criterion	0.099
	Environment Criterion	0.056
	Economic Criterion	0
	Legal Criterion	0

Table 4.2: Weights of Categories

Category	All Respondents															Average Weight
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Bidding	0.216	0.095	0.512	0.290	0.066	0.429	0.492	0.350	0.334	0.144	0.522	0.336	0.200	0.155	0.547	0.313
Construction	0.370	0.091	0.132	0.076	0.047	0.151	0.276	0.340	0.283	0.404	0.257	0.334	0.602	0.205	0.262	0.255
Environment	0.160	0.426	0.232	0.307	0.338	0.135	0.032	0.183	0.078	0.344	0.088	0.035	0.066	0.095	0.040	0.171
Economic	0.139	0.344	0.046	0.284	0.178	0.113	0.144	0.081	0.060	0.048	0.079	0.129	0.036	0.095	0.081	0.124
Legal	0.115	0.044	0.078	0.043	0.371	0.172	0.056	0.046	0.245	0.060	0.054	0.166	0.096	0.450	0.070	0.138

Table 4.3: Ranking of Categories

Category	Average Weight	Rank
Bidding	0.313	1
Construction	0.255	2
Environment	0.171	3
Legal	0.138	4
Economic	0.124	5

Table 4.4: Local Weights of Risk Factors

Category	Risk Factors	All Respondents															Average Local Weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Bidding	Inadequate Design	0.141	0.192	0.235	0.051	0.225	0.373	0.180	0.110	0.074	0.226	0.556	0.345	0.058	0.453	0.710	0.262
	Quality of Drawings and Details	0.263	0.079	0.088	0.145	0.178	0.104	0.184	0.065	0.169	0.083	0.275	0.371	0.040	0.160	0.155	0.157
	Unrealistic Construction Schedules	0.455	0.102	0.636	0.682	0.067	0.152	0.593	0.272	0.454	0.486	0.135	0.174	0.619	0.160	0.086	0.338
	Vagueness of Scope of Work	0.141	0.627	0.041	0.122	0.530	0.371	0.043	0.553	0.303	0.205	0.034	0.110	0.283	0.227	0.049	0.243
Construction	Suppliers Issues	0.121	0.398	0.116	0.105	0.375	0.247	0.204	0.217	0.064	0.035	0.476	0.050	0.046	0.272	0.055	0.185
	Subcontractors Issues	0.121	0.248	0.281	0.180	0.146	0.203	0.222	0.097	0.155	0.327	0.305	0.184	0.210	0.114	0.263	0.204
	Defective Work	0.204	0.082	0.404	0.428	0.042	0.158	0.099	0.121	0.160	0.211	0.103	0.061	0.518	0.109	0.066	0.184
	Damage to Material, Equipment and Facilities	0.070	0.131	0.111	0.047	0.068	0.174	0.083	0.200	0.082	0.229	0.062	0.099	0.137	0.161	0.082	0.116
	Poor Productivity of Manpower and Equipment	0.423	0.066	0.060	0.210	0.071	0.104	0.368	0.170	0.178	0.104	0.031	0.369	0.039	0.122	0.291	0.174
	Stringent Inspections by Engineers	0.061	0.075	0.028	0.030	0.298	0.114	0.024	0.195	0.361	0.094	0.023	0.237	0.051	0.222	0.243	0.137

Table 4.4: Local Weights of Risk Factors (Continued)

Category	Risk Factors	All Respondents															Average Local Weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Environment	Adverse Weather Conditions	0.594	0.155	0.194	0.088	0.225	0.149	0.156	0.167	0.311	0.073	0.699	0.610	0.060	0.210	0.327	0.268
	Subsurface Conditions	0.157	0.710	0.743	0.717	0.674	0.691	0.745	0.167	0.493	0.761	0.237	0.224	0.708	0.550	0.413	0.533
	Site Accessibility	0.249	0.135	0.063	0.195	0.101	0.160	0.099	0.666	0.196	0.166	0.064	0.166	0.231	0.240	0.260	0.199
Economic	Escalation in Prices	0.900	0.889	0.750	0.875	0.833	0.667	0.889	0.750	0.500	0.900	0.875	0.500	0.833	0.750	0.500	0.761
	Currency Fluctuation	0.100	0.111	0.250	0.125	0.167	0.333	0.111	0.250	0.500	0.100	0.125	0.500	0.167	0.250	0.500	0.239
Legal	Labor Disputes and Strikes	0.088	0.067	0.226	0.653	0.094	0.634	0.745	0.413	0.594	0.094	0.655	0.260	0.072	0.200	0.333	0.342
	Permit Delays	0.717	0.466	0.101	0.062	0.097	0.174	0.099	0.260	0.157	0.626	0.290	0.413	0.279	0.400	0.333	0.298
	Drawing and Approval Delays	0.195	0.467	0.673	0.285	0.809	0.192	0.156	0.327	0.249	0.280	0.055	0.327	0.649	0.400	0.334	0.360

Table 4.5: Local Ranking of Risk Factors

Category	Risk Factors	Average Local Weight	Rank
Bidding	Unrealistic Construction Schedules	0.338	1
	Inadequate Design	0.262	2
	Vagueness of Scope of Work	0.243	3
	Quality of Drawings and Details	0.157	4
Construction	Subcontractors Issues	0.204	1
	Suppliers Issues	0.185	2
	Defective Work	0.184	3
	Poor Productivity of Manpower and Equipment	0.174	4
	Stringent Inspections by Engineers	0.137	5
	Damage to Material, Equipment and Facilities	0.116	6
Environment	Subsurface Conditions	0.533	1
	Adverse Weather Conditions	0.268	2
	Site Accessibility	0.199	3
Economic	Escalation in Prices	0.761	1
	Currency Fluctuation	0.239	2
Legal	Drawing and Approval Delays	0.360	1
	Labor Disputes and Strikes	0.342	2
	Permit Delays	0.298	3

Table 4.6: Global Weights of Risk Factors

Category	Risk Factors	All Respondents															Average Global Weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Bidding	Inadequate Design	0.030	0.018	0.120	0.015	0.015	0.160	0.089	0.039	0.025	0.033	0.290	0.116	0.012	0.070	0.388	0.095
	Quality of Drawings and Details	0.057	0.008	0.045	0.042	0.012	0.045	0.091	0.023	0.056	0.012	0.144	0.125	0.008	0.025	0.085	0.052
	Unrealistic Construction Schedules	0.098	0.010	0.326	0.198	0.004	0.065	0.292	0.095	0.152	0.070	0.070	0.058	0.124	0.025	0.047	0.109
	Vagueness of Scope of Work	0.030	0.060	0.021	0.035	0.035	0.159	0.021	0.194	0.101	0.030	0.018	0.037	0.057	0.035	0.027	0.057
Construction	Suppliers Issues	0.045	0.170	0.027	0.032	0.127	0.033	0.056	0.074	0.018	0.014	0.122	0.017	0.028	0.056	0.014	0.056
	Subcontractors Issues	0.045	0.106	0.065	0.055	0.049	0.027	0.061	0.033	0.044	0.132	0.078	0.061	0.126	0.023	0.069	0.065
	Defective Work	0.075	0.035	0.094	0.131	0.014	0.021	0.027	0.041	0.045	0.085	0.026	0.020	0.312	0.022	0.017	0.065
	Damage to Material, Equipment and Facilities	0.026	0.056	0.026	0.014	0.023	0.023	0.023	0.068	0.023	0.093	0.016	0.033	0.082	0.033	0.021	0.037
	Poor Productivity of Manpower and Equipment	0.157	0.028	0.014	0.064	0.024	0.014	0.102	0.058	0.050	0.042	0.008	0.123	0.023	0.025	0.076	0.054
	Stringent Inspections by Engineers	0.023	0.032	0.006	0.009	0.101	0.015	0.007	0.066	0.102	0.038	0.006	0.079	0.031	0.046	0.064	0.042

Table 4.6: Global Weights of Risk Factors (Continued)

Category	Risk Factors	All Respondents															Average Global Weight
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	
Environment	Adverse Weather Conditions	0.095	0.014	0.026	0.007	0.011	0.022	0.005	0.031	0.024	0.025	0.062	0.021	0.004	0.020	0.013	0.025
	Subsurface Conditions	0.025	0.065	0.098	0.054	0.032	0.104	0.024	0.031	0.038	0.262	0.021	0.008	0.047	0.052	0.017	0.058
	Site Accessibility	0.040	0.012	0.008	0.015	0.005	0.024	0.003	0.122	0.015	0.057	0.006	0.006	0.015	0.023	0.010	0.024
Economic	Escalation in Prices	0.125	0.306	0.035	0.249	0.148	0.075	0.128	0.061	0.030	0.043	0.069	0.065	0.030	0.071	0.041	0.098
	Currency Fluctuation	0.014	0.038	0.012	0.036	0.030	0.038	0.016	0.020	0.030	0.005	0.010	0.065	0.006	0.024	0.041	0.025
Legal	Labor Disputes and Strikes	0.010	0.003	0.018	0.028	0.035	0.109	0.042	0.019	0.146	0.006	0.035	0.043	0.007	0.090	0.023	0.041
	Permit Delays	0.082	0.021	0.008	0.003	0.036	0.030	0.006	0.012	0.038	0.038	0.016	0.069	0.027	0.180	0.023	0.039
	Drawing and Approval Delays	0.022	0.021	0.052	0.012	0.300	0.033	0.009	0.015	0.061	0.017	0.003	0.054	0.062	0.180	0.023	0.058

Table 4.7: Global Ranking of Risk Factors

Risk Factors	Category	Global Weight (W_i)	Rank
Unrealistic Construction Schedules	Bidding	0.109	1
Escalation in Prices	Economic	0.098	2
Inadequate Design	Bidding	0.095	3
Subcontractors Issues	Construction	0.065	4
Defective Work	Construction	0.0646	5
Subsurface Conditions	Environment	0.0585	6
Drawing and Approval Delays	Legal	0.0577	7
Vagueness of Scope of Work	Bidding	0.0573	8
Suppliers Issues	Construction	0.0555	9
Poor Productivity of Manpower and Equipment	Construction	0.0539	10
Quality of Drawings and Details	Bidding	0.0517	11
Stringent Inspections by Engineers	Construction	0.0416	12
Labor Disputes and Strikes	Legal	0.0409	13
Permit Delays	Legal	0.0392	14
Damage to Material, Equipment and Facilities	Construction	0.0374	15
Currency Fluctuation	Economic	0.0255	16
Adverse Weather Conditions	Environment	0.0253	17
Site Accessibility	Environment	0.0241	18

4.3 Model Development

4.3.1 Utility Function Development

The primary step in developing the model was to establish a utility function for each risk factor. Unlike the AHP technique where only consistent evaluations are considered, the MAUT process does not require any particular testing because most responses are collected in an interview setting, and thus all properly completed surveys can be considered valid. In this research, a total of 17 responses were collected to the five parameters provided for each risk factor: the maximum and minimum loss percentages, probability of occurrence of losing the maximum and minimum loss percentages, and certainty equivalent. Each utility function was established based on the average value for each parameter as provided by the experts (see Table 4.8). Next, the shape of the utility function was selected by computing the expected value and comparing it to the average value of the certainty equivalent. The shape of the utility function for each risk factor was based on the risk attitude, as illustrated in Table 4.9. This consideration of risk attitudes measured the general trend of each risk factor in the market. The expected values were computed by summing the multiplication of the maximum and minimum percentage loss values by their associated probabilities. Upon determining the risk attitude and selecting the utility function shape, three coordinate points were established: the average value of the maximum loss percentages and its utility score, average value of the minimum loss percentages and its utility score, and certainty equivalent and its utility score. The utility score of the certainty equivalent was computed using Function 3.10. Table 4.10 summarizes the coordinate points and risk behaviors upon which the utility functions were based. The model is basically a set of utility functions depicting risk factors, as shown in Table 4.11. The coordinate points were substituted in Functions 3.3 through 3.5,

according to the risk attitude identified. Three equations with three unknowns were consequently formed and solved using MATLAB software.

In contrast to previous studies, the parameter values obtained could be further verified and logically demonstrated. For instance, the maximum financial impact of the unrealistic construction schedule risk factor could reach up to 13% of the contract value, as described by the experts. This percentage was composed of two parts, 10% which representing the maximum delay penalty stipulated in the UCPW to which a contractor can be subject, and 3% the other incurred costs represented as overhead and additional resources required. However, unrealistic construction schedule risk can also be the result of construction acceleration, which occurs when a contractor is legally entitled to an extension of time but still held to the original schedule due to the owner's insistence (Nelson, 2013). The maximum financial impact of adverse weather conditions was approximately 3% of the total contract value. A study carried out in the UK by Ballesteros-Perez et al. (2018) integrated the influence of adverse weather conditions into the project schedule development process. These researchers found that construction project completion time was on average extended by 21% of the initial contract period. In Saudi Arabia, an extension of 10% for weather conditions is considered reasonable. When attempting to translate the delay into cost in view of Article 39 of the UCPW, the delay can yield around a 4% penalty. Mills et al. (2009) examined the impact of defective work in a study conducted on Australian residential projects. That study found that the cost of rectification was 4% of the total contract value and the probability of occurrence was 12.5%. The results obtained in the present study (approximately 7%) can be considered rational when compared to the 4% in the above-mentioned study, which did not consider the effect of defects on project schedule. Finally, the results of the MAUT analysis confirmed those obtained by the AHP, where escalation in prices was perceived as a serious risk

(it was ranked second); the experts also exhibited risk aversion to price escalation, implying that contractors are unwilling to take on this particular risk factor. However, if the maximum financial impact of the escalation in prices was broken down, it would yield a value very close to that obtained by the experts.

Table 4.8: Financial Impact, Probability and Certainty Equivalent Values

Risk Factors	Parameters	All Respondents																	Average Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Inadequate Design	Max	2.0	20.0	60.0	10.0	50.0	40.0	2.0	50.0	10.0	1.0	8.0	15.0	20.0	25.0	5.0	30.0	18.0	21.53
	P (Max)	50.0	10.0	10.0	20.0	5.0	10.0	10.0	3.0	20.0	20.0	20.0	80.0	60.0	5.0	30.0	25.0	35.0	24.29
	Min	1.5	1.0	0.0	0.0	5.0	5.0	1.0	5.0	0.0	0.5	1.0	5.0	10.0	10.0	0.0	0.5	12.0	3.38
	P (Min)	50.0	90.0	90.0	80.0	95.0	90.0	90.0	97.0	80.0	80.0	80.0	20.0	40.0	95.0	70.0	75.0	65.0	75.71
	CE	1.8	2.0	10.0	0.5	10.0	10.0	1.5	6.0	1.0	0.8	2.0	11.0	16.0	13.0	3.0	5.0	15.0	6.38
Quality of Drawings and Details	Max	1.0	3.0	20.0	50.0	10.0	10.0	3.0	5.0	10.0	1.0	5.0	15.0	20.0	3.0	5.0	2.0	15.0	10.47
	P (Max)	40.0	1.0	5.0	70.0	50.0	10.0	20.0	60.0	20.0	20.0	10.0	60.0	60.0	25.0	40.0	30.0	30.0	32.41
	Min	0.5	1.0	3.0	10.0	2.0	5.0	1.0	1.0	0.0	0.5	1.0	5.0	10.0	1.0	1.0	0.0	10.0	3.06
	P (Min)	60.0	99.0	95.0	30.0	50.0	90.0	80.0	40.0	80.0	80.0	90.0	40.0	40.0	75.0	60.0	70.0	70.0	67.59
	CE	0.8	1.2	6.0	12.0	4.0	5.2	2.0	2.0	1.0	0.8	1.5	8.0	16.0	1.2	3.0	0.3	11.0	4.46
Unrealistic Construction Schedules	Max	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	4.0	25.0	15.0	10.0	20.0	10.0	15.0	30.0	12.88
	P (Max)	20.0	30.0	40.0	10.0	50.0	10.0	10.0	40.0	5.0	30.0	10.0	50.0	70.0	10.0	10.0	10.0	55.0	27.06
	Min	5.0	0.0	1.0	0.0	1.0	5.0	0.0	3.0	0.0	2.5	4.0	5.0	3.0	15.0	5.0	5.0	20.0	4.38
	P (Min)	80.0	70.0	60.0	90.0	50.0	90.0	90.0	60.0	95.0	70.0	90.0	50.0	30.0	90.0	90.0	90.0	45.0	72.94
	CE	6.0	2.0	4.0	1.0	3.0	7.0	3.0	5.0	0.5	3.0	5.0	6.0	7.0	17.0	6.0	8.0	25.0	6.38

Risk Factors	Parameters	All Respondents																	Average Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Vagueness of Scope of Work	Max	2.0	40.0	3.0	30.0	20.0	30.0	15.0	3.0	10.0	2.0	10.0	15.0	3.0	5.0	8.0	10.0	20.0	13.29
	P (Max)	20.0	20.0	30.0	60.0	30.0	10.0	70.0	50.0	5.0	20.0	15.0	60.0	10.0	20.0	20.0	15.0	35.0	28.82
	Min	1.0	1.0	0.0	10.0	2.0	5.0	10.0	1.0	0.0	1.0	3.0	5.0	0.0	1.0	1.0	2.0	10.0	3.12
	P (Min)	80.0	80.0	70.0	40.0	70.0	90.0	30.0	50.0	95.0	80.0	85.0	40.0	90.0	80.0	80.0	85.0	65.0	71.18
	CE	1.3	5.0	1.5	15.0	5.0	6.0	12.0	2.0	0.5	1.5	6.0	8.0	0.6	2.0	2.0	3.0	11.0	4.85
Suppliers Issues	Max	1.0	10.0	30.0	5.0	3.0	70.0	20.0	20.0	20.0	0.5	10.0	10.0	2.0	10.0	7.0	2.0	10.0	13.56
	P (Max)	40.0	40.0	50.0	10.0	50.0	5.0	30.0	60.0	10.0	10.0	25.0	25.0	90.0	5.0	30.0	20.0	70.0	33.53
	Min	0.5	0.0	7.0	0.0	0.0	5.0	10.0	5.0	5.0	0.0	0.0	2.0	0.0	5.0	3.0	0.0	5.0	2.79
	P (Min)	60.0	60.0	50.0	90.0	50.0	95.0	70.0	40.0	90.0	90.0	75.0	75.0	10.0	95.0	70.0	80.0	30.0	66.47
	CE	0.6	2.0	9.0	1.0	1.0	7.0	15.0	12.0	10.0	0.2	2.0	5.0	1.5	5.5	4.0	0.3	6.0	4.83
Subcontractors Issues	Max	1.0	15.0	25.0	10.0	3.0	30.0	20.0	30.0	30.0	2.0	15.0	8.0	5.0	15.0	15.0	20.0	35.0	16.41
	P (Max)	40.0	10.0	15.0	20.0	50.0	5.0	30.0	20.0	5.0	25.0	30.0	20.0	98.0	15.0	50.0	10.0	40.0	28.41
	Min	0.5	1.0	2.0	0.0	0.0	5.0	3.0	5.0	0.0	1.0	4.0	0.0	1.0	5.0	5.0	2.0	3.0	2.21
	P (Min)	60.0	90.0	85.0	80.0	50.0	95.0	70.0	80.0	95.0	75.0	70.0	80.0	2.0	85.0	50.0	90.0	60.0	71.59
	CE	0.6	2.0	8.0	3.0	1.0	6.0	10.0	10.0	1.0	1.5	5.0	5.0	4.8	6.0	10.0	6.0	4.0	4.94
Defective Work	Max	1.0	9.0	7.0	3.0	6.0	10.0	2.0	10.0	10.0	4.0	5.0	5.0	2.0	8.0	10.0	4.0	10.0	6.24
	P (Max)	30.0	20.0	30.0	20.0	40.0	60.0	20.0	70.0	2.0	70.0	40.0	10.0	99.0	5.0	40.0	5.0	25.0	34.47
	Min	0.5	0.6	1.0	0.0	3.0	0.4	0.0	2.0	0.0	2.0	0.0	0.0	1.0	0.6	2.0	0.1	3.0	0.95
	P (Min)	70.0	80.0	70.0	80.0	60.0	40.0	80.0	30.0	98.0	30.0	60.0	90.0	1.0	95.0	60.0	95.0	75.0	65.53
	CE	0.7	0.9	1.8	0.8	4.0	6.0	0.5	6.0	0.5	2.5	0.5	0.5	1.9	5.5	8.0	0.4	3.5	2.58

Risk Factors	Parameters	All Respondents																	Average Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Damage to Material, Equipment and Facilities	Max	0.8	5.0	50.0	30.0	5.0	50.0	30.0	10.0	20.0	0.5	7.0	10.0	10.0	5.0	10.0	8.0	35.0	16.84
	P (Max)	50.0	30.0	5.0	10.0	50.0	5.0	20.0	30.0	10.0	5.0	30.0	25.0	40.0	5.0	20.0	15.0	10.0	21.18
	Min	0.5	1.0	3.0	5.0	1.0	1.0	10.0	2.0	1.0	0.0	2.0	2.0	5.0	2.0	5.0	0.1	10.0	2.98
	P (Min)	50.0	70.0	95.0	90.0	50.0	95.0	80.0	70.0	90.0	95.0	70.0	75.0	60.0	95.0	80.0	85.0	90.0	78.82
	CE	0.6	1.3	5.0	5.5	3.0	2.0	20.0	3.0	1.5	0.2	2.5	7.0	6.0	2.3	6.0	3.0	11.0	4.70
Poor Productivity of Manpower and Equipment	Max	2.0	10.0	20.0	10.0	4.0	9.0	13.0	30.0	20.0	2.0	3.0	6.0	15.0	10.0	7.0	5.0	12.0	10.47
	P (Max)	40.0	10.0	50.0	20.0	50.0	10.0	20.0	80.0	10.0	50.0	40.0	10.0	90.0	10.0	30.0	5.0	30.0	32.65
	Min	1.5	1.0	4.0	0.0	1.0	2.0	4.0	5.0	1.0	1.0	0.0	1.0	10.0	5.0	3.0	0.4	0.5	2.38
	P (Min)	60.0	90.0	50.0	80.0	50.0	90.0	80.0	20.0	90.0	50.0	60.0	90.0	10.0	90.0	70.0	95.0	70.0	67.35
	CE	1.6	1.2	8.0	3.0	2.0	2.3	8.5	10.0	1.5	1.5	0.4	5.0	13.5	6.0	5.0	0.7	1.5	4.22
Stringent Inspections by Engineers	Max	0.5	5.0	3.0	1.0	6.0	10.0	20.0	5.0	10.0	5.0	6.0	6.0	1.0	10.0	5.0	5.0	10.0	6.38
	P (Max)	50.0	70.0	25.0	10.0	70.0	10.0	15.0	50.0	4.0	80.0	45.0	10.0	70.0	10.0	30.0	20.0	70.0	37.59
	Min	0.3	0.0	1.0	0.0	2.0	1.0	5.0	1.0	0.5	3.0	1.0	1.0	0.0	7.0	1.0	0.2	5.0	1.71
	P (Min)	50.0	30.0	75.0	90.0	30.0	90.0	85.0	50.0	96.0	20.0	55.0	90.0	30.0	90.0	70.0	80.0	30.0	62.41
	CE	0.4	2.0	2.0	0.5	3.0	2.0	10.0	1.5	1.0	3.5	2.5	5.0	0.4	7.5	2.0	2.5	6.0	3.04
Adverse Weather Conditions	Max	1.5	2.0	4.0	1.0	2.0	2.5	0.6	4.0	3.0	0.5	2.0	5.0	5.0	3.0	5.0	1.3	5.0	2.79
	P (Max)	30.0	5.0	15.0	10.0	50.0	5.0	30.0	20.0	5.0	15.0	20.0	5.0	60.0	5.0	20.0	50.0	10.0	20.88
	Min	1.0	0.5	1.0	0.0	0.0	0.0	0.0	1.0	0.0	0.0	0.5	1.0	1.0	1.0	1.0	0.0	2.0	0.59
	P (Min)	70.0	95.0	85.0	90.0	50.0	95.0	70.0	80.0	95.0	85.0	80.0	95.0	40.0	95.0	80.0	50.0	90.0	79.12
	CE	1.1	0.6	1.3	0.5	0.6	0.1	0.2	1.4	0.1	0.3	0.6	1.5	2.7	1.3	2.0	0.2	3.0	1.03

Risk Factors	Parameters	All Respondents																	Average Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Subsurface Conditions	Max	1.5	20.0	60.0	1.0	2.0	30.0	20.0	15.0	3.0	20.0	15.0	7.0	15.0	15.0	15.0	10.0	30.0	16.44
	P (Max)	60.0	40.0	5.0	10.0	50.0	5.0	30.0	20.0	5.0	3.0	40.0	10.0	50.0	5.0	50.0	3.0	40.0	25.06
	Min	1.0	2.0	0.0	0.0	1.0	5.0	10.0	5.0	0.0	1.0	5.0	1.0	5.0	10.0	5.0	1.0	20.0	4.24
	P (Min)	40.0	60.0	95.0	90.0	50.0	95.0	70.0	80.0	95.0	97.0	60.0	90.0	50.0	95.0	50.0	97.0	60.0	74.94
	CE	1.2	2.5	7.0	0.5	1.3	6.0	15.0	10.0	1.0	1.2	7.0	2.0	9.0	10.5	10.0	2.0	21.0	6.31
Site Accessibility	Max	0.7	3.0	2.0	1.0	1.0	2.0	0.4	3.0	0.5	0.1	6.0	5.0	1.0	5.0	5.0	0.3	10.0	2.71
	P (Max)	50.0	5.0	10.0	10.0	20.0	10.0	10.0	30.0	70.0	3.0	15.0	5.0	50.0	10.0	10.0	40.0	10.0	21.06
	Min	0.0	0.0	0.0	0.0	0.0	1.0	0.1	1.0	0.0	0.0	1.0	1.0	0.0	3.0	1.0	0.0	2.0	0.59
	P (Min)	50.0	95.0	90.0	90.0	80.0	90.0	90.0	70.0	30.0	97.0	85.0	95.0	50.0	90.0	90.0	60.0	90.0	78.94
	CE	0.6	0.1	0.2	0.5	0.5	1.4	0.1	2.0	0.2	0.0	1.5	2.0	0.2	4.0	1.2	0.1	2.5	1.00
Escalation in Prices	Max	30.0	5.0	15.0	30.0	20.0	10.0	20.0	5.0	10.0	20.0	10.0	15.0	5.0	10.0	10.0	30.0	20.0	15.59
	P (Max)	20.0	20.0	5.0	60.0	10.0	10.0	10.0	25.0	5.0	20.0	5.0	50.0	50.0	5.0	5.0	3.0	30.0	19.59
	Min	1.0	0.0	1.0	0.0	5.0	5.0	5.0	1.0	0.0	1.0	3.0	8.0	1.0	5.0	1.0	0.8	0.5	2.25
	P (Min)	80.0	80.0	95.0	40.0	90.0	90.0	90.0	75.0	95.0	80.0	95.0	50.0	50.0	95.0	95.0	97.0	70.0	80.41
	CE	5.0	3.0	2.0	10.0	6.0	6.0	7.0	2.0	1.0	5.0	4.0	10.0	2.5	5.5	2.0	4.0	8.0	4.88
Currency Fluctuation	Max	0.5	1.0	5.0	1.0	1.0	1.0	1.0	3.0	4.0	0.5	2.0	5.0	5.0	5.0	3.0	0.2	0.2	2.26
	P (Max)	3.0	5.0	10.0	3.0	3.0	5.0	1.0	30.0	1.0	2.0	5.0	5.0	3.0	5.0	1.0	1.0	1.0	4.94
	Min	0.2	0.0	1.0	0.0	0.0	0.0	0.0	1.0	0.5	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.34
	P (Min)	97.0	95.0	90.0	97.0	97.0	95.0	99.0	70.0	99.0	98.0	95.0	95.0	97.0	95.0	99.0	99.0	99.0	95.06
	CE	0.20	0.02	1.2	0.02	0.01	0.03	0.05	1.2	0.6	0.1	0.05	0.2	1.05	2.1	0.02	0.01	0.01	0.40

Risk Factors	Parameters	All Respondents																	Average Value
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Labor Disputes and Strikes	Max	0.7	10.0	20.0	5.0	1.0	5.0	20.0	2.0	25.0	10.0	4.0	4.0	10.0	8.0	10.0	20.0	10.0	9.69
	P (Max)	30.0	10.0	5.0	30.0	3.0	5.0	1.0	20.0	1.0	30.0	6.0	5.0	50.0	5.0	30.0	1.0	40.0	16.00
	Min	0.5	0.0	2.0	0.0	0.0	1.0	5.0	0.0	2.0	5.0	0.0	0.0	3.0	3.0	5.0	0.2	2.0	1.69
	P (Min)	70.0	90.0	95.0	70.0	97.0	95.0	99.0	80.0	99.0	70.0	94.0	95.0	50.0	95.0	70.0	99.0	60.0	84.00
	CE	0.6	0.5	5.0	1.0	0.5	1.5	6.0	1.0	2.5	7.0	0.3	1.0	5.0	4.0	7.0	2.0	4.0	2.88
Permit Delays	Max	1.0	5.0	5.0	1.0	1.0	5.0	0.5	3.0	2.0	1.0	7.0	3.0	10.0	5.0	20.0	2.0	11.0	4.85
	P (Max)	70.0	20.0	50.0	10.0	3.0	5.0	3.0	70.0	1.0	10.0	25.0	10.0	50.0	5.0	20.0	20.0	40.0	24.24
	Min	0.8	0.0	2.0	0.0	0.0	1.0	0.0	0.0	0.0	0.0	1.5	0.0	3.0	1.0	1.0	0.0	0.0	0.60
	P (Min)	30.0	80.0	50.0	90.0	97.0	95.0	97.0	30.0	99.0	90.0	75.0	90.0	50.0	95.0	80.0	80.0	60.0	75.76
	CE	0.8	0.4	3.0	0.5	0.5	1.5	0.2	1.0	0.3	0.5	2.0	1.0	5.0	2.0	2.0	0.3	4.0	1.47
Drawing and Approval Delays	Max	0.7	10.0	20.0	5.0	1.0	5.0	20.0	2.0	25.0	10.0	4.0	4.0	10.0	8.0	10.0	9.0	10.0	9.04
	P (Max)	30.0	10.0	5.0	30.0	3.0	5.0	1.0	20.0	1.0	30.0	6.0	5.0	50.0	5.0	30.0	3.0	40.0	16.12
	Min	0.5	0.0	2.0	0.0	0.0	1.0	5.0	0.0	2.0	5.0	0.0	0.0	3.0	3.0	2.0	0.2	2.0	1.51
	P (Min)	70.0	90.0	95.0	70.0	97.0	95.0	99.0	80.0	99.0	70.0	94.0	95.0	50.0	95.0	70.0	97.0	60.0	83.88
	CE	0.6	0.5	3.0	1.0	0.5	1.5	6.0	1.0	2.5	7.0	0.3	1.0	5.0	4.0	4.0	2.0	4.0	2.58

Table 4.9: Shape of Utility Functions

Condition	Utility Function Shape	Risk Attitude
$CE > EV$	Exponential	Risk Aversion
$CE = EV$	Straight	Risk Neutrality
$CE < EV$	Logarithmic	Risk Seeking

Table 4.10: Coordinate Points and Risk Attitude

Risk Factors	Utility Function Shape	Variables	X-coordinate	Y-coordinate
Inadequate Design	Risk Seeking	Max	21.53	0.00
		CE	6.38	0.76
		Min	3.38	1.00
Quality of Drawings and Details	Risk Seeking	Max	10.47	0.00
		CE	4.46	0.68
		Min	3.06	1.00
Unrealistic Construction Schedules	Risk Seeking	Max	12.88	0.00
		CE	6.38	0.73
		Min	4.38	1.00
Vagueness of Scope of Work	Risk Seeking	Max	13.29	0.00
		CE	4.85	0.71
		Min	3.12	1.00
Suppliers Issues	Risk Seeking	Max	13.56	0.00
		CE	4.83	0.66
		Min	2.79	1.00
Subcontractors Issues	Risk Seeking	Max	16.41	0.00
		CE	4.94	0.72
		Min	2.21	1.00
Defective Work	Risk Seeking	Max	6.24	0.00
		CE	2.58	0.66
		Min	0.95	1.00
Damage to Material, Equipment and Facilities	Risk Seeking	Max	16.84	0.00
		CE	4.70	0.79
		Min	2.98	1.00

Table 4.10: Coordinate Points and Risk Attitude (Continued)

Risk Factors	Utility Function Shape	Parameters	X-coordinate	Y-coordinate
Poor Productivity of Manpower and Equipment	Risk Seeking	Max	10.47	0.00
		CE	4.22	0.67
		Min	2.38	1.00
Stringent Inspections by Engineers	Risk Seeking	Max	6.38	0.00
		CE	3.04	0.62
		Min	1.71	1.00
Adverse Weather Conditions	Risk Seeking	Max	2.79	0.00
		CE	1.03	0.79
		Min	0.59	1.00
Subsurface Conditions	Risk Seeking	Max	16.44	0.00
		CE	6.31	0.75
		Min	4.24	1.00
Site Accessibility	Risk Seeking	Max	2.71	0.00
		CE	1.00	0.79
		Min	0.59	1.00
Escalation in Prices	Risk Aversion	Max	15.59	0.00
		CE	4.88	0.80
		Min	2.25	1.00
Currency Fluctuation	Risk Seeking	Max	2.26	0.00
		CE	0.40	0.95
		Min	0.34	1.00
Labor Disputes and Strikes	Risk Seeking	Max	9.69	0.00
		CE	2.88	0.84
		Min	1.69	1.00
Permit Delays	Risk Seeking	Max	4.85	0.00
		CE	1.47	0.76
		Min	0.6	1.00
Drawing and Approval Delays	Risk Seeking	Max	9.04	0.00
		CE	2.58	0.84
		Min	1.51	1.00

Table 4.11: Utility Functions of Risk Factors

Risk Factor	Utility Function
Inadequate Design	$u(x) = -1.1129 \ln(x + 9.0848) + 3.8077$
Quality of Drawings and Details	$u(x) = -0.7397 \ln(x - 0.4737) + 1.7028$
Unrealistic Construction Schedules	$u(x) = -2.7547 \ln(x + 15.0415) + 9.1715$
Vagueness of Scope of Work	$u(x) = -0.7584 \ln(x + 0.5941) + 1.9951$
Suppliers Issues	$u(x) = -0.6579 \ln(x + 0.2247) + 1.7259$
Subcontractors Issues	$u(x) = -1.0537 \ln(x + 6.7587) + 3.3115$
Defective Work	$u(x) = -3.4608 \ln(x + 14.8397) + 10.5495$
Damage to Material, Equipment and Facilities	$u(x) = -0.84 \ln(x + 3.0754) + 2.5127$
Poor Productivity of Manpower and Equipment	$u(x) = -0.999 \ln(x + 2.3207) + 2.5462$
Stringent Inspections by Engineers	$u(x) = -1.179 \ln(x + 1.7873) + 2.4762$
Adverse Weather Conditions	$u(x) = -8.1955 \ln(x + 16.3624) + 24.1966$
Subsurface Conditions	$u(x) = -1.0617 \ln(x + 3.5565) + 3.1804$
Site Accessibility	$u(x) = -4.8944 \ln(x + 8.7622) + 11.942$
Escalation in Prices	$u(x) = 28.5581e^{-0.0027x} - 27.3859$
Currency Fluctuation	$u(x) = -1.0911 \ln(x + 0.9396) + 1.269$
Labor Disputes and Strikes	$u(x) = -5.8559 \ln(x + 41.2706) + 23.0197$
Permit Delays	$u(x) = -2.488 \ln(x + 7.9911) + 6.3511$
Drawing and Approval Delays	$u(x) = -3.6338 \ln(x + 22.2598) + 12.5133$

4.3.2 Development of the Contingency Utility Function

The contingency utility function was used to combine all risk factors, determining the cost contingency percentage corresponding to the project's expected computed utility. The contingency utility function was developed in a manner similar to how the utility function for each risk factor was established. Hence, 17 experts were interviewed and asked to provide the highest, lowest, and most commonly allocated cost contingency percentages, as shown in Table 4.13. The actual contingency percentages represented a precise reflection of the local market when predicting project contingency percentages. The benefit of the most commonly allocated cost contingencies was the insight offered into current practice. The highest and lowest allocated cost contingency percentages were the basis upon which the contingency utility function was developed. The contingency utility function was created based on three coordinate points. The first was the average value of the highest contingency cost percentage and a utility score of 0. The second was the average value of the lowest contingency cost percentage and a utility score of 1. The third was manipulated between the highest and lowest percentages with a corresponding 0.5 utility score in order to observe the effects of the three risk behaviors on the contingency percentage. Therefore, the third point assumed three values. The first value was equal to the expected value, which was computed as the average of the highest and lowest contingency percentages obtained from the experts; it was found to be equal to 6.35. This assumption provided a cost contingency percentage related to a risk-neutral attitude because the expected value was equal to the certainty equivalent (see Table 4.9). Conversely, contractors may assume risk-seeking behavior when the competition is high and they need work, thus assuming a value lower than the expected value calculated for the third point. Finally, contractors may assume risk-averse behavior when expecting a high level of uncertainty and operating at full capacity, presuming a value higher than the expected value for

the third point. The consideration of risk attitudes here provides contractors with the opportunity to decide on which strategy to adopt when estimating project cost contingency, based on specific project conditions. The highest and lowest contingency percentages obtained formed a range within which the final project cost contingency percentage fell. Regarding the development of the contingency utility function, the highest contingency percentage corresponded to a utility score of 0 and the lowest a utility score of 1. Inversion of the scale would have caused the function to be more complicated and problematic to solve. Therefore, for the sake of simplicity, the range from 1.7 to 11 was normalized to a scale of 0 to 100 such that 1.7 and 11 were substituted with 100 and 0, respectively. The values in between preserved their relative distances as in the former range and can be calculated using Equation 4.1 (Stephanie, 2018). Equation 4.2 can be used to convert values from the range of 0 to 100 to the range of 1.7 to 11.

$$x_0 = \frac{(y_2 - y_0)}{(y_2 - y_1)} \times (x_2 - x_1) \quad (4.1)$$

$$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)} \quad (4.2)$$

Where;

x_0 and y_0 : The value of any considered point to be converted

x_1 and x_2 : The lower and upper limits of the new scale

y_1 and y_2 : The lower and upper limits of the original scale

Table 4.14 summarizes the coordinate points upon which the contingency utility function was established. For all risk behaviors, the two coordinate points were 1.7 and 11. For risk-neutral behavior, the third coordinate point was computed as the average of the highest and lowest cost contingency percentages, or 6.35. For risk-seeking behavior, the third coordinate point was computed as the average of the lowest cost contingency percentage and expected value, which

yielded 4. For risk-averse behavior, the third coordinate point was computed as the average of the highest cost contingency percentage and expected value, which yielded 8.7. Table 4.12 presents the coordinate points identified and their corresponding values converted on the new scale. It should be noted that because of the inversion of the scale, a predefined logarithmic equation was employed to represent risk-averse behavior and a predefined exponential equation was used to characterize risk-seeking behavior.

Table 4.12: Scale Conversion

X-coordinate Points	1.7	4	6.35	8.7	11
Corresponding Values on the New Scale	100	75	50	25	0

Table 4.13: Project Cost Contingency Percentages

Parameters	All Respondents																	Average Value
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Largest	7.0	8.0	10.0	3.0	5.0	12.0	10.0	12.0	20.0	5.0	8.0	10.0	15.0	20.0	15.0	12.0	15.0	11
Smallest	3.0	2.0	2.0	0.0	1.0	2.0	3.0	4.0	0.5	2.0	2.0	1.0	3.0	1.0	0.0	1.0	2.0	1.7
Most Common	5.0	5.0	5.0	0.5	2.5	5.0	5.0	8.0	5.0	3.0	4.0	5.0	10.0	3.0	7.0	10.0	10.0	5.5

Table 4.14: Coordinate Points of the Contingency Utility Function

Risk Attitude	Risk Aversion		Risk Neutrality		Risk Seeking	
Coordinate Points	x	y	x	y	x	y
	0	0	0	0	0	0
	25	0.5	50	0.5	75	0.5
	100	1	100	1	100	1

4.4 Model Validation

Two case studies were considered to test the model. The model was applied to local building construction projects in the Eastern Province of Saudi Arabia completed by Grades 1 and 2 general contractors. The fundamental notion was that the risk factors be evaluated according to the engineer's vision while considering their expectation of the impact of the risk factors and probability of occurrence. The evaluation had to be a value between the maximum and minimum financial impacts listed in Table 4.10. Users were asked to evaluate the risk factors based only on the information they had at the beginning of the project, despite the project already being finished. Users of the model were requested to analyze the risk factors according to the impact probability matrix presented by Lavanya and Malarvizhi (2008) at the PMI Global Congress. The authors discussed the risk management process followed for Nokia and Siemens projects. The matrix is shown in Table 4.15. Users were asked to determine the level of risk impact and probability of risk occurrence. The impact of risk was divided into three levels: high, medium, and low. Each level was assigned a quantitative rating of 100, 50, or 10, respectively. For example, when evaluating the “subcontractor issues” risk factor, the user would select a low level of impact if all subcontractors were very familiar with the work and the general contractor had worked with them previously. Similarly, the probability of occurrence of risk was divided into four levels: high, medium high, medium low, and low. Each level represented a range of probabilities; the highest level indicated a probability of risk occurrence of 80% to 100%, the medium high a probability of 60% to 79%, the medium low a probability of 30% to 59%, and the low a probability of 0% to 29%. The outcome of the impact probability matrix was a level of exposure associated with a quantitative score that combined the rating of the impact level and probability of occurrence. The exposure score was computed by multiplying the rating of the impact level by the upper limit of

the probability of occurrence, as shown in the matrix. The score obtained was used as a percentage to determine the value of the evaluation (x_i). By way of illustration, if the exposure score was determined to be 30, the evaluation of the “subcontractor issues” risk factor would have been equal to 6.47. The score was computed using Equation 4.1, a percentage of the range of the maximum and minimum financial impacts obtained in Table 4.10.

$$Evaluation(x_i) = min + exposure\ score \times (max - min) \quad (4.1)$$

Table 4.15: Impact-Probability Matrix

Risk Management Matrix		Likelihood			
		High $80\% \leq x \leq 100\%$	Medium high $60\% \leq x < 80\%$	Medium Low $30\% \leq x < 60\%$	Low $0\% < x < 30\%$
Impact	High (Rating: 100)	Exposure: Very high (Score: 100)	Exposure: Very high (Score: 80)	Exposure: High (Score: 60)	Exposure: Moderate (Score: 30)
	Medium (Rating: 50)	Exposure: High (Score: 50)	Exposure: Moderate (Score: 40)	Exposure: Moderate (Score: 30)	Exposure: Low (Score: 15)
	Low (Rating: 10)	Exposure: Low (Score: 10)	Exposure: Low (Score: 8)	Exposure: Low (Score: 6)	Exposure: Low (Score: 3)

The use of the impact-probability matrix for evaluation enables a more systematic approach than evaluating. First of all, the utility value of the evaluation was found using the obtained equations in table 4.11. Subsequently, the utility value was integrated with the global weight of each risk factor using equation 3.6 to compute the expected utility. The summation of the expected utility values of risk factors forms the project expected utility. The project expected utility was then substituted in the contingency utility function to obtain the cost contingency percentage. In other

words, the contingency utility function was set equal to the project expected utility. The obtained cost contingency percentage was compared with the actual consumption of cost contingency percentage initially allocated by contractors.

4.4.1 Case Study 1:

The first case study is a construction project of psychiatric children's hospital. The project is located in Dhahran, Eastern Province. The project duration is 24 months with a contract value of SR 70,000,000. A decision maker from the construction contractor that built this project was requested to evaluate all the risk factors in the contingency model as he allocates the contingency value for such project during the cost estimation stage. Table 4.16 summarizes the user's input and evaluation of the project under consideration. Table 4.17 shows the constants of the contingency utility function for the three risk behaviors. Different cost contingency percentages were predicted using the developed model for each risk attitude. It can be noted that the cost contingency is high when the user decides to adopt a risk aversion attitude. This can be seen a very logical result due to some potential reasons such as lack of competition which encourages contractors to reduce their willingness to take risk and therefore, increase price. The model predicted a value of 4.37% contingency when the user selects a risk seeking behavior. The actual expenditures from the project contingency account was 4% which is 9.25% below the model estimated contingency while the initial allocated cost contingency was 5%. The selection of risk seeking behavior implies that the competition is high and that the contractor wants to maintain his competitive advantage. This explains why the risk seeking behavior results in the lowest cost contingency. It can be noticed that the least predicted cost contingency still guarantees the contractor with the desired profit margin as it does not cut off any of the contractor's profit margin. In other words, the incurred cost resulted from risk factors, which is 4%, was totally covered by the predicted cost contingency,

which is 4.37%, with a surplus of only 0.37%. Furthermore, if the contractor has little interest in the project due to any reason such as work overextension or when dealing with stakeholders with whom the contractor has previous bad experience, it became logical that the cost contingency be the higher. The detailed calculations through which the cost contingency percentages were obtained are shown below.

Table 4.16: Summary of the User's Input and Calculations

Risk Factors	Global Weight (W_i)	Exposure Score	Evaluation (x_i)	Utility Value ($u(x_i)$)	Expected Utility (EU_a)
Inadequate Design	0.095	80	17.90	0.1404	0.0133
Quality of Drawings and Details	0.0517	60	7.51	0.2600	0.0134
Unrealistic Construction Schedules	0.109	30	6.93	0.6602	0.0720
Vagueness of Scope of Work	0.0573	30	6.17	0.5452	0.0312
Suppliers Issues	0.0555	40	7.10	0.4160	0.0231
Subcontractors Issues	0.065	40	7.89	0.4830	0.0314
Defective Work	0.0646	60	4.12	0.3660	0.0236
Damage to Material, Equipment and Facilities	0.0374	60	11.30	0.2739	0.0102
Poor Productivity of Manpower and Equipment	0.0539	80	8.85	0.1351	0.0073
Stringent Inspections by Engineers	0.0416	40	3.58	0.4955	0.0206

Adverse Weather Conditions	0.0253	30	1.25	0.6870	0.0174
Subsurface Conditions	0.0585	80	14.00	0.1382	0.0081
Site Accessibility	0.0241	15	0.91	0.8364	0.0202
Escalation in Prices	0.098	15	4.25	0.8463	0.0829
Currency Fluctuation	0.0255	15	0.63	0.7785	0.0199
Labor Disputes and Strikes	0.0409	30	4.09	0.6815	0.0279
Permit Delays	0.0392	100	4.85	0.0001	0.0000
Drawing and Approval Delays	0.0577	50	5.28	0.4656	0.0269
Project Expected Utility (EU_p)					0.449

Table 4.17: Summary of the Developed Contingency Utility Functions and Results

Risk Attitude	Risk Aversion	Risk Neutrality	Risk Seeking
Utility Function Shape	Logarithmic	Linear	Exponential
Certainty Equivalent	$8.7 \equiv 25$	$6.35 \equiv 50$	$4 \equiv 75$
Constant (a)	0.4551	0.01	0.0957
Constant (b)	12.5	0	0.0244
Constant (c)	-1.1495	0	-0.0957
Cost Contingency Percentage	$21.03 \equiv 9.04\%$	$44.9 \equiv 6.82\%$	$71.27 \equiv 4.37\%$

As mentioned earlier in section 4.4, the calculated project expected utility was substituted in the contingency utility functions with the above constant to obtain the cost contingency percentage. In other words, the contingency utility function was set equal to the project expected utility and solved for the value of x.

$u(x) = a \times \ln(x + b) + c$	$u(x) = ax$	$u(x) = ae^{bx} + c$
$0.4551 \times \ln(x + 12.5) - 1.1495 = 0.449$	$0.01 \times x = 0.449$	$0.0957 \times e^{0.0244x} - 0.0957 = 0.449$
$x = e^{3.5} - 12.5$	$x = \frac{0.449}{0.01}$	$x = \frac{\ln(5.7)}{0.0244}$
$x = 21.03$	$x = 44.90$	$x = 71.27$

The obtained values of x above are on the converted scale and need to be converted back to the original scale between 1.7 and 11. Those calculations are shown below.

$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$	$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$	$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$
$y_0 = 11 - \frac{21.03(11 - 1.7)}{(100 - 0)}$	$y_0 = 11 - \frac{44.9(11 - 1.7)}{(100 - 0)}$	$y_0 = 11 - \frac{71.27(11 - 1.7)}{(100 - 0)}$
$x = 9.04\%$	$x = 6.82\%$	$x = 4.37\%$

4.4.2 Case Study 2:

The second case study was a construction project for an administration building consisting of four stories and extended across an area of 4,000m². The project was located in Dhahran, Eastern Province. The project's duration was 48 months and had a contract value of SR 86,000,000. Table 4.18 summarizes the users' input and evaluation of the project. Table 4.19 shows the constants of the contingency utility function for the three risk behaviors. Different cost contingency percentages were predicted using the model, corresponding to each risk attitude. It should be noted that the cost contingency was high when the user decided to adopt a risk-averse attitude. This is a very logical result due to reasons such as a potential lack of competition that might encourage the contractor to resist risk and therefore increase price. The model predicted a value of 3.27% contingency when the user selected risk-seeking behavior. The actual expenditure from the project contingency account was 3%, which was 9% below the model's estimated contingency; the initial allocated cost contingency was 7%. However, the contractor was still awarded the bid based on the 7% and made an extra unexpected profit of 4%. The optimum contingency cost is the value that simultaneously ensures winning the bid and maximizing profit. Thus, the choice of risk attitude is left to the user based on the status of the project in terms of competition, working capacity of the contracting firm, past experience with the owner, and so on. In this case, if the user selected a risk-averse attitude, the model would have predicted a contingency value of 7.5%. Finally, a risk-seeking strategy would have provided the contractor with the least possible contingency value to cover expected risks. The selection of risk-seeking behavior implies that competition is high and the contractor wants to maintain a competitive advantage. This explains why the risk-seeking behavior resulted in the lowest cost contingency. The least predicted cost contingency still guaranteed the contractor the desired profit margin. In other words, the 3% cost

incurred from risk factors was totally covered by the predicted cost contingency of 3.27%, with a surplus of only 0.27%. If the contractor has little interest in the project due to reasons such as work overextension or when dealing with stakeholders with whom the contractor has had previous bad experiences, it is logical that the cost contingency be higher. The detailed calculations by which the cost contingency percentages were obtained are shown below.

Table 4.18: Summary of the User's Input and Calculations

Risk Factors	Global Weight (W_i)	Exposure Score	Evaluation (x_i)	Utility Value ($u(x_i)$)	Expected Utility (EU_a)
Inadequate Design	0.095	80	17.90	0.1404	0.0133
Quality of Drawings and Details	0.0517	40	6.02	0.4356	0.0225
Unrealistic Construction Schedules	0.109	30	6.93	0.6602	0.0720
Vagueness of Scope of Work	0.0573	30	6.17	0.5453	0.0312
Suppliers Issues	0.0555	60	9.25	0.2465	0.0137
Subcontractors Issues	0.065	60	10.73	0.2963	0.0193
Defective Work	0.0646	30	2.54	0.6679	0.0431
Damage to Material, Equipment and Facilities	0.0374	3	3.40	0.9436	0.0353
Poor Productivity of Manpower and Equipment	0.0539	30	4.81	0.5838	0.0315
Stringent Inspections by Engineers	0.0416	30	3.11	0.6031	0.0251

Adverse Weather Conditions	0.0253	30	1.25	0.6870	0.0174
Subsurface Conditions	0.0585	3	4.61	0.9508	0.0556
Site Accessibility	0.0241	8	0.76	0.9119	0.0220
Escalation in Prices	0.098	15	4.25	0.8464	0.0829
Currency Fluctuation	0.0255	15	0.63	0.7771	0.0198
Labor Disputes and Strikes	0.0409	3	1.93	0.9672	0.0396
Permit Delays	0.0392	8	0.94	0.9035	0.0354
Drawing and Approval Delays	0.0577	8	2.11	0.9093	0.0525
Project Expected Utility (EU_p)					0.6322

Table 4.19: Summary of the Developed Contingency Utility Functions and Results

Risk Attitude	Risk Aversion	Risk Neutrality	Risk Seeking
Utility Function Shape	Logarithmic	Linear	Exponential
Certainty Equivalent	$8.7 \equiv 25$	$6.35 \equiv 50$	$4 \equiv 75$
Constant (a)	0.4551	0.01	0.0957
Constant (b)	12.5	0	0.0244
Constant (c)	-1.1495	0	-0.0957
Cost Contingency Percentage	$37.65 \equiv 7.5\%$	$63.22 \equiv 5.12\%$	$83.15 \equiv 3.27\%$

As mentioned earlier in section 4.4, the calculated project expected utility was substituted in the contingency utility functions with the above constant to obtain the cost contingency percentage. In other words, the contingency utility function was set equal to the project expected utility and solved for the value of x.

$u(x) = a \times \ln(x + b) + c$	$u(x) = ax$	$u(x) = ae^{bx} + c$
$0.4551 \times \ln(x + 12.5) - 1.1495 = 0.6322$	$0.01 \times x = 0.6322$	$0.0957 \times e^{0.0244x} - 0.0957 = 0.6322$
$x = e^{3.9} - 12.5$	$x = \frac{0.6322}{0.01}$	$x = \frac{\ln(7.61)}{0.0244}$
$x = 37.65$	$x = 63.22$	$x = 83.15$

The obtained values of x above are on the converted scale and need to be converted back to the original scale between 1.7 and 11. Those calculations are shown below.

$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$	$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$	$y_0 = y_2 - \frac{x_0(y_2 - y_1)}{(x_2 - x_1)}$
$y_0 = 11 - \frac{37.65(11 - 1.7)}{(100 - 0)}$	$y_0 = 11 - \frac{63.22(11 - 1.7)}{(100 - 0)}$	$y_0 = 11 - \frac{83.15(11 - 1.7)}{(100 - 0)}$
$x = 7.50\%$	$x = 5.12\%$	$x = 3.27\%$

4.5 Computer Implementation

4.5.1 Overview of the Computer Application

The proposed model was coded using Java programming language through NetBeans IDE (Integrated Development Environment). The use of Java provided a very powerful platform to carry out the complex computations in a short time. In addition, the developed software offered a user-friendly interface for building contracting firms to predict the contingency value. The developed code is shown in Appendix C. The prototype consists of two dialog windows such that users are requested to evaluate 18 risk factors in terms of the expected impact on project cost and the expected probability of occurrence of risk factors according to the Impact Probability Matrix as shown in figures 5.1 and 5.2. Furthermore, it requests users to select the desired risk attitude depending on the nature and objective of project. Users may select a risk aversion attitude if lack of competition exists or when expecting a high level of uncertainty, and may select a risk seeking attitude when expecting a high level of competition. The selection of risk attitudes depends, in the first place, on the objective of contractors from bidding on any particular project.

Risk Factor	Impact	Probability
1 Inadequate Design	High	Medium High
2 Quality of Drawings and Details	High	Medium Low
3 Unrealistic Construction Schedules	Medium	Medium Low
4 Vagueness of Scope of Work	Medium	Medium Low
5 Suppliers Issues	Medium	Medium High
6 Subcontractors Issues	Medium	Medium High
7 Defective Work	High	Medium Low
8 Damage to Material, Equipment and Facilities	High	Medium Low
9 Poor Productivity of Manpower and Equipment	High	Medium High
10 Stringent Inspections by Engineers	Medium	Medium High
11 Adverse Weather Conditions	Medium	Medium Low
12 Subsurface Conditions	High	Medium High
13 Site Accessibility	Medium	Low
14 Escalation in Prices	Medium	Low
15 Currency Fluctuation	Medium	Low
16 Labor Disputes and Strikes	Medium	Medium Low
17 Permit Delays	High	High
18 Drawing and Approval Delays	Medium	High

Figure 5.1: Dialog Window of Risk Factors Evaluation

Select the Most Appropriate Strategy

☐ Risk Seeking

☒ Risk Neutrality

☐ Risk Aversion

Calculate Cost Value

Output (X)

4.37%

6.82%

9.04%

Figure 5.2: Dialog Window of Selecting Risk Attitude

CHAPTER FIVE

SUMMARY OF THE STUDY, CONCLUSION AND RECOMMENDATIONS

This chapter firstly aims to present the findings of this research. In view of the results, it furthermore aims to provide recommendations to either enhance the accuracy of the developed model or provide general instructions on the issue of risk management in construction projects. The last section in this chapter endeavors to propose various thoughts for future studies in this field.

5.1 Summary of the Study

The adequate management of risk is vital, especially in a very dynamic business environment. For decades the strategy of cost contingency allocation has been widely adopted to address risk and uncertainty in construction projects. The prediction of cost contingency percentages should pursue the optimum percentage that balances business competitiveness with the achievement of project objectives. The main goal of this study was to develop a cost contingency prediction model that would enable local contracting firms to systematically estimate cost contingency within the framework of risk management while under unit price/lump sum contracts within the design-bid-build delivery system. This objective mandated the identification and determination of the most significant risk factors affecting the allocation of cost contingency to building construction projects in the Saudi Arabian construction industry from the contractors' point of view. An extensive literature review was performed to identify risk factors that influence decisions regarding the amount of cost contingency. The UCPW was closely examined to extrapolate those risk factors where the responsibility falls upon the contractor and determine the most common risk treatment strategies practiced for each. A structured questionnaire was designed to conduct interviews with

decision makers and experts in the field of bid pricing and cost estimation in Grades 1 and 2 companies located in the Eastern Province of Saudi Arabia. The data collected were input into the AHP process, which provided importance scores for each risk factor. MAUT was used to combine and transfer all risk factors into contingency utility functions. These utility functions were then established using MATLAB software and subsequently coded via the Java programming language to develop a user-friendly interface prototype software. The model was validated using two case studies and integrating the outcomes of the two techniques.

5.2 Findings

5.2.1 Major Findings

It was possible to develop a reliable and valid computer-based model based on AHP and MAUT that accurately predicts the contingency values for building projects within the framework of risk management and under unit price/lump sum contracts within the design-bid-build delivery systems. The proposed model predicts the contingency value required to keep contracting firms safe from threats to profit. Different risk attitudes can be taken into account, enabling building contractors to predict the most appropriate contingency value depending on the nature and objective of their project.

5.2.2 Minor Findings

- “Unrealistic construction schedules” comprised the most significant risk factor with the greatest impact on the size of the contingency percentage, followed by “escalation in prices” and “inadequate design.” The least serious risk factors as perceived by contracting firms were “site accessibility,” followed by “adverse weather conditions,” and “currency fluctuation.”

- Bidding-related risks were the most influential on project contingency, followed by risks related to construction, the environment, legal entanglements, and economics.
- The most influential risk factors within the bidding category were “unrealistic construction schedules” and “inadequate design.”
- The most influential risk factors within the construction category were “subcontractor issues” and “supplier issues.”
- The most influential risk factors within the environment category were “subsurface conditions” and “adverse weather conditions.”
- The most influential risk factors within the legal category were “drawing and approval delays” and “labor disputes and strikes.”
- The most influential risk factors within the economic category were “escalation in prices” and “currency fluctuation.”
- In accordance with the UCPW, it was possible to investigate and determine the most prevalent risk treatment strategies practiced to address risk. As per the UCPW, the strategies adopted were confined to risk transfer and retention. Risk was either transferred to the owner or an insurance company. Conversely, risk retention implied the allocation of a contingency value.

These were as follows:

- Transfer to owner
 - Payment delay
 - Change in scope
 - War and civil disorder
 - Change in law or regulation
 - Escalation in price

- Currency fluctuation
 - Accuracy of quantity estimation
- Transfer to insurance company
 - Labor injury or accident
 - Security and theft
 - Natural disaster
- Retained by contractor
 - Unrealistic construction schedule
 - Vagueness of work scope
 - Inadequate design
 - Quality of drawings and details
 - Defective work
 - Poor productivity of manpower and equipment
 - Damage to material, equipment, and facilities
 - Subcontractor issues
 - Supplier issues
 - Adverse weather conditions
 - Subsurface conditions
 - Site accessibility
 - Stringent inspections by engineers
- Although it is stipulated in the UCPW that the client is the party who holds responsibility for escalations in prices and currency fluctuation, there was a consensus of opinion that the contract is rarely committed and therefore these risks are shouldered by contractors. The same

consensus of opinion was found regarding drawing and approval delays, labor disputes and strikes, and permit postponements.

- This study found that contractors exhibit a risk-averse attitude when operating at full capacity or expecting a high level of uncertainty, resulting in high cost contingency percentages. This can also be seen in contractors' lack of enthusiasm for work.
- Contractors exhibit a risk-seeking attitude when the competition is intense and they are eager for work, resulting in lower cost contingency percentages.
- The general rule is that contractors perceive risk factors over which they have little control as more significant than the converse.
- It was also found that the average value of the most commonly allocated cost contingency was 5.5%.

5.3 Conclusion

This research established a solid reference and basis for decision makers and risk management practitioners. This study provides a powerful tool for systematically predicting the cost of risk for building projects in Saudi Arabia to an estimated accuracy of 10%. This will enhance current management and estimation practices. This study also offers a real-world description of the issues and risks that building contracting firms face in Saudi Arabia and how such factors impact overall bids.

5.4 Recommendations

The model provides a powerful tool that will enable contracting firms to dispense with other more arbitrary approaches to resolving this type of issue. Contractors are advised to take advantage of the model to enhance their competitive advantage and maintain fair profit margins. The model

proved to be accurate in terms of predicting cost contingency. Nevertheless, allocation of cost contingency percentages does not relieve contracting firms from managing risk properly by reducing the probability of occurrence and impact of the consequences. The risk factors included in this study were those in which the responsibility falls upon the contractor, as per the UCPW. However, this may not always be the case; clients may not always be committed to their obligations and contract conditions. Sources of risk might result from a client's breach of contract. Such cases would be beyond the intent of the model and require different mitigation strategies. Thus, contractors are strongly advised to effectively administer their contracts during the bidding phase by highlighting expected items of conflict, and in the construction phase by keeping a record of claims.

The model contributes significantly to the overall industry as it augments projects' expected outcomes and ensures more efficient utilization of government and private resources. The accuracy of the model can be further enhanced in two main ways. The first is by using actual empirical data to define the maximum and minimum financial impacts rather than obtaining them from experts. The second would be through establishing the utility functions via more advanced mathematical approaches.

5.5 Future Studies

Future research could cover other regions in Saudi Arabia, including the Riyadh and Makkah Provinces. The prioritization and ranking of risk factors would likely differ if such a study was conducted. On a larger scale, similar research should be conducted to assist local contracting firms with predicting cost contingency when bidding in international markets. Future studies might also focus on the client's point of view to assist in establishing government budgets and determining the required funding for proposed projects. In this context, the identification of risk factors should

also be carried out from the owner's point of view. Developing a cost contingency prediction model appropriate for various International Federation of Consulting Engineers contracts represents another promising direction for a future extension of this research. The interest in this research was the unit price/lump sum contract under the design-bid-build project delivery system; future studies could, for instance, focus on lump-sum or cost-plus contracts under any type of project delivery system, including design-build or multiple prime contracts. Lastly, future work might explore different project types such as highways, industrial works, and heavy construction.

REFERENCES

- [1] A Risk Management Standard (2002). The Institute of Risk Management.
- [2] AACE International (2019). Cost Engineering Terminology. Recommended Practice 10S-90, Morgantown, W.Va.
- [3] Abo Abdo, S. (2015). Factors Affecting Contingency Amount in Bidding for Large Construction Projects: Contractors Perspective. King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
- [4] About the Eastern Region (2019). Saudi Arabia: Asharqia Chamber.
- [5] Adams, J. (2014). Managing Risk: Framing your Problems, BoeringerIngelheim Alumni Seminar, SchlossGracht, and Cologne 9-11.
- [6] Ahmad, I. (1992). Contingency Allocation: A Computer-aided Approach. American Association of Cost Engineers. Transactions of the American Association of Cost Engineers, 1, 5.
- [7] Ahuja, H. N., Dozzi, S. P., and Abourizk, S. M. (1994). Project Management: Techniques in Planning and Controlling Construction Projects. New York: Wiley.
- [8] Akadiri, P. O., Olomolaiye, P. O., and Chinyio, E. A. (2013). Multi-Criteria Evaluation Model for the Selection of Sustainable Materials for Building Projects. Automation in Construction, 30, 113–125.
- [9] Akinradewo, O. F., and Awodele, O. A. (2016). Evaluation of the Adequacy and Utilization of Contingency Fund in Building Projects in Nigeria. OALib, 03(09), 1–12.
- [10] Akintoye, A. S., and MacLeod, M. J. (1997). Risk Analysis and Management in Construction. International Journal of Project Management, 15(1), 31–38.

- [11] Alshibani, A. (2008). Optimizing and Controlling Earthmoving Operations Using Spatial Technologies. Concordia University, Montreal, Quebec, Canada.
- [12] Al-Bahar, J. F., and Crandall, K. C. (1990). Systematic Risk Management Approach for Construction Projects. *Journal of Construction Engineering and Management*, 116(3), 533–546.
- [13] Amoudi, O., Alobeiad, A., and Hamadeh, M. (2015). Identification and Allocation of Risks in Construction Projects from Owner Perspective in Syria. *Journal of King Abdulaziz University - Engineering Sciences*, 87–111.
- [14] Aven, T. (2011). *Quantitative Risk Assessment: The Scientific Platform*. Cambridge: Cambridge University Press.
- [15] Baccarini, David (2004). Accuracy in Estimating Project Cost Construction Contingency - A Statistical Analysis, COBRA 2004: RICS International Construction Conference, Responding to Change, 7-8 September, 2004. Headingley Stadium, U.K.
- [16] Bakhshi, P., and Touran, A. (2014). An Overview of Budget Contingency Calculation Methods in Construction Industry. *Procedia Engineering*, 85, 52–60.
- [17] Ballesteros-Pérez, P., Smith, S. T., Lloyd-Papworth, J. G., and Cooke, P. (2018). Incorporating the Effect of Weather in Construction Scheduling and Management with Sine Wave Curves: Application in the United Kingdom. *Construction Management and Economics*, 36(12), 666–682.
- [18] Bello, Wasiu and Odusami, Koleola (2008). The Practice of Contingency Allocation in Construction Projects in Nigeria, COBRA 2008: Construction and Building Research Conference of the Royal Institution of Chartered Surveyors.

- [19] Burroughs, S., and Juntima, G. (2004). Exploring Techniques for Contingency Setting. AACE International Transactions.
- [20] Chen, D., and Hartman, F. (2000). A Neural Network Approach to Risk Assessment and Contingency Allocation. AACE International Transactions.
- [21] Chiang, Y.-H. (2009). Subcontracting and its Ramifications: A Survey of the Building Industry in Hong Kong. *International Journal of Project Management*, 27(1), 80–88.
- [22] Chitkara, K. (2004). *Construction Project Management, Planning, Scheduling, and Controlling*. Tata McGraw Hill, 4th edition, India.
- [23] Contractor Classification Agency (2019). Saudi Arabia: Ministry of Municipal and Rural Affairs.
- [24] Cook, Jason (2006). Estimating Required Contingency Funds for Construction Projects Using Multiple Linear Regression. 65.
- [25] Dalal, J., Mohapatra, P. and Mitra, G. (2010). Prioritization of Rural Roads: AHP in Group Decision. *Engineering, Construction and Architectural Management*. 17. 135-158.
- [26] Darko A., Chan A., Ameyaw E., Owusu E., Pärn E. and Edwards, D. (2019). Review of Application of Analytic Hierarchy Process (AHP) in Construction, *International Journal of Construction Management*, 19:5, 436-452.
- [27] Dozzi, S., AbouRizk, S., and Schroeder, S. (1996). Utility-Theory Model for Bid Markup Decisions. *Journal of Construction Engineering and Management*, 122(2).
- [28] El-Sayegh, S. M. (2008). Risk Assessment and Allocation in the UAE Construction Industry. *International Journal of Project Management*, 26(4), 431–438.

- [29] EL-Touny, A., Ibrahim, A., and Amer, M. (2014). Estimating Cost Contingency for Highway Construction Projects Using Analytic Hierarchy Processes. *International Journal of Computer Science Issues*, 11(6).
- [30] Enshassi, A., Mohamed, S., and Mosa, J. (2008). Risk Management in Building Projects in Palestine: Contractors' Perspective. *Emirates Journal for Engineering Research*. 13.
- [31] Filip, Fl. Gh. (2002). *Decizie Asistată de calculator*. București: Editura Tehnică.
- [32] Fisk, E. R., and Reynolds, W. D. (2010). *Construction Project Administration*. Boston: Pearson.
- [33] Franek, J., and Kresta, A. (2014). Judgment Scales and Consistency Measure in AHP. *Procedia Economics and Finance*, 12, 164–173.
- [34] Ganiyu, A. (2010). *Subcontracting Strategy in Industrial Projects*. King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
- [35] Ghosh, S., and Jintanapakanont, 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(8), 633–643.
- [36] Gładysz, B., and Kluczek, A. (2019). An Indicators Framework for Sustainability Assessment of RFID Systems in Manufacturing. *Lecture Notes in Mechanical Engineering Advances in Manufacturing II*, 274–286.
- [37] Goh, C., and Abdul-Rahman, H. (2013). The Identification and Management of Major Risks in the Malaysian Construction Industry. *Journal of Construction in Developing Countries*, 18(1), 19–32.

- [38] Goepel, K.D. (2018). Implementation of an Online Software Tool for the Analytic Hierarchy Process (AHP-OS). *International Journal of the Analytic Hierarchy Process*, 10 (3), 469-487.
- [39] Goepel, K. D. (2019, September 15). AHP – High Consistency Ratio. Retrieved from <https://bpmsg.com/ahp-high-consistency-ratio/>
- [40] Han, S. H., Diekmann, J. E., and Ock, J. H. (2005). Contractor's Risk Attitudes in the Selection of International Construction Projects. *Journal of Construction Engineering and Management*, 131(3), 283–292.
- [41] Iqbal, S., Choudhry, R., Holschemacher, K., Ali, A., and Tamošaitienė, J. (2015). Risk Management in Construction Projects. *Technological and Economic Development of Economy*, 21(1), 65–78.
- [42] Jannadi, O. A. (2008). Risks Associated with Trenching Works in Saudi Arabia. *Building and Environment*, 43(5), 776–781.
- [43] Jarkas, A. M., and Haupt, T. C. (2015). Major Construction Risk Factors Considered by General Contractors in Qatar. *Journal of Engineering, Design and Technology*, 13(1), 165–194.
- [44] Jayasena, H. (2005). Bid-Price Variability in the Sri Lankan Construction Industry. National University of Singapore, Singapore.
- [45] Jayasudha, K., and Vidivelli, B. (2016). Analysis of Major Risks in Construction Projects. *Journal of Engineering and Applied Sciences*, 11(11).
- [46] Dey, P. (2002). Project Risk Management: A Combined Analytic Hierarchy Process and Decision Tree Approach. *Cost Engineering*, 44(3).

- [47] Kangari, R. (1995). Risk Management Perceptions and Trends of U.S. Construction. *Journal of Construction Engineering and Management*, 121(4), 422–429.
- [48] Keeney, R. L., and Raiffa, H. (1975). *Decision Analysis with Multiple Conflicting Objectives Preference and Value Tradeoffs*.
- [49] Khaliluddin, M. (2010). *Contract Risk Allocation in Saudi Arabian Construction Projects*. King Fahd University of Petroleum and Minerals, Dhahran, Saudi Arabia.
- [50] Kish, L. (1995). *Survey Sampling*. New York: John Wiley and Sons.
- [51] Larson, E., and Gray, C. (2011). *Project Management. The Managerial Process*. (5th Ed.). New York, NY: McGraw-Hill/Irwin.
- [52] Laryea, S., and Hughes, W. (2008). How Contractors Price Risk in Bids: Theory and Practice. *Construction Management and Economics*, 26(9), 911–924.
- [53] Laryea, S., Badu, E. and Dontwi, I. K. (2007). The Price of Risk in Construction Projects: Contingency Approximation Model. 5th International Conference on Construction Project Management / 2nd International Conference on Construction Engineering and Management, 1-2 March, Nanyang Technological University, Singapore.
- [54] Lavanya, N., and Malarvizhi, T. (2008). *Risk Analysis and Management: A Vital Key to Effective Project Management*. Paper presented at PMI® Global Congress 2008—Asia Pacific, Sydney, New South Wales, Australia. Newtown Square, PA: Project Management Institute.
- [55] Lifson, M. W., & Shaifer, E. F. (1982). *Decision and risk analysis for construction management*. New York: Wiley.
- [56] Lixăndroiu, D. (2015). A Model for Determining the Utility Function Using Fuzzy Numbers. *Bulletin of the Transilvania University of Braşov*, 8(57).

- [57] Loch, C., Meyer, A. and Pich, M. T. (2006). *Managing the Unknown: A New Approach to Project Risk Management*. Hoboken, NJ: Wiley.
- [58] Loosemore, M., Raftery, J., and Reilly, C. (2006). *Risk Management in Projects*. London: Taylor and Francis.
- [59] Mak, S., Wong, J., and Picken, D. (1998). The Effect on Contingency Allowances of Using Risk Analysis in Capital Cost Estimating: A Hong Kong Case Study. *Construction Management and Economics*, 16(6), 615–619.
- [60] Marzouk, M., and Moselhi, O. (2003). A Decision Support Tool for Construction Bidding. *Construction Innovation*, 3(2), 111–124.
- [61] Mesaros, P., Mandicak, T., Behunova, A., Smetankova, J., and Krajnikova, K. (2020). Impact of BIM Technology on Development of Digital and Managerial Competencies of Project Managers in Construction Industry. 4th EAI International Conference on Management of Manufacturing Systems EAI/Springer Innovations in Communication and Computing, 175–184.
- [62] Mills, A., Love, P. E., and Williams, P. (2009). Defect Costs in Residential Construction. *Journal of Construction Engineering and Management*, 135(1), 12–16.
- [63] Moffett, M. L., and Suarez-Almazor, M. E. (2005). Prospect Theory in the Valuation of Health. *Expert Review of Pharmacoeconomics and Outcomes Research*, 5(4), 499–505.
- [64] Mohamed, D., Srour, F., Tabra, W., and Zayed, T. (2009). A Prediction Model for Construction Project Time Contingency. *Construction Research Congress 2009*.
- [65] Moselhi, O. (1997). Risk Assessment and Contingency Estimating. *AACE International Transactions*, 90-95.

- [66] Nassar, K. (2002). Cost Contingency Analysis for Construction Projects Using Spreadsheets. 44. 26-31.
- [67] Nelson, D. (2013). What is Constructive about Acceleration? Hill International, Inc.
- [68] Nepal, M. P., Park, M., and Son, B. (2006). Effects of Schedule Pressure on Construction Performance. *Journal of Construction Engineering and Management*, 132(2), 182–188.
- [69] Neufville, R. D., and King, D. (1991). Risk and Need-for-Work Premiums in Contractor Bidding. *Journal of Construction Engineering and Management*, 117(4), 659–673.
- [70] Nieto-Morote, A., and Ruz-Vila, F. (2011). A Fuzzy Approach to Construction Project Risk Assessment. *International Journal of Project Management*, 29(2), 220–231.
- [71] Olsson, R. (2007). In Search of Opportunity Management: Is the Risk Management Process Enough? *International Journal of Project Management*, 25(8), 745–752.
- [72] Polat, G. (2012). Ann Approach to Determine Cost Contingency in International Construction Projects. *Journal of Applied Management and Investments*, 1(2), 195–201.
- [73] Polat, G., and Bingol, B.N. (2011). Using Fuzzy Logic Approach for Determining Cost Contingency in International Construction Projects. *Second World Conference on Information Technology*, 23-30 November, Antalya, Turkey.
- [74] Political, Economic and Social Development (2016). Saudi Arabia: Ministry of Foreign Affairs.
- [75] Public Works Construction Contracts (2007). United Kingdom: Department of Finance.
- [76] Raftery, J. (2003). *Risk Analysis in Project Management*. London: E and FN Spon.
- [77] Rajendhran, N., and Sundar, P. (2011). *A Study of Risk Assessment and Management in Construction*. PSG College of Technology, Coimbatore, India.

- [78] Rehacek, P. (2017). Risk Management in Construction Projects. *Journal of Engineering and Applied Sciences*, 12(20), 5347–5352.
- [79] Rey, S. (2001). Mathematical Models in Geography. *International Encyclopedia of the Social and Behavioral Sciences*, 9393–9399.
- [80] Saaty, T. L. (1980). *The Analytic Hierarchy Process*. New York.
- [81] Saaty, T. L. (2000). *Fundamentals of Decision Making and Priority Theory with the Analytic Hierarchy Process*. Pittsburgh: RWS Publications.
- [82] Saunders, F. (2016). Differentiating between Risk and Uncertainty in the Project Management Literature. The University of Manchester.
- [83] Schmidt, K., Aumann, I., Hollander, I., Damm, K., and Schulenburg, J.-M. G. V. D. (2015). Applying the Analytic Hierarchy Process in Healthcare Research: A Systematic Literature Review and Evaluation of Reporting. *BMC Medical Informatics and Decision Making*, 15(1).
- [84] Shash, A. A. (1998). Bidding Practices of Subcontractors in Colorado. *Journal of Construction Engineering and Management*, 124(3), 219–225.
- [85] Slovic, P., Fischhoff, B., and Lichtenstein, S. (1984). Behavioral Decision Theory Perspectives on Risk and Safety. *Acta Psychologica*, 56(1-3), 183–203.
- [86] Smith, G. R., and Bohn, C. M. (1999). Small to Medium Contractor Contingency and Assumption of Risk. *Journal of Construction Engineering and Management*, 125(2), 101–108.
- [87] Snow, J. (2010). *Developing a Risk Management Plan*. Boston: The New Partners Initiative Technical Assistance.
- [88] Sonmez, R., Ergin, A., and Birgonul, M. T. (2007). Quantitative Methodology for Determination of Cost Contingency in International Projects. *Journal of Management in Engineering*, 23(1), 35–39.

- [89] Šotić, A., and Rajić, R. (2015). The Review of the Definition of Risk. *Online Journal of Applied Knowledge Management*, 3(3).
- [90] Stephanie (2018). Normalized Data / Normalization. Retrieved from <https://www.statisticshowto.datasciencecentral.com/normalized/>
- [91] Survey of Construction Activity (2018). Saudi Arabia: General Authority for Statistics.
- [92] The Unified Contract for Public Works (2013). Saudi Arabia: Ministry of Finance.
- [93] Wang, J., and Yuan, H. (2011). Factors Affecting Contractors' Risk Attitudes in Construction Projects: Case Study from China. *International Journal of Project Management*, 29(2), 209–219.
- [94] Wiguna, P., and Scott, S. (2005). Nature of the Critical Risk Factors Affecting Project Performance in Indonesian Building Contracts. *Association of Researchers in Construction Management*, 1, 225–235.
- [95] Willows, R.I. and Connell, R.K. (2003). Climate Adaptation: Risk, Uncertainty and Decision-making. UKCIP Technical Report, Oxford.
- [96] Winch, G. (2012). *Managing Construction Projects an Information Processing Approach*. Chichester, U.K.: Wiley.
- [97] Zou, P. X., Zhang, G., and Wang, J. (2007). Understanding the Key Risks in Construction Projects in China. *International Journal of Project Management*, 25(6), 601–614.

APPENDIX A

Research Survey

Ministry of Education
King Fahd University of Petroleum and Minerals
College of Environmental Design
Construction Engineering and Management Department



Dear Gentlemen,

I, Mohammad Al Salti, a graduate student at King Fahd University of Petroleum and Minerals, Dhahran, KSA, under the supervision of the experienced Professor, Dr. Ali Shash is conducting a research on the topic: **DEVELOPMENT OF AN INTEGRATED MATHEMATICAL MODEL BASED ON AHP AND MAUT TECHNIQUES FOR ALLOCATING CONTINGENCY VALUE FOR BUILDING PROJECTS IN SAUDI ARABIA.**

This research primarily aims to develop a model to predict the amount of contingency cost to be allocated by local contractors to domestic construction projects in the Kingdom of Saudi Arabia under the assumption of adopting a design-bid-build project delivery system with a unit price/lump sum contract through integrating the Analytical Hierarchy Process and Multi Attribute Utility Theory (MAUT) techniques.

The required data to perform this research is collected through two structured surveys. The first survey is the AHP which aims to provide importance scores for each identified risk factor. The second survey is the MAUT which aims to combine and transfer all risk factors into a contingency utility function. At the end, the contingency utility function will enable contractors to estimate the required amount of contingency cost.

Your valuable participation in this research would definitely contribute positively to the overall industry including your organization. Your precious time and effort are greatly appreciated. The provided data shall be treated with a high level of confidentiality and shall only be used for educational and research purposes.

Yours faithfully,

Mohammad Al Salti

Graduate Student

E-mail: g201803380@kfupm.edu.sa

Mobile Number: +966 554421331

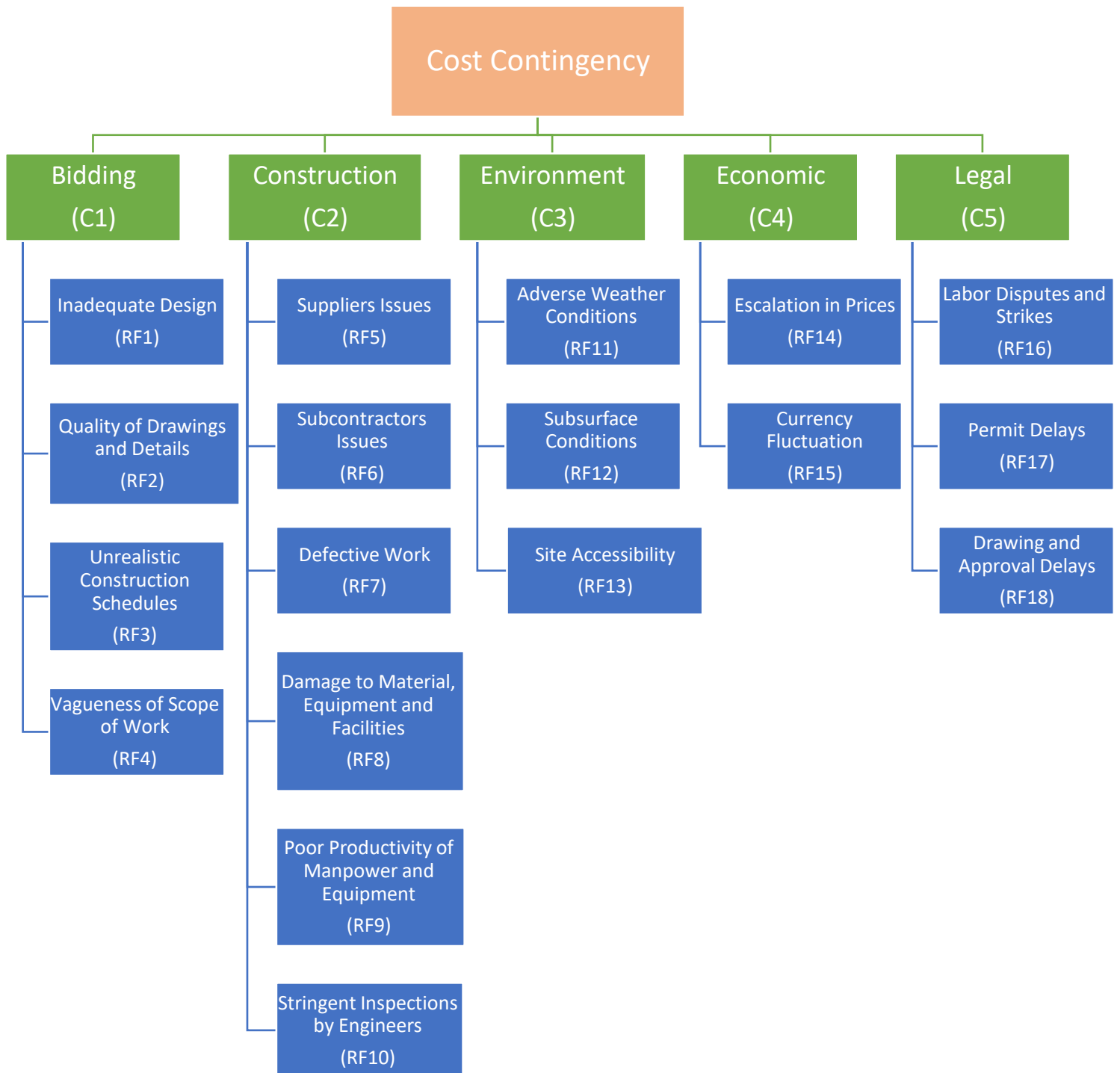
Dr. Ali A. Shash

Professor

E-mail: aashash@kfupm.edu.sa

Office: +966 13 8607898

The following figure shows 18 different risk factors classified under 5 categories namely, bidding, construction, environmental, legal, and economic.



Section (1): General Information

1. Respondent Information:

Name	
Organization Name	
Organization Address	
E-mail Address	
Mobile Number	

2. Job Position:

- a. Project Manager []
- b. Construction Manager []
- c. Cost Estimator []
- d. Other, Please Specify _____ []

3. Field of Study:

- a. Civil []
- b. Mechanical []
- c. Electrical []
- d. Other, Please Specify _____ []

4. Total years of experience:

- a. Less than 5 years []
- b. 5 to 10 years []
- c. 11 to 15 years []
- d. Over 15 years []

5. Organization Classification:

- a. Grade 1 []
- b. Grade 2 []
- c. Grade 3 []
- d. Other, Please Specify _____ []

Section (2): AHP Survey

Kindly evaluate the listed risk factors against each other in the tables below using the following scale. In other words, determine how much influential is a risk factor in the column on the left comparing to any risk factor in the row at the top. Note that if the risk factor in the row at the top is more important than the risk factor in the column on the left, use the reciprocals of the numbers below. However, there are six pairwise comparison matrices.

Intensity of Importance	Definition
1	Equal Importance
3	Moderate Importance
5	Strong Importance
7	Very Strong Importance
9	Extreme Importance
2, 4, 6 and 8	Intermediate Values
Reciprocals of the above numbers	When assigning an importance intensity value between two elements (i) and (j), the reciprocal of that importance intensity value is assigned when comparing between (j) and (i).

1. The pairwise comparison matrix of the criteria:

Criterion	Bidding	Construction	Environment	Economic	Legal
Bidding	1				
Construction		1			
Environment			1		
Economic				1	
Legal					1

2. The pairwise comparison matrix of the attributes under the bidding criterion:

Attribute	Inadequate Design	Quality of Drawings and Details	Unrealistic Construction Schedules	Vagueness of Scope of Work
Inadequate Design	1			
Quality of Drawings and Details		1		
Unrealistic Construction Schedules			1	
Vagueness of Scope of Work				1

3. The pairwise comparison matrix of the attributes under the construction criterion:

Attribute	Suppliers Issues	Subcontractors Issues	Defective Work	Damage to Material, Equipment and Facilities	Poor Productivity of Manpower and Equipment	Stringent Inspections by Engineers
Suppliers Issues	1					
Subcontractors Issues		1				
Defective Work			1			
Damage to Material, Equipment and Facilities				1		
Poor Productivity of Manpower and Equipment					1	
Stringent Inspections by Engineers						1

4. The pairwise comparison matrix of the attributes under the environment criterion:

Attribute	Adverse Weather Conditions	Subsurface Conditions	Site Accessibility
Adverse Weather Conditions	1		
Subsurface Conditions		1	
Site Accessibility			1

5. The pairwise comparison matrix of the attributes under the economic criterion:

Attribute	Escalation in Prices	Currency Fluctuation
Escalation in Prices	1	
Currency Fluctuation		1

6. The pairwise comparison matrix of the attributes under the legal criterion:

Attribute	Labor Disputes and Strikes	Permit Delays	Drawings and Approvals Delays
Labor Disputes and Strikes	1		
Permit Delays		1	
Drawing and Approval Delays			1

Section (3): MAUT Survey

This section consists of five tables for all risk factors classified under 5 categories. Kindly follow the subsequent instructions to fill the tables.

- In box (A), provide the maximum monetary loss as a percentage of the total contract value that you expect the considered risk factor can cause if occurred.
- In box (C), provide the probability of occurrence of losing the specified amount in box (A). For example, there are 2 projects out of 10 in which the loss can reach the maximum value provided in (A), then the probability is 20%.
- In box (B), provide the minimum monetary loss as a percentage of the total contract value that you expect the considered risk factor can cause if occurred.
- In box (C'), provide the probability of occurrence of losing the specified amount in box (B). Simply, it should be the complement of the value in (C).
- In box (D), provide the amount that you are willing to pay as a percentage of the total contract value, to insure that the threat caused by the risk factor is eliminated. In other words, you shall hold no responsibility or liability if the risk occurred. Note that the value in box (D) should be a percentage between the minimum and the maximum values.

In table 6, based on your experience, determine the largest, smallest and the most common contingency percentages that can be added to construction projects.

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
	Maximum Loss Percentage	(A)	(C)	(D)
	Minimum Loss Percentage	(B)	(C')	

1. MAUT survey for the attributes under the bidding criterion:

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
Inadequate Design	Maximum Loss			
	Minimum Loss			
Quality of Drawings and Details	Maximum Loss			
	Minimum Loss			
Unrealistic Construction Schedules	Maximum Loss			
	Minimum Loss			
Vagueness of Scope of Work	Maximum Loss			
	Minimum Loss			

2. MAUT survey for the attributes under the construction criterion:

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
Suppliers Issues	Maximum Loss			
	Minimum Loss			
Subcontractors Issues	Maximum Loss			
	Minimum Loss			
Defective Work	Maximum Loss			
	Minimum Loss			

Damage to Material, Equipment and Facilities	Maximum Loss			
	Minimum Loss			
Poor Productivity of Manpower and Equipment	Maximum Loss			
	Minimum Loss			
Stringent Inspections by Engineers	Maximum Loss			
	Minimum Loss			

3. MAUT survey for the attributes under the environment criterion:

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
Adverse Weather Conditions	Maximum Loss			
	Minimum Loss			
Subsurface Conditions	Maximum Loss			
	Minimum Loss			
Site Accessibility	Maximum Loss			
	Minimum Loss			

4. MAUT survey for the attributes under the economic criterion:

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
Escalation in Prices	Maximum Loss			
	Minimum Loss			
Currency Fluctuation	Maximum Loss			
	Minimum Loss			

5. MAUT survey for the attributes under the legal criterion:

Risk Factor	Parameters	Cost	Probability	Certainty Equivalent
Labor Disputes and Strikes	Maximum Loss			
	Minimum Loss			
Permit Delays	Maximum Loss			
	Minimum Loss			
Drawing and Approval Delays	Maximum Loss			
	Minimum Loss			

6. MAUT survey for contingency utility function:

Parameters	Contingency Percentage
Largest	
Smallest	
Most Common	

APPENDIX B

Interviews Outcomes

Section (1): Respondents' Information

Name	Organization Name	E-mail Address
Amin Abu Saa	Shade Corporation Limited	a.abusaa@shadeco.com
Mohammad Al Hrogi	Top Summit Contracting Company	hrogi850@gmail.com
khalid Al Saif	Saudi Hadaid Company	Khalid.saif@ideal-precast.com
Bishoy Fakhry	Ibrahim Asmael General Contracting Establishment	bishoy@asmael.com
Ibrahim Al Ramadan	Comatec - Al Rashed	ibrahim.alramadan@comatec.com.sa
Emad Atia	Saudi Arabian Baytur Construction Company	emad.atia@baytur.com.sa
Hossam Ali	Al-Hogail Contracting Company Limited	hossam_ali89@yahoo.com
Marwan Dawood	Ideal Pre-Cast Company	marwandawood@ideal-precast.com
Mohammed Al Mutiri	SRACO Company	al-maimony@hotmail.com
Mahdi Abu Hatab	Al-Mira Center for Trading and Contracting Limited	mahdi@al-mira.com
Asem Snoubar	Nesma and Partners Contracting Company Limited	asems@nesma.com
George Bouassi	Al-Nobl Contracting Company	georgebouassi@alnobl.com.sa
Hashem El Assir	Nesma and Partners Contracting Company Limited	hashem.elassir@nesma.com
Abdullah Al Qahtani	Zamil Steel Pre-Engineered Buildings Company Limited	eng.a.a.q@hotmail.com
Ehab El Saied	Faisal Thaar Al Otaibi Contracting Establishment	ehabelsaied83@gmail.com
Fred Linde	Arabian Castles for General Contracting	f.vdlinde@acgc.com.sa
Mustafa Al Najjar	Nesma and Partners Contracting Company Limited	mustafa.alnajjar@nesma.com

Section (2): AHP Evaluation

- Respondent 1
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.216	Inadequate Design	0.141	0.030
		Quality of Drawings and Details	0.263	0.057
		Unrealistic Construction Schedules	0.455	0.098
		Vagueness of Scope of Work	0.141	0.030
		Total	1	0.216
Construction	0.37	Suppliers Issues	0.121	0.045
		Subcontractors Issues	0.121	0.045
		Defective Work	0.204	0.075
		Damage to Material, Equipment and Facilities	0.070	0.026
		Poor Productivity of Manpower and Equipment	0.423	0.157
		Stringent Inspections by Engineers	0.061	0.023
		Total	1	0.37

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.16	Adverse Weather Conditions	0.594	0.095
		Subsurface Conditions	0.157	0.025
		Site Accessibility	0.249	0.040
		Total	1	0.16
Economic	0.139	Escalation in Prices	0.900	0.125
		Currency Fluctuation	0.100	0.014
		Total	1	0.139
Legal	0.115	Labor Disputes and Strikes	0.088	0.010
		Permit Delays	0.717	0.082
		Drawings and Approvals Delays	0.195	0.022
		Total	1	0.115

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.33	2	1	3
C2		1	2	2	3
C3			1	2	1
C4				1	1
C5					1
Consistency Ratio	0.065				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	0.5	0.33	1
RF2		1	0.5	2
RF3			1	3
RF4				1
Consistency Ratio	0.004			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	1	0.33	3	0.2	3
RF6		1	0.33	3	0.2	3
RF7			1	2	0.33	2
RF8				1	0.33	1
RF9					1	5
RF10						1
Consistency Ratio	0.082					

Risk Factors	RF11	RF12	RF13
RF11	1	3	3
RF12		1	0.5
RF13			1
Consistency Ratio	0.056		

Risk Factors	RF14	RF15
RF14	1	9
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.17	0.33
RF12		1	5
RF13			1
Consistency Ratio	0.098		

- Respondent 2
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.095	Inadequate Design	0.192	0.018
		Quality of Drawings and Details	0.079	0.008
		Unrealistic Construction Schedules	0.102	0.010
		Vagueness of Scope of Work	0.627	0.060
		Total	1	0.095
Construction	0.426	Suppliers Issues	0.398	0.170
		Subcontractors Issues	0.248	0.106
		Defective Work	0.082	0.035
		Damage to Material, Equipment and Facilities	0.131	0.056
		Poor Productivity of Manpower and Equipment	0.066	0.028
		Stringent Inspections by Engineers	0.075	0.032
		Total	1	0.426

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.091	Adverse Weather Conditions	0.155	0.014
		Subsurface Conditions	0.710	0.065
		Site Accessibility	0.135	0.012
		Total	1	0.091
Economic	0.344	Escalation in Prices	0.889	0.306
		Currency Fluctuation	0.111	0.038
		Total	1	0.344
Legal	0.044	Labor Disputes and Strikes	0.067	0.003
		Permit Delays	0.466	0.021
		Drawings and Approvals Delays	0.467	0.021
		Total	1	0.044

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.25	1	0.33	2
C2		1	4	2	8
C3			1	0.14	3
C4				1	7
C5					1
Consistency Ratio	0.04				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	4	2	0.17
RF2		1	1	0.17
RF3			1	0.25
RF4				1
Consistency Ratio	0.089			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	2	4	5	8	3
RF6		1	2	3	4	5
RF7			1	1	1	0.5
RF8				1	4	3
RF9					1	2
RF10						1
Consistency Ratio	0.1					

Risk Factors	RF11	RF12	RF13
RF11	1	0.25	1
RF12		1	6
RF13			1
Consistency Ratio	0.019		

Risk Factors	RF14	RF15
RF14	1	8
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.14	0.14
RF12		1	1
RF13			1
Consistency Ratio	0		

- Respondent 3
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.512	Inadequate Design	0.235	0.120
		Quality of Drawings and Details	0.088	0.045
		Unrealistic Construction Schedules	0.636	0.326
		Vagueness of Scope of Work	0.041	0.021
		Total	1	0.512
Construction	0.232	Suppliers Issues	0.116	0.027
		Subcontractors Issues	0.281	0.065
		Defective Work	0.404	0.094
		Damage to Material, Equipment and Facilities	0.111	0.026
		Poor Productivity of Manpower and Equipment	0.060	0.014
		Stringent Inspections by Engineers	0.028	0.006
		Total	1	0.232

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.132	Adverse Weather Conditions	0.194	0.026
		Subsurface Conditions	0.743	0.098
		Site Accessibility	0.063	0.008
		Total	1	0.132
Economic	0.046	Escalation in Prices	0.750	0.035
		Currency Fluctuation	0.250	0.012
		Total	1	0.046
Legal	0.078	Labor Disputes and Strikes	0.226	0.018
		Permit Delays	0.101	0.008
		Drawings and Approvals Delays	0.673	0.052
		Total	1	0.078

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	3	6	8	5
C2		1	3	3	4
C3			1	4	3
C4				1	0.33
C5					1
Consistency Ratio	0.085				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	4	0.2	7
RF2		1	0.17	3
RF3			1	9
RF4				1
Consistency Ratio	0.096			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.33	0.2	0.5	4	6
RF6		1	1	3	4	8
RF7			1	7	6	8
RF8				1	2	4
RF9					1	4
RF10						1
Consistency Ratio	0.077					

Risk Factors	RF11	RF12	RF13
RF11	1	0.2	4
RF12		1	9
RF13			1
Consistency Ratio	0.074		

Risk Factors	RF14	RF15
RF14	1	3
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	3	0.25
RF12		1	0.2
RF13			1
Consistency Ratio	0.09		

- Respondent 4
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.29	Inadequate Design	0.051	0.015
		Quality of Drawings and Details	0.145	0.042
		Unrealistic Construction Schedules	0.682	0.198
		Vagueness of Scope of Work	0.122	0.035
		Total	1	0.29
Construction	0.307	Suppliers Issues	0.105	0.032
		Subcontractors Issues	0.180	0.055
		Defective Work	0.428	0.131
		Damage to Material, Equipment and Facilities	0.047	0.014
		Poor Productivity of Manpower and Equipment	0.210	0.064
		Stringent Inspections by Engineers	0.030	0.009
		Total	1	0.307

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.076	Adverse Weather Conditions	0.088	0.007
		Subsurface Conditions	0.717	0.054
		Site Accessibility	0.195	0.015
		Total	1	0.076
Economic	0.284	Escalation in Prices	0.875	0.249
		Currency Fluctuation	0.125	0.036
		Total	1	0.284
Legal	0.043	Labor Disputes and Strikes	0.653	0.028
		Permit Delays	0.062	0.003
		Drawings and Approvals Delays	0.285	0.012
		Total	1	0.043

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	2	4	0.5	5
C2		1	5	2	6
C3			1	0.25	3
C4				1	5
C5					1
Consistency Ratio	0.091				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	0.2	0.14	0.33
RF2		1	0.14	1
RF3			1	7
RF4				1
Consistency Ratio	0.097			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.25	0.17	4	0.33	7
RF6		1	0.33	4	0.5	5
RF7			1	7	3	9
RF8				1	0.2	3
RF9					1	4
RF10						1
Consistency Ratio	0.093					

Risk Factors	RF11	RF12	RF13
RF11	1	0.17	0.33
RF12		1	5
RF13			1
Consistency Ratio	0.098		

Risk Factors	RF14	RF15
RF14	1	7
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	8	3
RF12		1	0.17
RF13			1
Consistency Ratio	0.077		

- Respondent 5
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.066	Inadequate Design	0.225	0.015
		Quality of Drawings and Details	0.178	0.012
		Unrealistic Construction Schedules	0.067	0.004
		Vagueness of Scope of Work	0.530	0.035
		Total	1	0.066
Construction	0.338	Suppliers Issues	0.375	0.127
		Subcontractors Issues	0.146	0.049
		Defective Work	0.042	0.014
		Damage to Material, Equipment and Facilities	0.068	0.023
		Poor Productivity of Manpower and Equipment	0.071	0.024
		Stringent Inspections by Engineers	0.298	0.101
		Total	1	0.338

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.047	Adverse Weather Conditions	0.225	0.011
		Subsurface Conditions	0.674	0.032
		Site Accessibility	0.101	0.005
		Total	1	0.047
Economic	0.178	Escalation in Prices	0.833	0.148
		Currency Fluctuation	0.167	0.030
		Total	1	0.178
Legal	0.371	Labor Disputes and Strikes	0.094	0.035
		Permit Delays	0.097	0.036
		Drawings and Approvals Delays	0.809	0.300
		Total	1	0.371

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.17	3	0.25	0.13
C2		1	4	3	1
C3			1	0.17	0.2
C4				1	0.33
C5					1
Consistency Ratio	0.091				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	2	3	0.33
RF2		1	5	0.25
RF3			1	0.2
RF4				1
Consistency Ratio	0.092			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	4	5	7	7	1
RF6		1	3	4	3	0.33
RF7			1	0.25	0.33	0.2
RF8				1	1	0.17
RF9					1	0.33
RF10						1
Consistency Ratio	0.079					

Risk Factors	RF11	RF12	RF13
RF11	1	0.25	3
RF12		1	4
RF13			1
Consistency Ratio	0.09		

Risk Factors	RF14	RF15
RF14	1	5
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	1	0.11
RF12		1	0.13
RF13			1
Consistency Ratio	0.002		

- Respondent 6
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.429	Inadequate Design	0.373	0.160
		Quality of Drawings and Details	0.104	0.045
		Unrealistic Construction Schedules	0.152	0.065
		Vagueness of Scope of Work	0.371	0.159
		Total	1	0.429
Construction	0.135	Suppliers Issues	0.247	0.033
		Subcontractors Issues	0.203	0.027
		Defective Work	0.158	0.021
		Damage to Material, Equipment and Facilities	0.174	0.023
		Poor Productivity of Manpower and Equipment	0.104	0.014
		Stringent Inspections by Engineers	0.114	0.015
		Total	1	0.135

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.151	Adverse Weather Conditions	0.149	0.022
		Subsurface Conditions	0.691	0.104
		Site Accessibility	0.160	0.024
		Total	1	0.151
Economic	0.113	Escalation in Prices	0.667	0.075
		Currency Fluctuation	0.333	0.038
		Total	1	0.113
Legal	0.172	Labor Disputes and Strikes	0.634	0.109
		Permit Delays	0.174	0.030
		Drawings and Approvals Delays	0.192	0.033
		Total	1	0.172

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	2	5	4	2
C2		1	0.5	1	1
C3			1	1	1
C4				1	0.5
C5					1
Consistency Ratio	0.054				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	5	2	1
RF2		1	0.5	0.5
RF3			1	0.25
RF4				1
Consistency Ratio	0.078			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	1	2	2	2	2
RF6		1	2	1	1	2
RF7			1	1	2	2
RF8				1	2	2
RF9					1	0.5
RF10						1
Consistency Ratio	0.044					

Risk Factors	RF11	RF12	RF13
RF11	1	0.2	1
RF12		1	4
RF13			1
Consistency Ratio	0.006		

Risk Factors	RF14	RF15
RF14	1	2
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	4	3
RF12		1	1
RF13			1
Consistency Ratio	0.01		

- Respondent 7
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.492	Inadequate Design	0.180	0.089
		Quality of Drawings and Details	0.184	0.091
		Unrealistic Construction Schedules	0.593	0.292
		Vagueness of Scope of Work	0.043	0.021
		Total	1	0.492
Construction	0.276	Suppliers Issues	0.204	0.056
		Subcontractors Issues	0.222	0.061
		Defective Work	0.099	0.027
		Damage to Material, Equipment and Facilities	0.083	0.023
		Poor Productivity of Manpower and Equipment	0.368	0.102
		Stringent Inspections by Engineers	0.024	0.007
		Total	1	0.276

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.032	Adverse Weather Conditions	0.156	0.005
		Subsurface Conditions	0.745	0.024
		Site Accessibility	0.099	0.003
		Total	1	0.032
Economic	0.144	Escalation in Prices	0.889	0.128
		Currency Fluctuation	0.111	0.016
		Total	1	0.144
Legal	0.056	Labor Disputes and Strikes	0.745	0.042
		Permit Delays	0.099	0.006
		Drawings and Approvals Delays	0.156	0.009
		Total	1	0.056

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	4	8	3	7
C2		1	7	3	8
C3			1	0.14	0.33
C4				1	3
C5					1
Consistency Ratio	0.098				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	1	0.25	6
RF2		1	0.2	7
RF3			1	7
RF4				1
Consistency Ratio	0.1			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	2	1	3	0.5	7
RF6		1	3	6	0.5	7
RF7			1	1	0.14	6
RF8				1	0.25	7
RF9					1	8
RF10						1
Consistency Ratio	0.099					

Risk Factors	RF11	RF12	RF13
RF11	1	0.17	2
RF12		1	6
RF13			1
Consistency Ratio	0.056		

Risk Factors	RF14	RF15
RF14	1	8
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	6	6
RF12		1	0.5
RF13			1
Consistency Ratio	0.056		

- Respondent 8
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.35	Inadequate Design	0.110	0.039
		Quality of Drawings and Details	0.065	0.023
		Unrealistic Construction Schedules	0.272	0.095
		Vagueness of Scope of Work	0.553	0.194
		Total	1	0.35
Construction	0.34	Suppliers Issues	0.217	0.074
		Subcontractors Issues	0.097	0.033
		Defective Work	0.121	0.041
		Damage to Material, Equipment and Facilities	0.200	0.068
		Poor Productivity of Manpower and Equipment	0.170	0.058
		Stringent Inspections by Engineers	0.195	0.066
		Total	1	0.34

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.183	Adverse Weather Conditions	0.167	0.031
		Subsurface Conditions	0.167	0.031
		Site Accessibility	0.666	0.122
		Total	1	0.183
Economic	0.081	Escalation in Prices	0.750	0.061
		Currency Fluctuation	0.250	0.020
		Total	1	0.081
Legal	0.046	Labor Disputes and Strikes	0.413	0.019
		Permit Delays	0.260	0.012
		Drawings and Approvals Delays	0.327	0.015
		Total	1	0.046

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	2	2	4	4
C2		1	4	4	6
C3			1	4	5
C4				1	3
C5					1
Consistency Ratio	0.099				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	3	0.25	0.17
RF2		1	0.25	0.2
RF3			1	0.33
RF4				1
Consistency Ratio	0.096			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	4	2	0.5	0.5	2
RF6		1	1	0.5	1	0.5
RF7			1	1	1	0.5
RF8				1	1	1
RF9					1	0.5
RF10						1
Consistency Ratio	0.091					

Risk Factors	RF11	RF12	RF13
RF11	1	1	0.25
RF12		1	0.25
RF13			1
Consistency Ratio	0		

Risk Factors	RF14	RF15
RF14	1	3
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	2	1
RF12		1	1
RF13			1
Consistency Ratio	0.056		

- Respondent 9
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.334	Inadequate Design	0.074	0.025
		Quality of Drawings and Details	0.169	0.056
		Unrealistic Construction Schedules	0.454	0.152
		Vagueness of Scope of Work	0.303	0.101
		Total	1	0.334
Construction	0.283	Suppliers Issues	0.064	0.018
		Subcontractors Issues	0.155	0.044
		Defective Work	0.16	0.045
		Damage to Material, Equipment and Facilities	0.082	0.023
		Poor Productivity of Manpower and Equipment	0.178	0.050
		Stringent Inspections by Engineers	0.361	0.102
		Total	1	0.283

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.078	Adverse Weather Conditions	0.311	0.024
		Subsurface Conditions	0.493	0.038
		Site Accessibility	0.196	0.015
		Total	1	0.078
Economic	0.06	Escalation in Prices	0.5	0.030
		Currency Fluctuation	0.5	0.030
		Total	1	0.06
Legal	0.245	Labor Disputes and Strikes	0.594	0.146
		Permit Delays	0.157	0.038
		Drawings and Approvals Delays	0.249	0.061
		Total	1	0.245

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	2	3	6	1
C2		1	3	5	2
C3			1	1	0.25
C4				1	0.25
C5					1
Consistency Ratio	0.044				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	0.33	0.25	0.2
RF2		1	0.33	0.5
RF3			1	2
RF4				1
Consistency Ratio	0.038			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.5	0.33	0.5	0.5	0.25
RF6		1	0.5	2	2	0.33
RF7			1	2	0.5	0.33
RF8				1	0.25	0.33
RF9					1	0.33
RF10						1
Consistency Ratio	0.077					

Risk Factors	RF11	RF12	RF13
RF11	1	0.5	2
RF12		1	2
RF13			1
Consistency Ratio	0.056		

Risk Factors	RF14	RF15
RF14	1	1
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	3	3
RF12		1	0.5
RF13			1
Consistency Ratio	0.056		

- Respondent 10
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.144	Inadequate Design	0.226	0.033
		Quality of Drawings and Details	0.083	0.012
		Unrealistic Construction Schedules	0.486	0.070
		Vagueness of Scope of Work	0.205	0.030
		Total	1	0.144
Construction	0.404	Suppliers Issues	0.035	0.014
		Subcontractors Issues	0.327	0.132
		Defective Work	0.211	0.085
		Damage to Material, Equipment and Facilities	0.229	0.093
		Poor Productivity of Manpower and Equipment	0.104	0.042
		Stringent Inspections by Engineers	0.094	0.038
		Total	1	0.404

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.344	Adverse Weather Conditions	0.073	0.025
		Subsurface Conditions	0.761	0.262
		Site Accessibility	0.166	0.057
		Total	1	0.344
Economic	0.048	Escalation in Prices	0.900	0.043
		Currency Fluctuation	0.100	0.005
		Total	1	0.048
Legal	0.06	Labor Disputes and Strikes	0.094	0.006
		Permit Delays	0.626	0.038
		Drawings and Approvals Delays	0.280	0.017
		Total	1	0.06

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.2	0.5	3	4
C2		1	1	5	8
C3			1	6	9
C4				1	0.33
C5					1
Consistency Ratio	0.09				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	4	0.33	1
RF2		1	0.2	0.5
RF3			1	2
RF4				1
Consistency Ratio	0.034			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.17	0.25	0.25	0.17	0.2
RF6		1	1	3	4	3
RF7			1	0.5	2	4
RF8				1	3	3
RF9					1	1
RF10						1
Consistency Ratio	0.087					

Risk Factors	RF11	RF12	RF13
RF11	1	0.13	0.33
RF12		1	6
RF13			1
Consistency Ratio	0.077		

Risk Factors	RF14	RF15
RF14	1	9
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.2	0.25
RF12		1	3
RF13			1
Consistency Ratio	0		

- Respondent 11
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.522	Inadequate Design	0.556	0.290
		Quality of Drawings and Details	0.275	0.144
		Unrealistic Construction Schedules	0.135	0.070
		Vagueness of Scope of Work	0.034	0.018
		Total	1	0.522
Construction	0.257	Suppliers Issues	0.476	0.122
		Subcontractors Issues	0.305	0.078
		Defective Work	0.103	0.026
		Damage to Material, Equipment and Facilities	0.062	0.016
		Poor Productivity of Manpower and Equipment	0.031	0.008
		Stringent Inspections by Engineers	0.023	0.006
		Total	1	0.257

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.088	Adverse Weather Conditions	0.699	0.062
		Subsurface Conditions	0.237	0.021
		Site Accessibility	0.064	0.006
		Total	1	0.088
Economic	0.079	Escalation in Prices	0.875	0.069
		Currency Fluctuation	0.125	0.010
		Total	1	0.079
Legal	0.054	Labor Disputes and Strikes	0.655	0.035
		Permit Delays	0.290	0.016
		Drawings and Approvals Delays	0.055	0.003
		Total	1	0.054

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	5	3	5	7
C2		1	3	5	7
C3			1	1	1
C4				1	2
C5					1
Consistency Ratio	0.099				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	3	5	9
RF2		1	3	9
RF3			1	7
RF4				1
Consistency Ratio	0.097			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	3	7	9	9	9
RF6		1	5	9	9	9
RF7			1	2	6	6
RF8				1	3	5
RF9					1	2
RF10						1
Consistency Ratio	0.098					

Risk Factors	RF11	RF12	RF13
RF11	1	4	8
RF12		1	5
RF13			1
Consistency Ratio	0.098		

Risk Factors	RF14	RF15
RF14	1	7
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	3	9
RF12		1	7
RF13			1
Consistency Ratio	0.084		

- Respondent 12
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.336	Inadequate Design	0.345	0.116
		Quality of Drawings and Details	0.371	0.125
		Unrealistic Construction Schedules	0.174	0.058
		Vagueness of Scope of Work	0.110	0.037
		Total	1	0.336
Construction	0.334	Suppliers Issues	0.050	0.017
		Subcontractors Issues	0.184	0.061
		Defective Work	0.061	0.020
		Damage to Material, Equipment and Facilities	0.099	0.033
		Poor Productivity of Manpower and Equipment	0.369	0.123
		Stringent Inspections by Engineers	0.237	0.079
		Total	1	0.334

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.035	Adverse Weather Conditions	0.610	0.021
		Subsurface Conditions	0.224	0.008
		Site Accessibility	0.166	0.006
		Total	1	0.035
Economic	0.129	Escalation in Prices	0.500	0.065
		Currency Fluctuation	0.500	0.065
		Total	1	0.129
Legal	0.166	Labor Disputes and Strikes	0.260	0.043
		Permit Delays	0.413	0.069
		Drawings and Approvals Delays	0.327	0.054
		Total	1	0.166

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	2	7	3	1
C2		1	7	3	4
C3			1	0.2	0.2
C4				1	1
C5					1
Consistency Ratio	0.084				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	1	3	2
RF2		1	3	3
RF3			1	3
RF4				1
Consistency Ratio	0.086			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.2	2	0.33	0.14	0.14
RF6		1	3	1	1	0.5
RF7			1	1	0.2	0.33
RF8				1	0.2	0.33
RF9					1	3
RF10						1
Consistency Ratio	0.088					

Risk Factors	RF11	RF12	RF13
RF11	1	2	5
RF12		1	1
RF13			1
Consistency Ratio	0.098		

Risk Factors	RF14	RF15
RF14	1	1
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.5	1
RF12		1	1
RF13			1
Consistency Ratio	0.056		

- Respondent 13
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.2	Inadequate Design	0.058	0.012
		Quality of Drawings and Details	0.040	0.008
		Unrealistic Construction Schedules	0.619	0.124
		Vagueness of Scope of Work	0.283	0.057
		Total	1	0.2
Construction	0.602	Suppliers Issues	0.046	0.028
		Subcontractors Issues	0.210	0.126
		Defective Work	0.518	0.312
		Damage to Material, Equipment and Facilities	0.137	0.082
		Poor Productivity of Manpower and Equipment	0.039	0.023
		Stringent Inspections by Engineers	0.051	0.031
		Total	1	0.602

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.066	Adverse Weather Conditions	0.060	0.004
		Subsurface Conditions	0.708	0.047
		Site Accessibility	0.231	0.015
		Total	1	0.066
Economic	0.036	Escalation in Prices	0.833	0.030
		Currency Fluctuation	0.167	0.006
		Total	1	0.036
Legal	0.096	Labor Disputes and Strikes	0.072	0.007
		Permit Delays	0.279	0.027
		Drawings and Approvals Delays	0.649	0.062
		Total	1	0.096

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.2	3	5	4
C2		1	7	9	9
C3			1	3	0.33
C4				1	0.33
C5					1
Consistency Ratio	0.094				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	2	0.11	0.14
RF2		1	0.11	0.11
RF3			1	4
RF4				1
Consistency Ratio	0.092			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.14	0.11	0.2	3	0.5
RF6		1	0.2	3	5	3
RF7			1	5	8	9
RF8				1	3	5
RF9					1	1
RF10						1
Consistency Ratio	0.1					

Risk Factors	RF11	RF12	RF13
RF11	1	0.11	0.2
RF12		1	4
RF13			1
Consistency Ratio	0.074		

Risk Factors	RF14	RF15
RF14	1	5
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.2	0.14
RF12		1	0.33
RF13			1
Consistency Ratio	0.068		

- Respondent 14
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.155	Inadequate Design	0.453	0.070
		Quality of Drawings and Details	0.160	0.025
		Unrealistic Construction Schedules	0.160	0.025
		Vagueness of Scope of Work	0.227	0.035
		Total	1	0.155
Construction	0.205	Suppliers Issues	0.272	0.056
		Subcontractors Issues	0.114	0.023
		Defective Work	0.109	0.022
		Damage to Material, Equipment and Facilities	0.161	0.033
		Poor Productivity of Manpower and Equipment	0.122	0.025
		Stringent Inspections by Engineers	0.222	0.046
		Total	1	0.205

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.095	Adverse Weather Conditions	0.210	0.020
		Subsurface Conditions	0.550	0.052
		Site Accessibility	0.240	0.023
		Total	1	0.095
Economic	0.095	Escalation in Prices	0.750	0.071
		Currency Fluctuation	0.250	0.024
		Total	1	0.095
Legal	0.45	Labor Disputes and Strikes	0.200	0.090
		Permit Delays	0.400	0.180
		Drawings and Approvals Delays	0.400	0.180
		Total	1	0.45

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	0.5	2	2	0.33
C2		1	2	2	0.33
C3			1	1	0.25
C4				1	0.25
C5					1
Consistency Ratio	0.019				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	4	2	2
RF2		1	1	1
RF3			1	0.5
RF4				1
Consistency Ratio	0.044			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	3	2	1	2	2
RF6		1	1	1	1	0.5
RF7			1	0.5	1	0.5
RF8				1	1	0.5
RF9					1	0.5
RF10						1
Consistency Ratio	0.029					

Risk Factors	RF11	RF12	RF13
RF11	1	0.33	1
RF12		1	2
RF13			1
Consistency Ratio	0.019		

Risk Factors	RF14	RF15
RF14	1	3
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	0.5	0.5
RF12		1	1
RF13			1
Consistency Ratio	0		

- Respondent 15
 - Computed Weights

Category	Weight	Risk Factors	Local Weight	Global Weight
Bidding	0.547	Inadequate Design	0.710	0.388
		Quality of Drawings and Details	0.155	0.085
		Unrealistic Construction Schedules	0.086	0.047
		Vagueness of Scope of Work	0.049	0.027
		Total	1	0.547
Construction	0.262	Suppliers Issues	0.055	0.014
		Subcontractors Issues	0.263	0.069
		Defective Work	0.066	0.017
		Damage to Material, Equipment and Facilities	0.082	0.021
		Poor Productivity of Manpower and Equipment	0.291	0.076
		Stringent Inspections by Engineers	0.243	0.064
		Total	1	0.262

Category	Weight	Risk Factors	Local Weight	Global Weight
Environment	0.04	Adverse Weather Conditions	0.327	0.013
		Subsurface Conditions	0.413	0.017
		Site Accessibility	0.260	0.010
		Total	1	0.04
Economic	0.081	Escalation in Prices	0.500	0.041
		Currency Fluctuation	0.500	0.041
		Total	1	0.081
Legal	0.07	Labor Disputes and Strikes	0.333	0.023
		Permit Delays	0.333	0.023
		Drawings and Approvals Delays	0.334	0.023
		Total	1	0.07

○ Pairwise Comparisons

Criterion	C1	C2	C3	C4	C5
C1	1	3	7	9	9
C2		1	5	7	3
C3			1	0.33	0.33
C4				1	2
C5					1
Consistency Ratio	0.098				

Risk Factors	RF1	RF2	RF3	RF4
RF1	1	7	9	9
RF2		1	3	3
RF3			1	3
RF4				1
Consistency Ratio	0.09			

Risk Factors	RF5	RF6	RF7	RF8	RF9	RF10
RF5	1	0.33	1	0.33	0.17	0.33
RF6		1	3	5	2	0.5
RF7			1	1	0.33	0.2
RF8				1	0.33	0.33
RF9					1	3
RF10						1
Consistency Ratio	0.099					

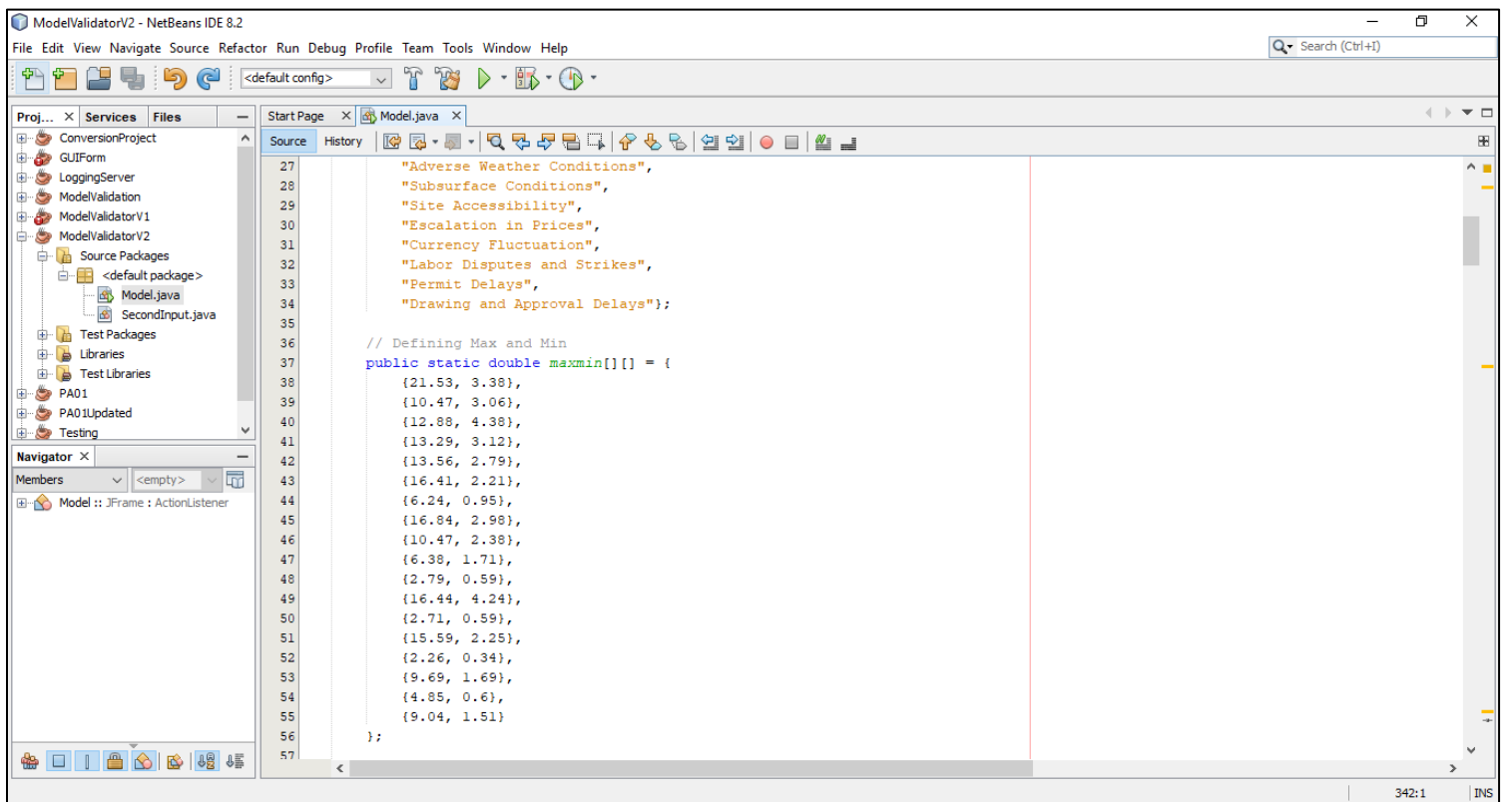
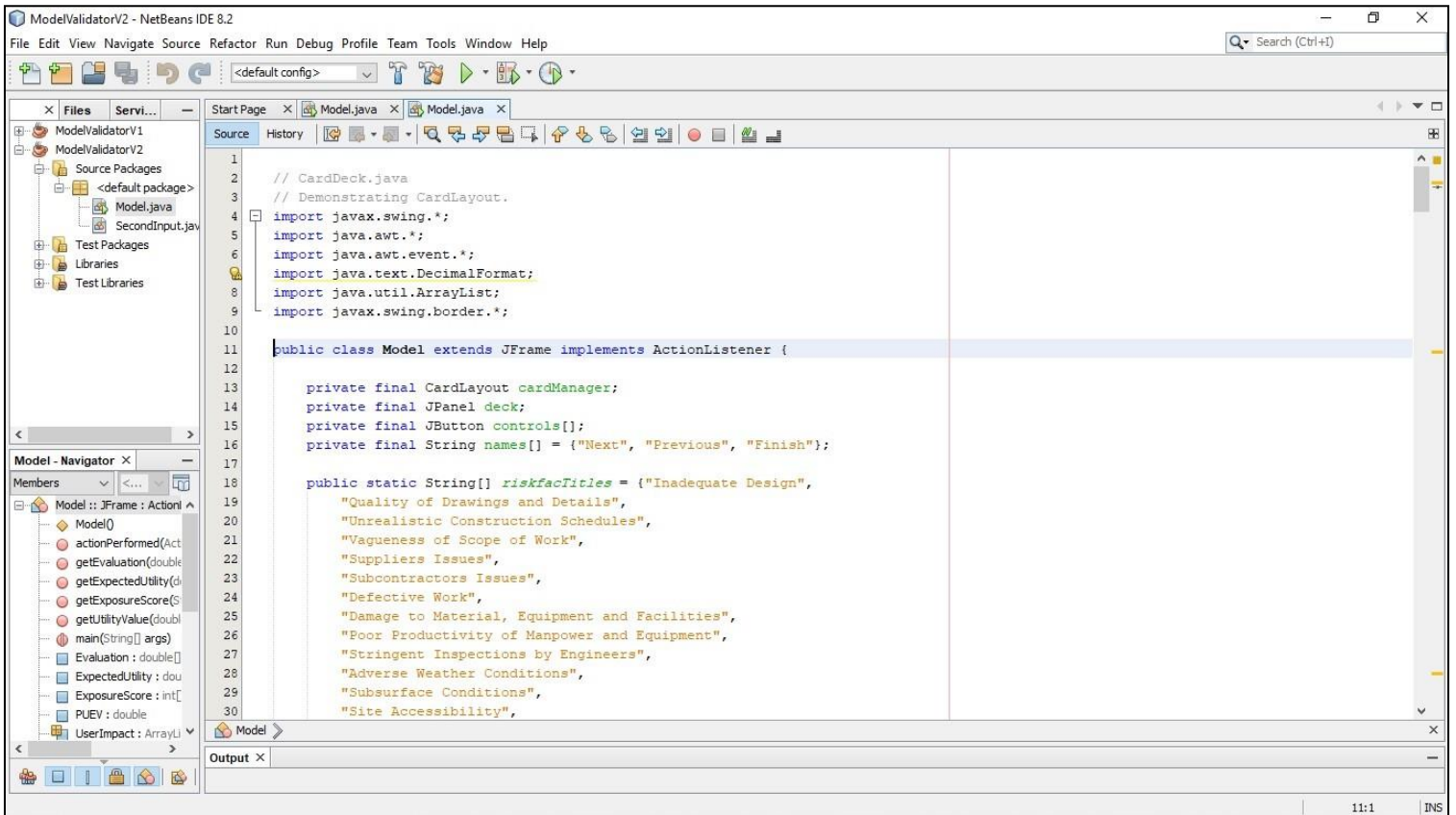
Risk Factors	RF11	RF12	RF13
RF11	1	1	1
RF12		1	2
RF13			1
Consistency Ratio	0.056		

Risk Factors	RF14	RF15
RF14	1	1
RF15		1
Consistency Ratio	0	

Risk Factors	RF11	RF12	RF13
RF11	1	1	1
RF12		1	1
RF13			1
Consistency Ratio	0		

APPENDIX C

Computer Code



ModelValidatorV2 - NetBeans IDE 8.2

File Edit View Navigate Source Refactor Run Debug Profile Team Tools Window Help

Search (Ctrl+I)

Proj... Services Files

Start Page Model.java

Source History

```
57
58 //Define Global Weights
59 public static double global_weights[] = {0.09500, 0.05170, 0.10900, 0.05730, 0.05550, 0.06500, 0.06460, 0.03740, 0.05390, 0.04
60 // Defining ExposureScores
61 public int ExposureScore[] = new int[18];
62 public double Evaluation[] = new double[18];
63 public double UtilityValue[] = new double[18];
64 public double ExpectedUtility[] = new double[18];
65 public double PUEV=0.0;
66
67 ArrayList<String> UserImpact = new ArrayList<>(); //Creating arraylist
68 ArrayList<String> UserProb = new ArrayList<>(); //Creating arraylist
69
70 public JPanel[] card1 = new JPanel[18];
71
72 public JLabel[] jLabelImpact = new JLabel[18];
73 public JLabel[] jLabelProbability = new JLabel[18];
74 public JComboBox[] jComboBox1 = new JComboBox[18]; // you just declared an array of petList
75 public JComboBox[] jComboBox2 = new JComboBox[18]; // you just declared an array of petList
76
77 public Model() {
78     super("Model Validator");
79
80     Container c = getContentPane();
81
82     // create the JPanel with CardLayout
83     deck = new JPanel();
84     cardManager = new CardLayout();
85     deck.setLayout(cardManager);
86
87     String[] Impacts = {"Low", "Medium", "High"};
```

342:1 INS

ModelValidatorV2 - NetBeans IDE 8.2

File Edit View Navigate Source Refactor Run Debug Profile Team Tools Window Help

Search (Ctrl+I)

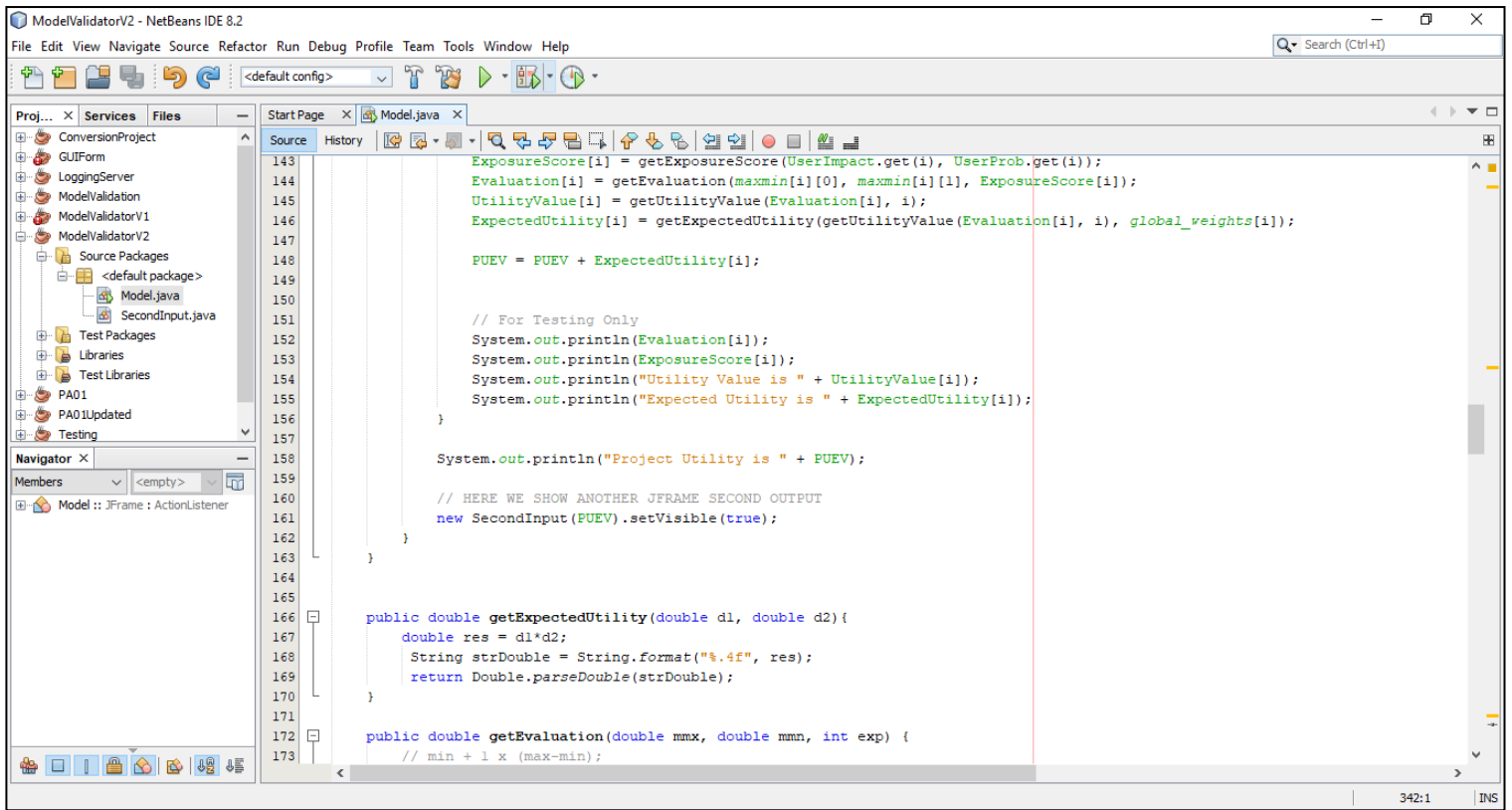
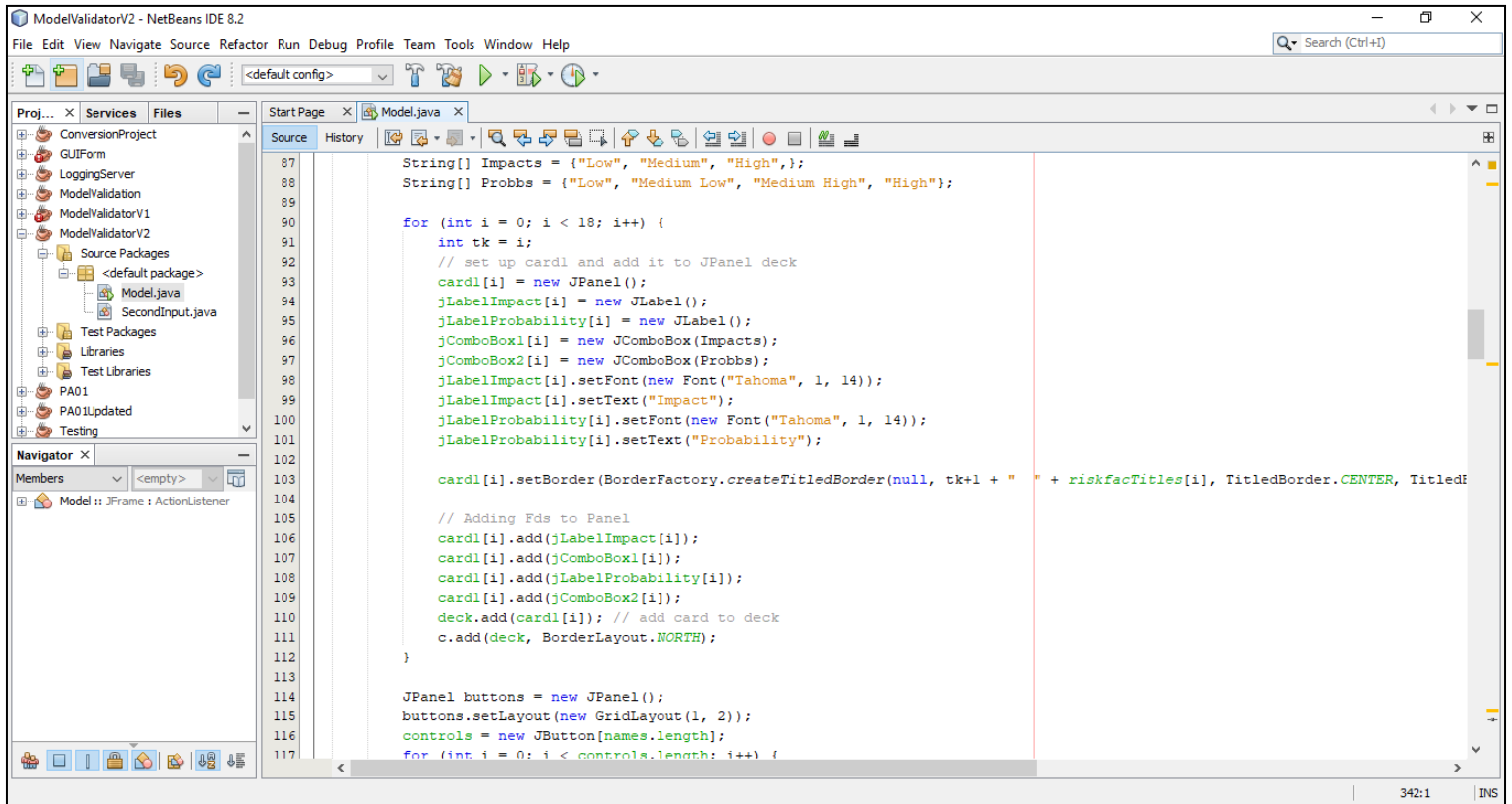
Proj... Services Files

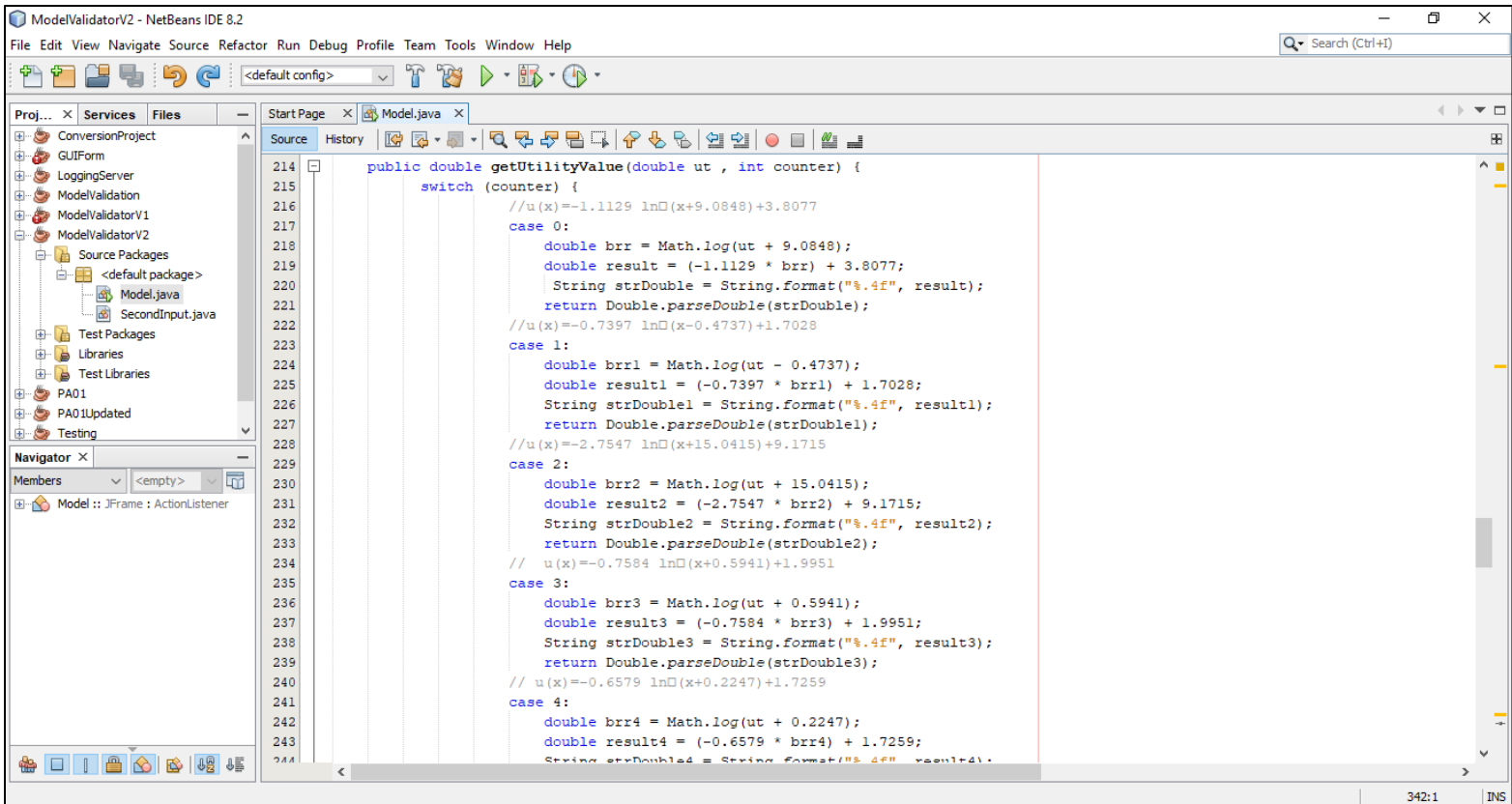
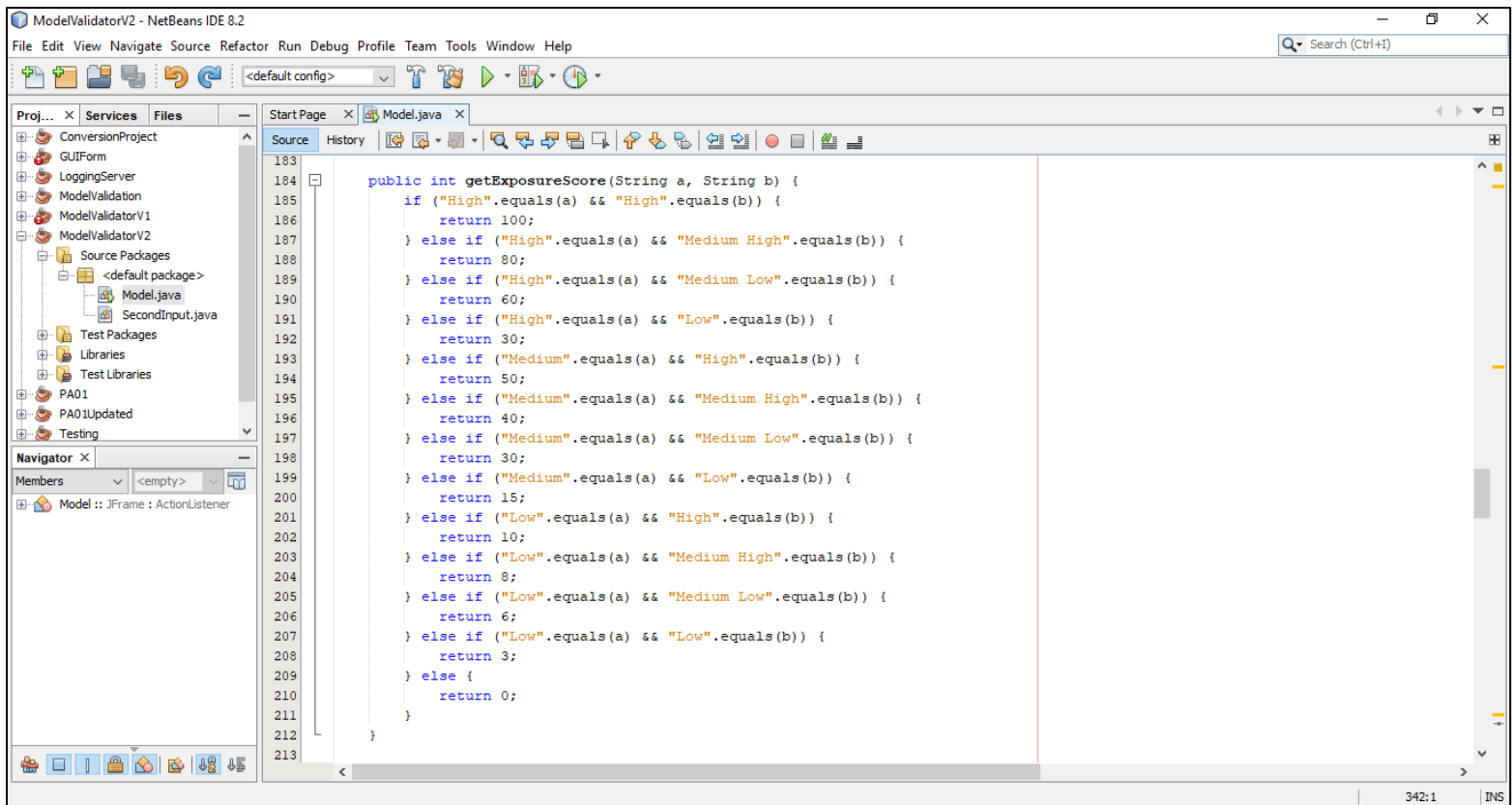
Start Page Model.java

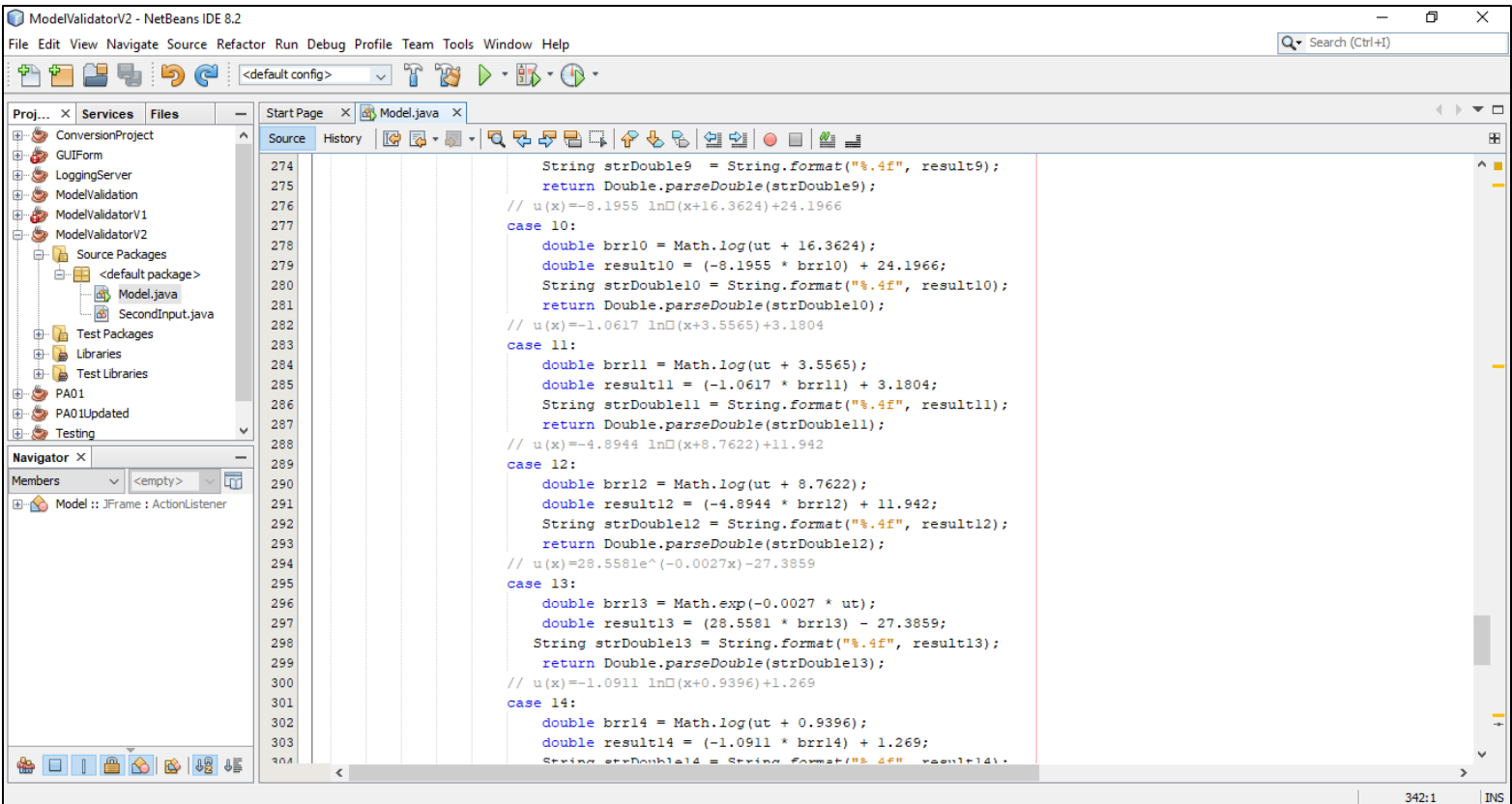
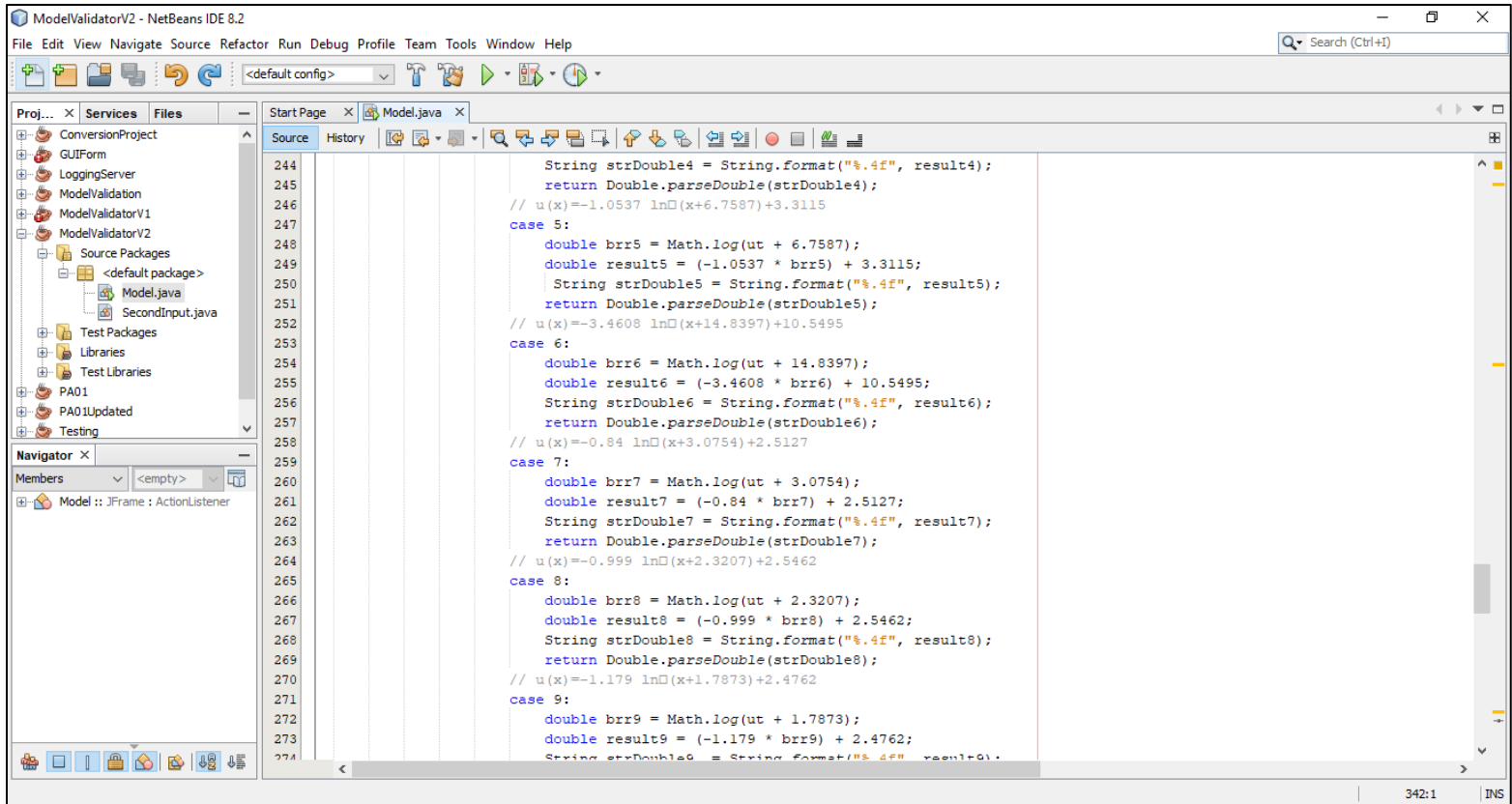
Source History

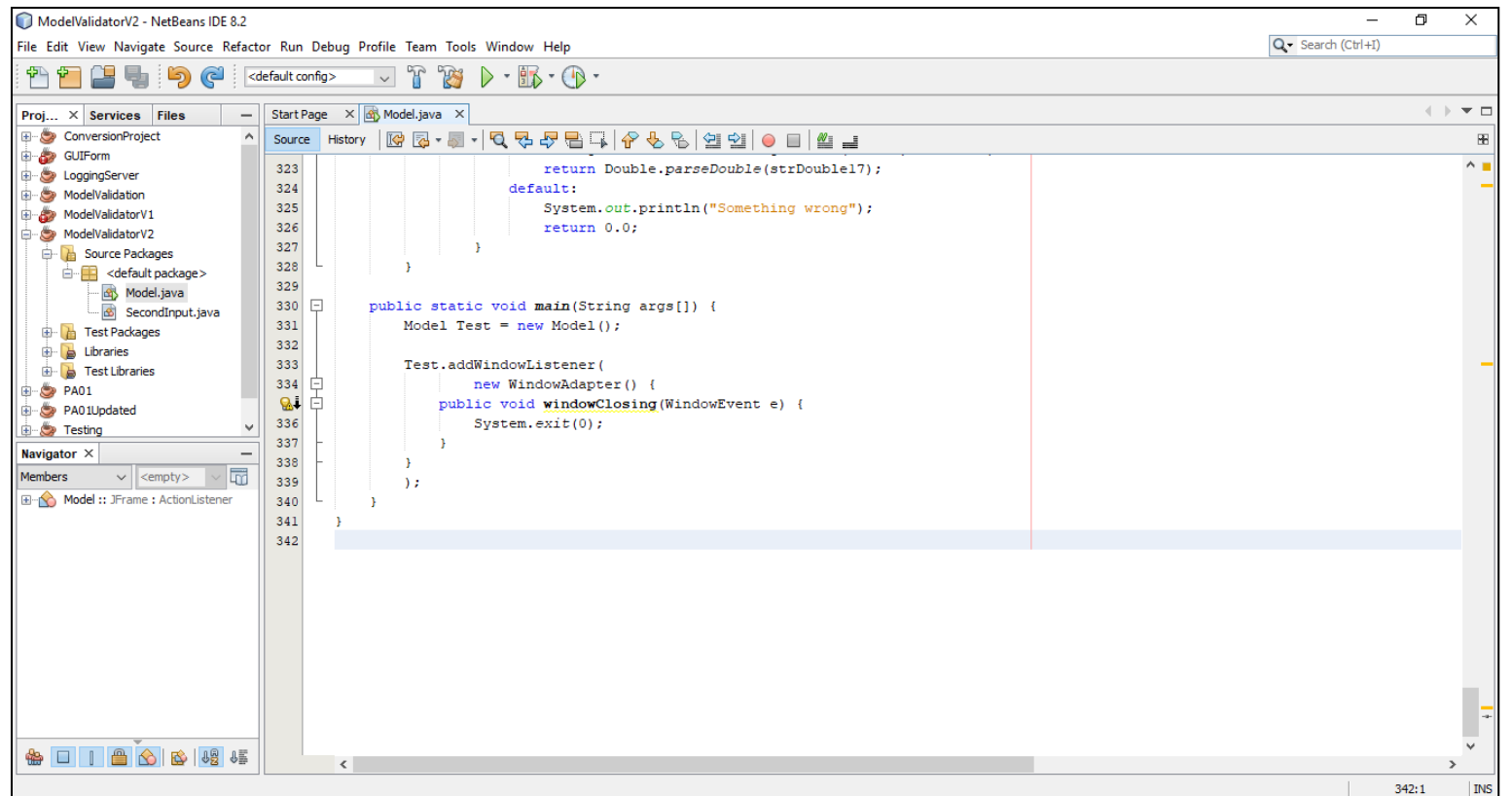
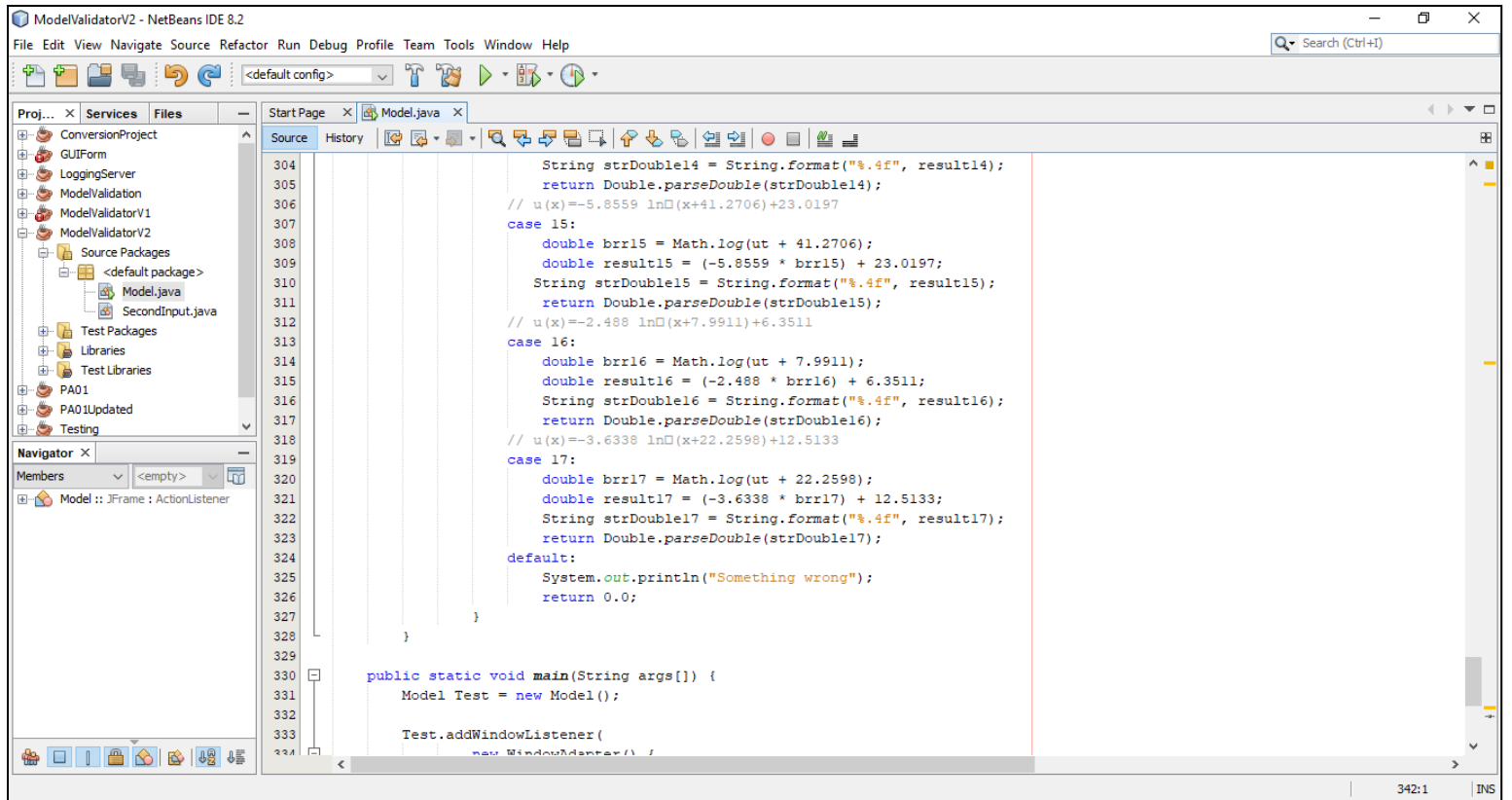
```
113
114 JPanel buttons = new JPanel();
115 buttons.setLayout(new GridLayout(1, 2));
116 controls = new JButton[names.length];
117 for (int i = 0; i < controls.length; i++) {
118     controls[i] = new JButton(names[i]);
119     controls[i].addActionListener(this);
120     buttons.add(controls[i]);
121 }
122 // add JPanel deck and JPanel buttons to the applet
123 c.add(buttons, BorderLayout.SOUTH);
124 setSize(600, 150);
125 show();
126
127
128 @Override
129 public void actionPerformed(ActionEvent e) {
130     if (e.getSource() == controls[0]) {
131         cardManager.next(deck); // show next card
132         // Call Method for Calculating Other Things
133     } else if (e.getSource() == controls[1]) {
134         cardManager.previous(deck); // show previous card
135     } else if (e.getSource() == controls[2]) {
136         this.hide();
137
138         for (int i = 0; i < 18; i++) {
139             UserImpact.add(jComboBox1[i].getSelectedItem().toString());
140             UserProb.add(jComboBox2[i].getSelectedItem().toString());
141             System.out.println(UserImpact.get(i) + " ----- " + UserProb.get(i));
142
143             ExposureScore[i] = getExposureScore(UserImpact.get(i), UserProb.get(i));
```

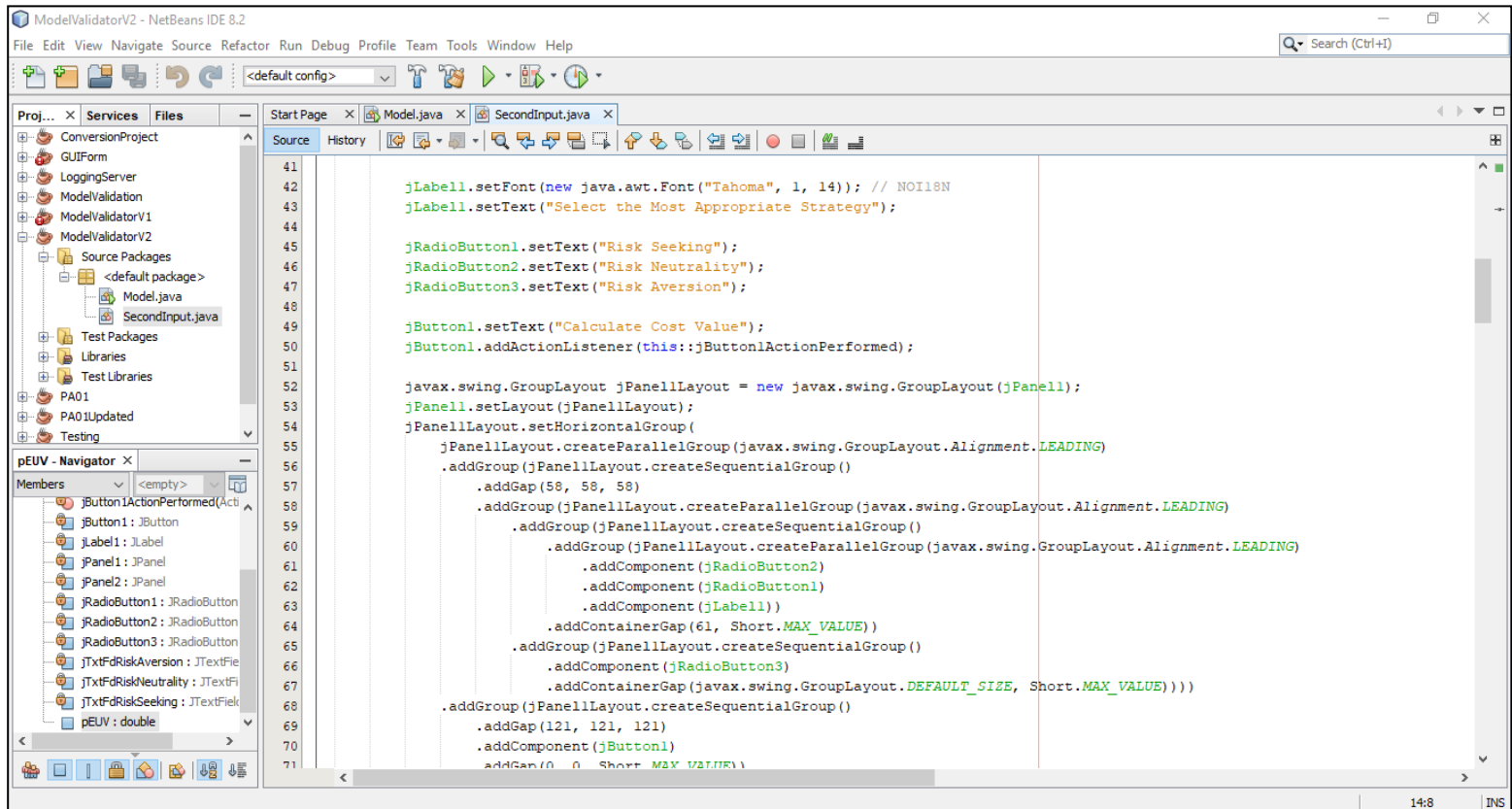
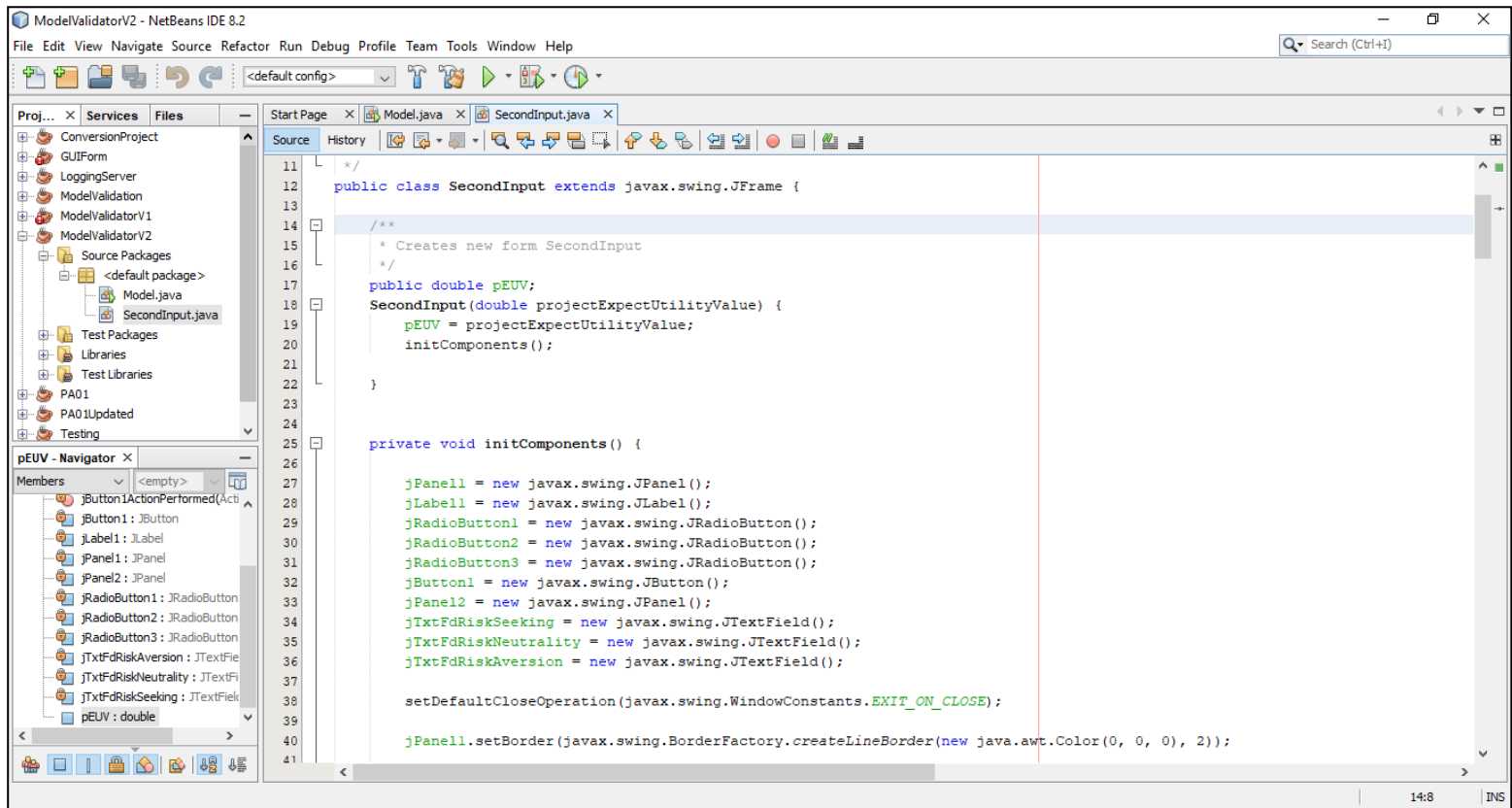
342:1 INS

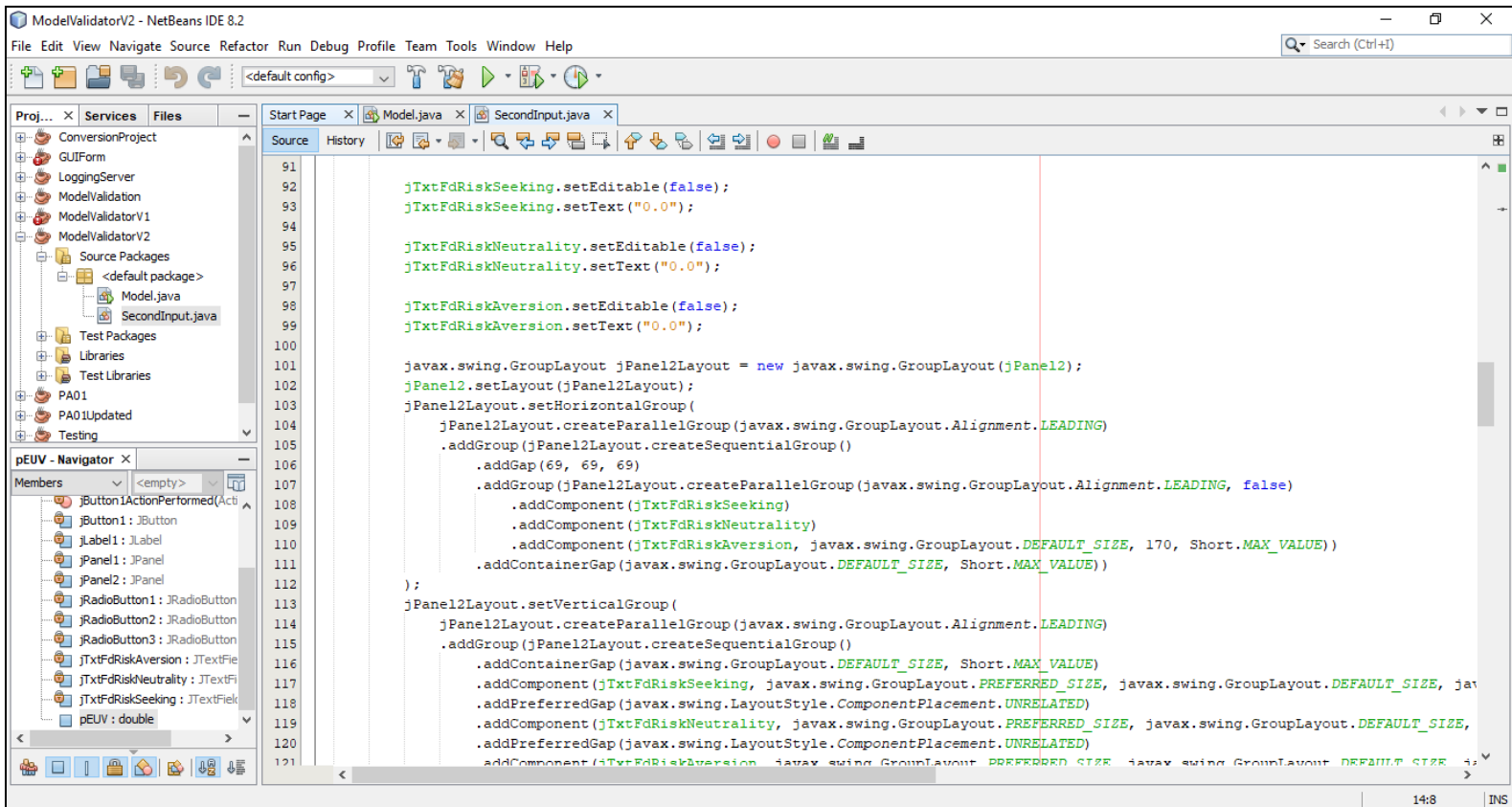
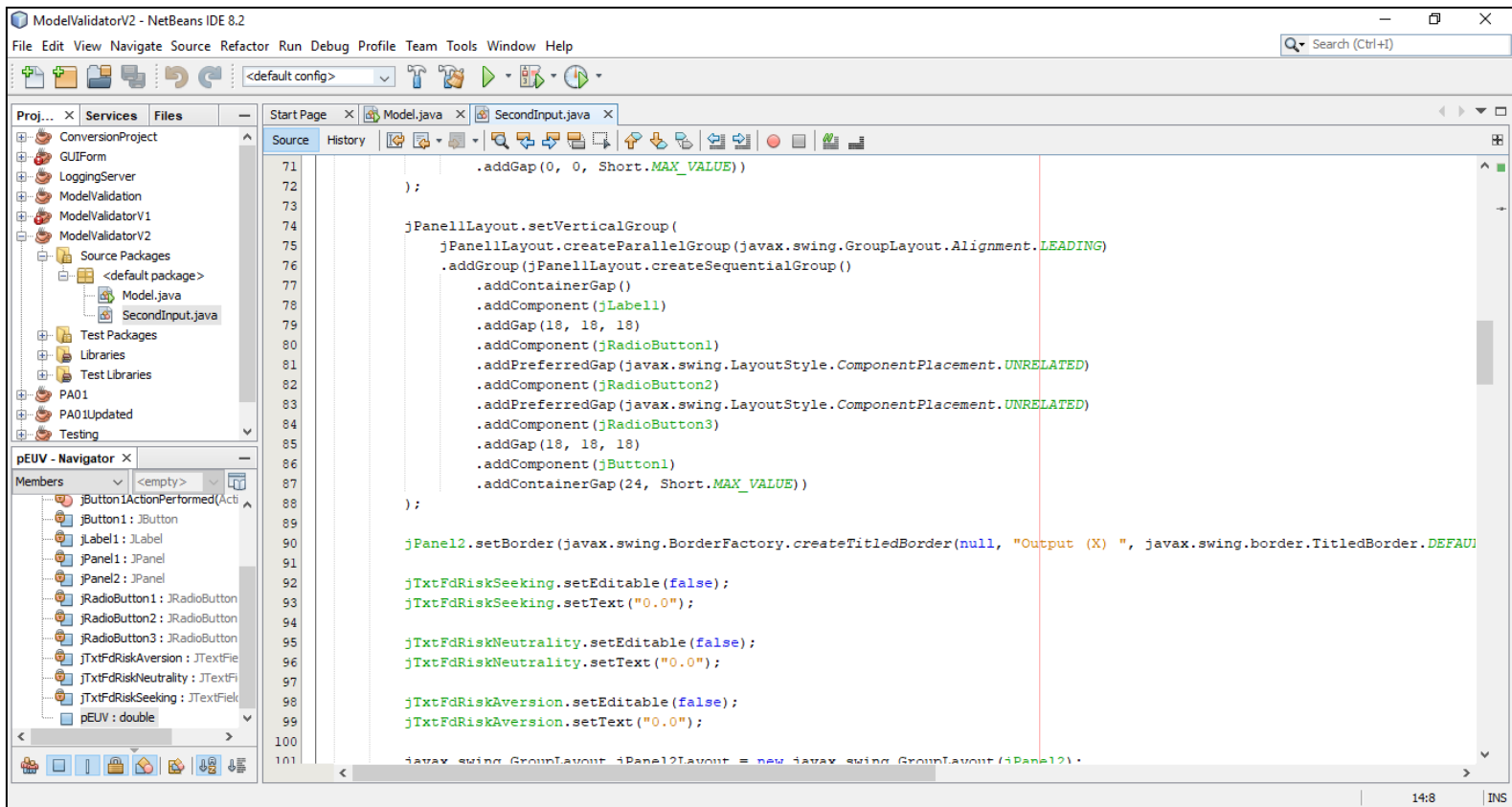


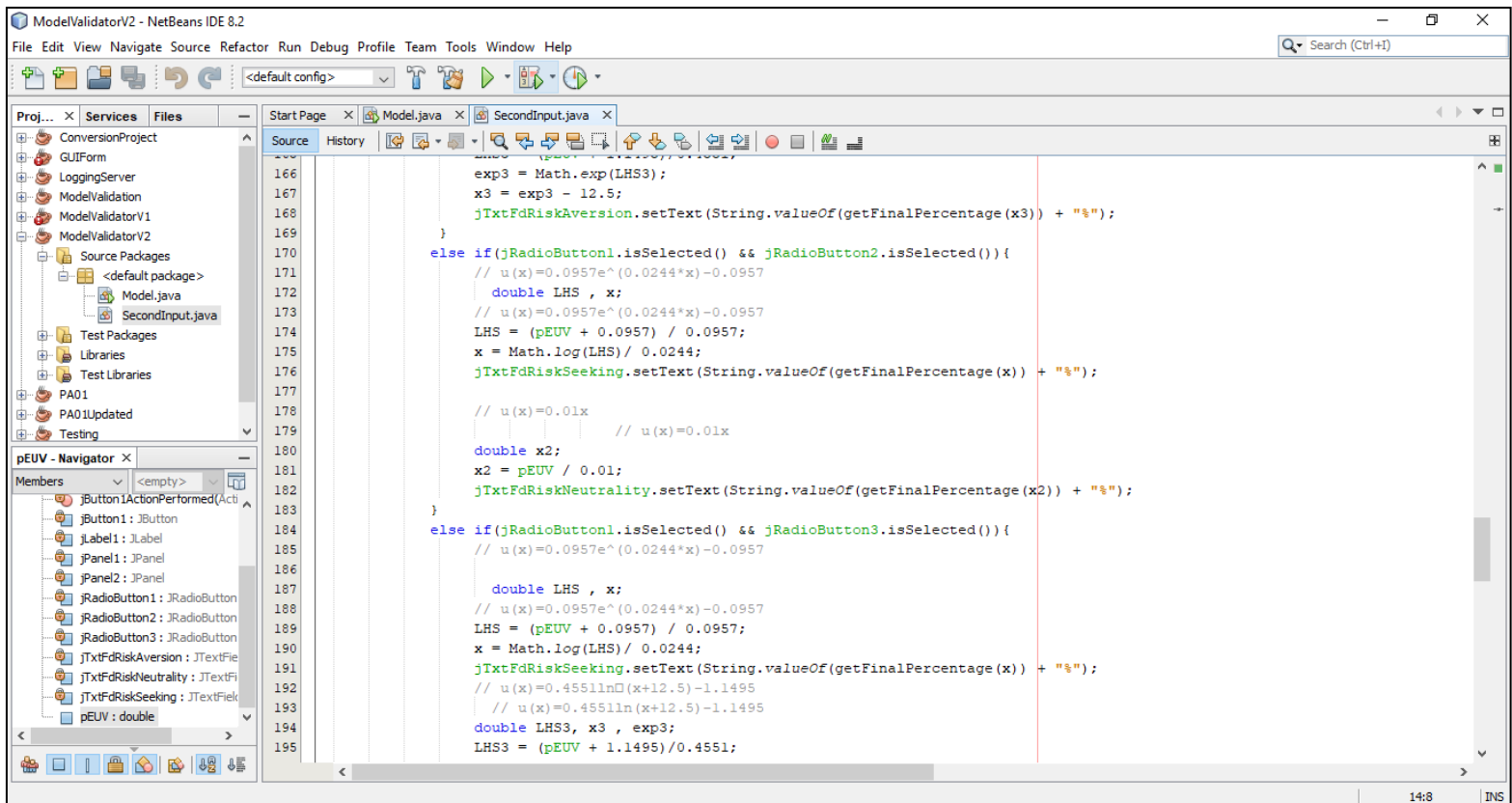
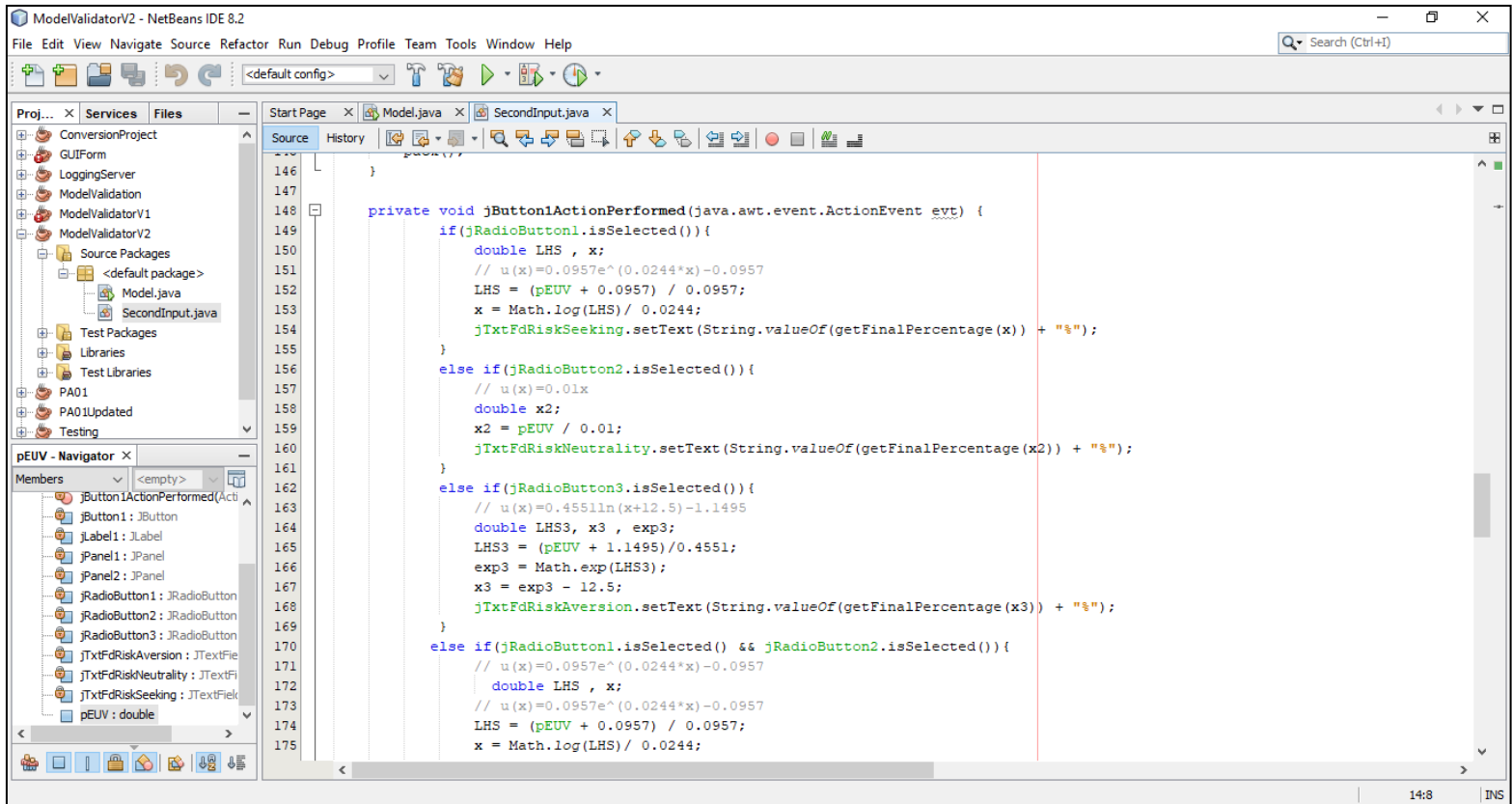


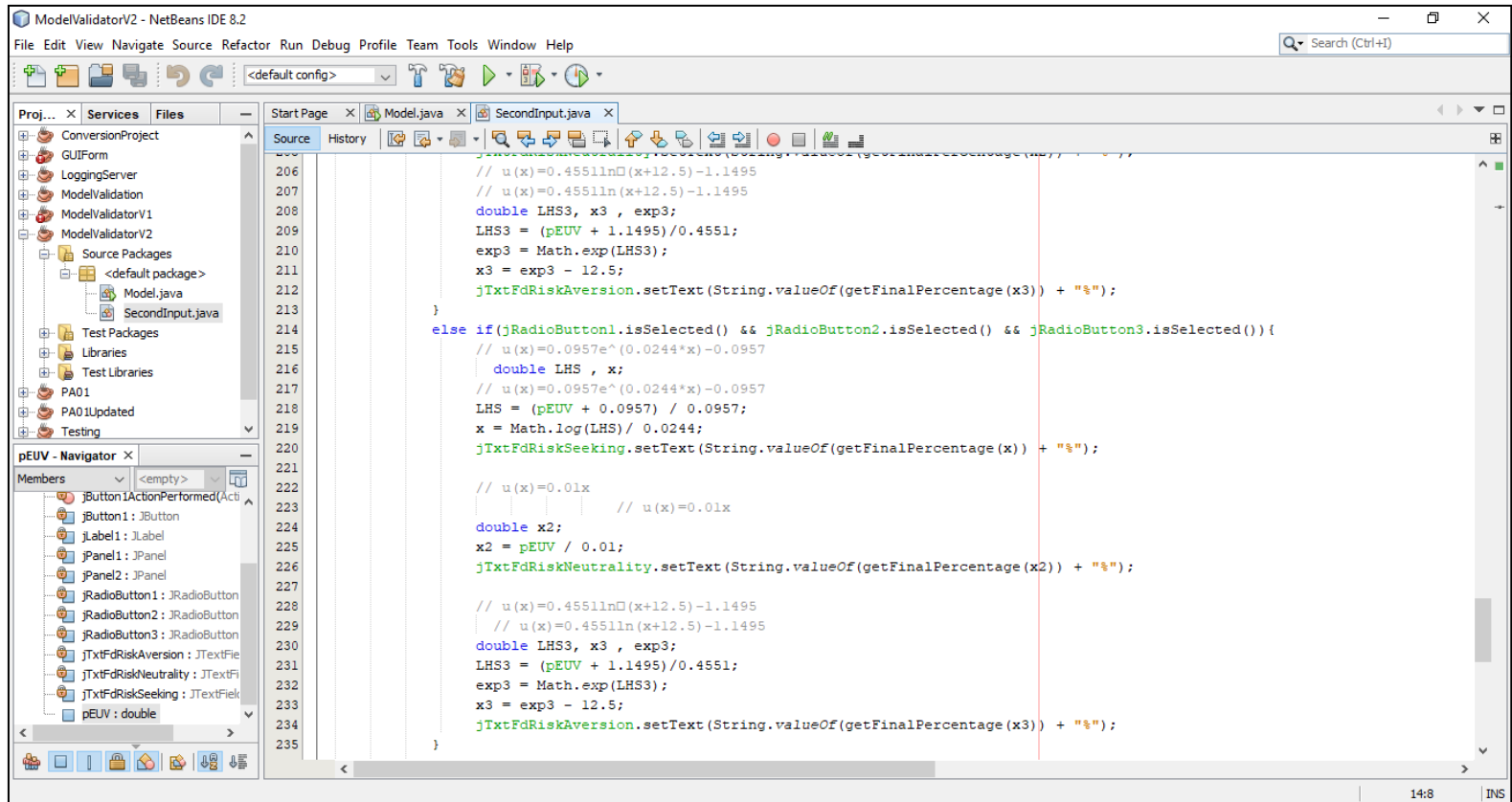
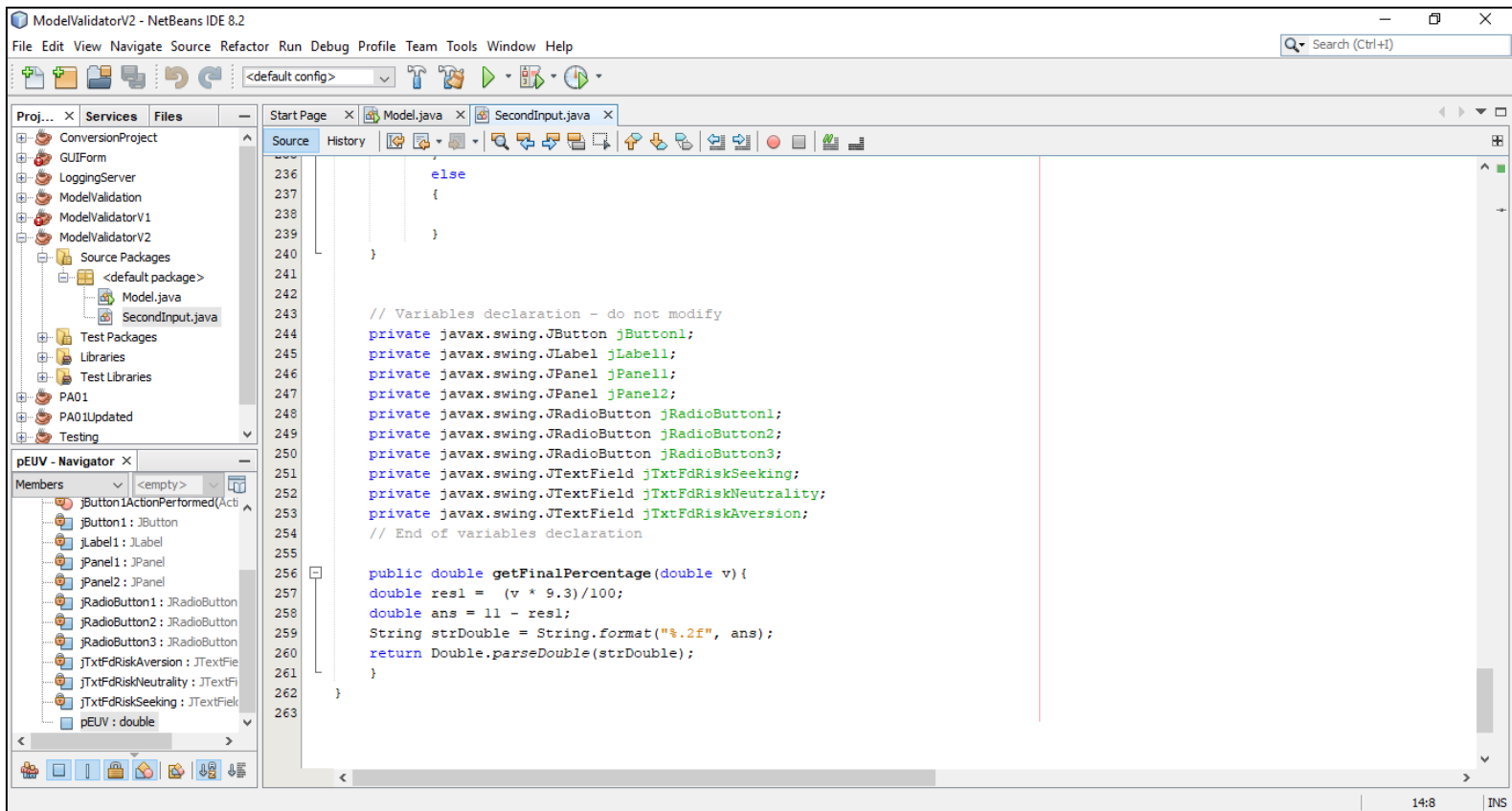












VITAE

Name : Mohammad Moutasem Al Salti

Nationality : Palestinian

Date of Birth : 11/12/1994

Email : mgalsalti@gmail.com

Address : Al Murabba District, Riyadh - 12613 - 3420

Academic Background : Bachelor of Science in Civil Engineering

Mohammad is a recipient of scholarship jointly awarded by King's Salman's Educational Program and Prince Sultan University, from which he earned a bachelor's degree in civil engineering, with focus on construction engineering management, with a distinguished GPA of 3.92 out of 4. He was on the Dean's List throughout his undergrad studies and received a certificate of appreciation from the Deanship of Student Affairs for academic excellence. Mohammad's passion has led him to explore the emerging technologies and software including BIM technology, Navisworks, Revit and Primavera. He has established a profound understanding in this field, which allowed him to present multiple lectures to the public. To consolidate his knowledge, Mohammad interned with Samsung Construction and Trading Corporation and Llbnaa Fnoon Contracting Company for a year. Professionally, Mohammad has worked as a junior site manager at Mada Al-Binaa Contracting Company in several government projects, where he conducted cost and schedule risk analysis, solved invoicing disputes with client, and prepared project schedule. After Mohammad's enrollment in his graduate studies at KFUPM, he became an avid researcher working on multiple

research projects in his area of interest, while maintaining a 4 out of 4 CGPA. Mohammad was nominated to peer review for the International Journal of Construction Management. His research interest includes the application of artificial neural network in construction, automation and robotics in construction, BIM technology, life cycle costing, feasibility analysis, sustainability, green buildings, construction productivity estimation, cost estimation, risk management and multi-criteria decision-making. Far from academia, Mohammad is deeply committed to social activism and humanitarian work; he has received numerous rewards and recognition for his participation in various occasions and events including the International Psychological Health and TEDx. He is a certified social pioneer and an active member of Ghadan, a non-profit organization advocating for youth empowerment and social entrepreneurship in the Kingdom. In addition, he co-founded Rehla Club in 2014, which organized field trips to several private and governmental entities including the Consultative Council, and served as President for two consecutive years. He also took the initiative to tutor students several topics in Thermodynamics and Reinforced Concrete.