IDENTIFICATION AND MODELLING OF CONSTRUCTION SUPPLY CHAIN RISK TRIGGERS

Parana Thanthirige Ranil Shanaka Sugathadasa

(118077M)

Thesis submitted in fulfillment of the requirements for the Degree
Doctor of Philosophy

Department of Transport and Logistics Management

University of Moratuwa
Sri Lanka

July 2018

Declaration of Originality

I declare that this is my own work and this PhD thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or institute of higher learning and to the best of my knowledge and belief, it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Signature: .... Date: ....

Copyright Statement

Signature: …………………….   Date: …………………….

Statement of the Supervisors

The above candidate has carried out research for the PhD thesis Dissertation under my supervision.

1. Name of the supervisor: ……………………………..

2. Name of the supervisor: ……………………………..

Signature of the supervisor: .... Date: ....

Abstract

The primary research problem was to identify and study the nature of triggers of construction supply chain risks within the context of the Sri Lankan construction industry. All of the important supply chain risk owners of the construction supply chains such as construction contractors, materials suppliers, consultants, client and construction industry as a whole as well as risk triggers created by them were considered in the research and this level of research has not been conducted before. The construction supply chain risk triggers are identified and categorized under construction industry specified risks, stakeholder generated risks and materials supply related risks. Stakeholder generated risks are further categorized as client generated risks, consultant generated risks and contractor generated risks. This is the first time in the literature, which used a holistic categorization for construction supply chain risks. Construction industry specified risk triggers are all types of risks from the construction industry/country/global context which are broken into the sand problem, regulations, seasonal trends and labour problem. Stakeholder generated risks triggers are contractor generated risks, consultants generated risks, and client generated risks. Contractor generated risks triggers are planning risks, decision making risks, financial risks, communication risks and sub-contractor risks. Client generated risk triggers are risks on communicating the scope of work and risks on fund supply. Consultant generated risks triggers are risks on submitting accurate designs and estimates. Materials supply related risk triggers are materials supply related quality risks, materials supply related availability risks, materials supply related on time delivery risks, materials supply related price risks. This is the first time in the literature, which used risk triggers to classify construction supply chain risks. Further, the research presents an interaction model the Risk Relationship Diagram (RRD) explaining the risk triggers and their impacts in the construction supply chains considering all the supply chain partners. The RRD can be used as a tool to assess the impact of triggers created by each stakeholder on others or how the triggers created by other stakeholders will affect each stakeholder. The model is useful in academic and practitioner perspective to investigate risk triggers at various points of the supply chain and to assess the risks and mitigation methods. Equations are derived to explain the relationship between each of the risk owners and respective risk triggers. Using the respective equations, each respective risk owner generated risk in value of money or time for a past project/contractor/consultant/client/materials supplier can be calculated. Using the answer, the perceived risk for each of the respective risk trigger for future similar project/contractor/consultant/client/materials supplier can be calculated. Using this model, the total risk impact for a given construction project can be derived. It is identified that the human generated risks, infrastructure/resource limitation risks and unavoidable risks are deep rooted primary risk triggers of any of the construction supply chains. However, the results presented are based on the Sri Lankan context and when the findings are applied for different socio economic context, the methodology explained can be used to a good extent but the models should be verified with the new context-This study reveals the risk profile of the Sri Lankan construction industry also. Further, twenty five risk topics were identified for the Sri Lankan construction supply chains. This research reveals twelve methods of risk identification as a holistic approach of construction supply chain risk identification. The methods can be used with suitable modifications to identify risks in any other supply chain also. The Double Triangulation Methodology introduced in this research can be applied in other research as a viable research methodology. In the Double Triangulation Methodology, it is suggested that it is compulsory to validate the results using minimum two other different data sets/two other approaches (ex: both qualitative and quantitative approaches).

Acknowledgement

Conducting this research study is not possible without the help and support of main supervisors, Prof. Amal S Kumarage, Department of Transport and Logistics Management of University of Moratuwa and Dr. Lee Styger of Sydney Business School, University of Wollongong. The knowledge, passion and guidance of my esteemed supervisors are gratefully acknowledged. I must be thankful to Prof Asoka Perera of the Department of Civil Engineering, University of Moratuwa who kept me focused on the research whilst advising with useful insights. I take this opportunity to thank, Eng.S.N.Bentotage & Dr. T. Sivakumar, the former Heads of the Department, Prof.Amal S Kumarage, Head of the Department and Dr. Varuna Adikariwattage, Post Graduate Coordinator of the Department of Transport and Logistics Management as well as Post Graduate Division and Faculty of Post Graduate Studies for the support extended.

I must be thankful to all those who supported from the industry with their valuable insights in obtaining the data.

I take this opportunity to thank my late father and beloved mother for motivating me to pursue a PhD and my loving wife and two sons for all their sacrifices.

Doing a PhD were a challenging years spent by me. I know the Universal Power supported me a lot when I was in difficulty. Thank you Universe!

P.T.R.S. Sugathadasa
Department of Transport and Logistics Management
Faculty of Engineering
University of Moratuwa

Table of Contents

Declaration of Originality i

Copyright Statement ii

Statement of the Supervisor iii

Abstract iv

Acknowledgement v

List of Tables x

Chapter 01 1

1.0 INTRODUCTION 1

1.1 Introduction to the Research 1

1.2 Background of the Research 2

1.3 Research Problem 3

1.4 Objectives of the Research 4

1.5 Scope of Work 4

1.6 Methodology 5

1.7 Limitations of the Research 6

1.8 Structure of the Thesis 7

Chapter 02 9

2.0 CRITICAL ANALYSIS OF RELATED LITERATURE 9

2.1 Introduction 9

2.2 Principles of Supply Chain Management (SCM) 9

2.3 Construction Supply Chain Management (CSCM) 15

2.4 Understanding Risk 17

2.5 Classification of Risks 19

2.6 Supply Chain Risk Identification, Analysis and Management 24

2.7 Construction Supply Chain Risk Management 30

2.8 Construction Project Risk Management 34

2.9 Construction Risk Analysis and Risk Identification 41

2.10 Background to Sri Lankan Construction Industry 43

2.10.1 Comparison of the Constituent, Methodology and Process. 45

2.10.2 Comparison of the Challenges 45

2.11 Literature Gaps 52

2.12 Summary of the Chapter 53

Chapter 03 54

3.0 RESEARCH DESIGN AND METHODOLOGY 54

3.1 Introduction 54

3.2 Discussion on Different Research Methodologies 54

3.2.1 Quantitative, Qualitative and Mixed Methods 54

3.2.2 Triangulation 57

3.3 Identification and Justification of the Methodology for the Research 58

3.4 Theory Behind the Research Design and Methodology 61

3.5 Map of the Research Design and Methodology 67

3.5.1 Achieving Objectives 1 and 2 69

3.6 Achieving Objective 3 73

3.6.1 Achieving Step 1 of Objective 3 73

3.6.2 Achieving Objective 3, 4 and 5 from Historical Data 76

3.6.3 Achieving Step 2 of Objective 04 from Perceived Data 81

3.7 Summary 82

Chapter 04 84

4.0 FINDINGS AND DISCUSSION 1-RISK TRIGGERS & RISK PROFILES .. 84

4.1 Introduction 84

4.2 Exploration the Risk Topics, Risk Owners and Risk Triggers 84
4.3 Validating the Risk Topics Using Triangulation 87
4.4 Deriving the Risk Triggers..88
4.5 Assessing the Probabilities and Impact from Historical Data.....................97
4.6 Assessing the Probabilities and Impact from Perceived Data...................103
4.7 Deriving an Accurate Probability for Each Risk Trigger 109
4.8 Contribution from Risk Categories (Perceived Vs Historical) 109
4.9 Contribution from Risk Owners (Perceived Vs Historical) 110
4.10 Impact of Selected Risk Triggers on Cost and Time - Case Study...........111
4.10.1 Regression Analysis – Historical Data...112
4.10.2 Case 01: Cost and Time Impact of Labour Supply Risks 113
4.10.3 Case 02: Cost and Time Impact of Seasonal Trends Risks..............114
4.10.4 Case 03: Cost and Time Impact of Risk on Com: the Sc: Work........115
4.10.5 Case 04: Cost and Time Impact of Risk on Sub: Ac:e De: and Est:..115
4.11 Summary 117
Chapter 05 118
05. FINDINGS AND DISCUSSION 2 - INTERACTION MODEL 118
5.1 Introduction 118
5.2 Arriving at Risk Relationship Diagram 118
5.2.1 Summerizing the Risk Patterns using a Tree Diagram. 126
5.3 Validation of the RRD by Qualitative Triangulation 132
5.4 Validation of the RRD Quantitatively 133
5.5 Triangulation of RRD Quantitatively 137
5.5.1 Correlation Coefficients Matrix for Major Risk Classifications........137
5.5.2 Case 01 138
5.5.3 Case 02 141

5.5.4 Case 03 ... 143
5.5.5 Case 04 ... 145
5.5.6 Case 05 ... 148
5.5.7 Case 06 ... 150
5.5.8 Case 07 ... 151
5.5.9 Case 08 ... 152
5.5.10 Case 09 ... 153
5.5.11 Case 10 ... 154
5.5.12 Case 11 ... 156
5.5.13 Case 12 ... 159
5.5.14 Case 13 ... 160
5.5.15 Case 14 ... 161
5.5.16 Construction Supply Chain Risk ... 162
5.6 Mapping of the Risk Cycle for the Construction Supply Chains ... 165
5.7 Investigating the Deep Rooted Primary Risks ... 165
5.8 Further Discussion ... 171
Chapter 06 ... 177
6.0 CONCLUSION AND RECOMMENDATIONS ... 177
6.1 Introduction ... 177
6.2 Conclusion and Contribution to the Knowledge ... 177
6.3 Limitations of the Research ... 185
6.4 Future Research ... 186
Reference List ... 187
Appendices ... 218

List of Tables

Table 2.2-1: Views on Supply Chain Management 10
Table 2.2-2: Insights about Supply Chain Implementation 12
Table 2.3-1: Importance of Construction Supply Chain Management (CSCM) 16
Table 2.5-1: Supply Chain Risk Classification 19
Table 2.5-2: Supply Chain Risk Categories and Their Triggers 23
Table 2.6-1: Risk Identification and Analysis Approaches 25
Table 2.6-2: Literature on Related Topics of Supply Chain Risk Management 29
Table 2.7-1: Importance of Risk Management in Construction Projects 31
Table 2.7-2: Risk Management and Risk Identification in Construction 33
Table 2.8-1: Construction Risk Classification 35
Table 2.9-1: Insights into Risk Analysis 41
Table 2.10-1: Growth of Construction Related Variables During 2016 42
Table 2.10-2: Literature Depiciting the Reasons for Time and Cost Overruns 45
Table 2.10-3: The Reasons for Productivity issues 45
Table 4.2-1: Risk Focus of Construction Supply Chain Stakeholders 86
Table 4.2-2: Some of the Risk Topics Frequently Quoted by Risk Owners 87
Table 4.3-1: Risk Topic and Risk Rank 88
Table 4.4-1: Each Risk Owner's Perspective about Triggers of Their Risks 89
Table 4.4-2: Definition of Risk Trigger/Risk Owner/Risk Category 90
Table 4.4-3: Analysis of the Selected Risk Topics to Assess the Risk Triggers 93
Table 4.5-1: Matrix of Risk Triggers for 38 Construction Projects 98
Table 4.5-2: Risk Profile from the Historical Data 101
Table 4.6-1: Risk Profile from the Perceived Data 104
Table 4.6-2: Risk Profile Comparison of Historical Data and Perceived Data 106
Table 4.10-1: Dependent and Independent Variables 112
Table 4.10-2: Summary of the Risk Behaviors of Studied Cases 116
Table 5.2-1: Various Risk Trigger- Risk Owner- Risk Classification Patterns 120
Table 5.2-2: Understanding Tier one and Tier Two Risk Triggers 128
Table 5.3-1: Sample Table on Selected Quotes about RRD by the Respondents 132
Table 5.4-1: Independent and Dependent Variables 134

Table 5.5-1: Primary Risk – Correlation Coefficients 137
Table 5.5-2: Correlation Coefficients of Y_1, Y_4, Y_5, Y_6 and Y_7 138
Table 5.5-3: Correlation Co-efficient Y_2 and Y_8, Y_9, Y_{10}....................................... 141
Table 5.5-4: Correlation Coefficients Y_3, Y_{11}, Y_{12}, Y_{13}, Y_{14}.................................. 143
Table 5.5-5: Correlation Coefficients $Y_{8.1}$, Y_{15}, Y_{16}, Y_{17}, Y_{18}, Y_{19} 146
Table 5.5-6: Correlation Coefficients $Y_{9.1}$, Y_{20}, Y_{21} 148
Table 5.5-7: Correlations Coefficients $Y_{11.1}$, $Y_{12.1}$, $Y_{13.1}$, $Y_{14.1}$ and $Y_{5.1}$................... 155
Table 5.5-8: Correlation Coefficients $Y_{3.2}$, $Y_{15.1}$, $Y_{16.1}$, $Y_{17.1}$, $Y_{18.1}$, and $Y_{19.1}$......... 156
Table 5.5-9: Summary of Regression Analysis... 162
Table 5.7-1: Sample Table of the Root Cause Analysis 165

List of Figures

Figure 1.1: Overview about Construction Supply Chains.. 1
Figure 3.1: Relationship among the Different Research Methodologies 53
Figure 3.2: Different Triangulation Methods and Related Literature 58
Figure 3.3: Proposed Mixed Method Research Approach.. 61
Figure 3.4: Approach for the Data Collection 66
Figure 3.5: Triangulation Road Map 67
Figure 3.6: Summery of Data Sets and Objectives Achieved 68
Figure 3.7: Risk Topic Identification Methods 69
Figure 3.8: Map of the Methodology to Achieve Objectives 1 and 2 72
Figure 3.9: Data Usage to Achieve Objective 3 73
Figure 3.10: Map of the Methodology to achieve Objective 3- Data Set 1............... 75
Figure 3.11: Methodology to Achieve Objectives 3, 4 and 5-Data Set 2.................. 80
Figure 3.12: Methodology to Achieve Objective 4 - Data Set 3 82
Figure 3.13: Descriptive Analysis of Data Set 3 82
Figure 4.1: Construction Industry Specific Risks - Tree Diagram 94
Figure 4.2: Materials Supply Related Risks - Tree Diagram.................................... 95
Figure 4.3: Stakeholder Generated Risks - Tree Diagram.. 96
Figure 4.4: Risk Profile from Historical Data 103
Figure 4.6: Probability Comparison 107
Figure 4.7: Impact Comparison 108

Figure 4.8: Validation of the Imposed Probability by Triangulation 109
Figure 4.9: Probabilities of Risk Categories.. 110
Figure 4.10: Probabilities of Risk Owners 111
Figure 5.1: Construction Supply Chain Risk - Tree Diagram 127
Figure 5.2: Risk Relationship Diagram (RRD) 131
Figure 5.3: Risk Relationship Diagram with Y Coding 135
Figure 5.4: Perceived Risk... 136
Figure 5.5: Quantitatively Proved Risk Relationship Diagram (RRD) 164
Figure 5.6: Mapping of the Risk Cycle for the Construction Supply Chains.......... 165
Figure 5.7: Mapping of Demand Risks of Construction Materials……………….168

List of Abbreviations

BCP	- Business Continuity Planning
CSCM	- Construction Supply Chain Management
CSCMP	- Council of Supply Chain Management Professionals
CTR-Cost	- Time-Risk diagram
COQ	- Costs of Quality
EPC	- Engineering, Procurement and Construction
ERIC-S	- Evaluating Risk in Construction–Schedule Model
HRBS	- Hierarchical Risk Breakdown Structure
ICTAD	- Institution of Construction Training and Development
JV	- joint venture
MSCM	- Manufacturing Supply Chain Management
PERT	- Project Evaluation and Review Technique
RC	- Risk Cycle
RO	- Risk Owner
RRD	- Risk Relationship Diagram

RT - Risk Trigger

RC - Risk Classification

VMI - Vendor Managed Inventory

List of Appendices

Appendix I - Extract from Data Set: Background Study 220

Appendix II - Extract from Data Set 1 (Sample Data Set)...................................... 224

Appendix III - Calculating the Frequency of Common Risk Topics 227

Appendix IV - Data Set 2: List of Reviewed Construction Projects........................ 228

Appendix V - Data Set 2 229

Appendix VI - Data Set 3... 231

Appendix VII - Data Set 3: Descriptive Analysis 235

Appendix VIII- Data Set 2: Identify Root causes 238

Appendix IX - Data Set 2: Sample Calculations.. 240

Appendix X - Comments about RRD: Data Set 1... 241

Appendix XI - Data Set 2 Regression Analysis: A Case Study............................... 247

Appendix XII - Regression Analysis Chapter 5 (From Data Set 3)......................... 270

Appendix XIII - Deep Rooted Primary Risk Triggers 300

Chapter 01

1.0 INTRODUCTION

1.1 Introduction to the Research

Azhar et al. (2016) state that construction is one of the most dynamic, risky, and challenging sectors. The high degree of risk is due to the nature of its business activities and construction processes. Unpredictability of the external environment further worsen the situation. The construction industry is not good in managing risks because a considerable percentage of projects fail to meet deadlines and cost targets, and it is common for clients, consultants, contractors, materials suppliers and the public to suffer as a result. According to Ahmed and Azhar (2004), construction risks are generally perceived as events or a series of events that negatively influence project objectives of cost, time and quality.

Contextually, a construction project is an environment which results in a physical civil engineering outcome, and the risk of a given project is linked to it directly. Moreover, the risk of a given project is linked directly to the scope, budget, timelines and quality expectations of the given project. The risks of a given project are directly or indirectly linked to its supply chains. Figure 1.1 provides an illustration of supply chains that operating within the construction industry.

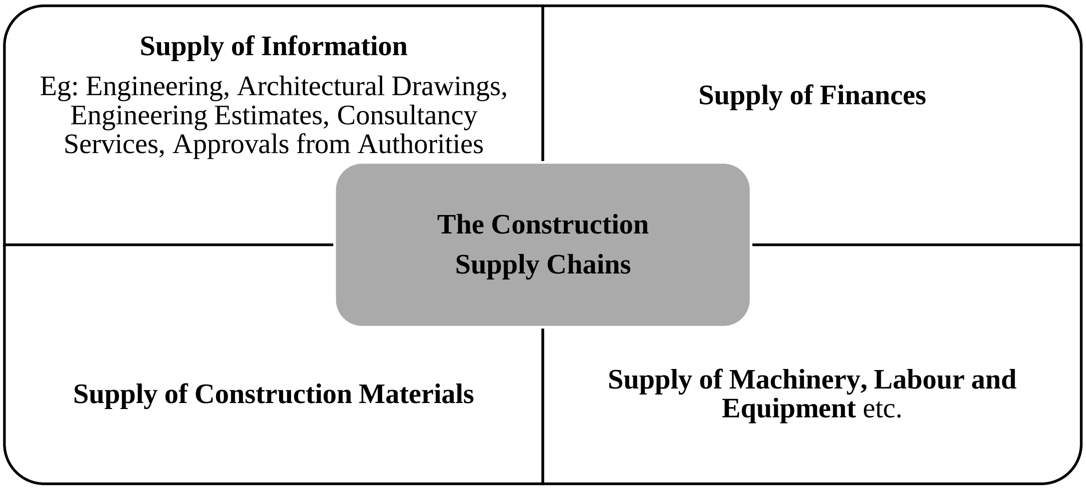


***Figure 1.1*: Overview about Construction Supply Chains (Source: Author)**

Construction supply chains can contain hundreds of firms, contractors; subcontractors; material and equipment suppliers; engineering and design firms; and consulting firms etc. (Brien, 2001; Taylor et al., 1999). The construction industry supply chain is highly fragmented and made up of many small and medium size suppliers and subcontractors (Briscoe et al., 2001; Dainty et al., 2001). Construction projects need a high level of coordination among various stakeholders, who may even have conflicting interests (Wong et al., 1999). Materials often have to be imported resulting in the supply chain becoming global and more difficult to manage.

Some of the risks associated with the construction supply chains are reasonably predictable or readily identifiable. Some other risks are more difficult to observe. According to Azhar et al. (2016), the level and scope of those risks vary from project to project. As construction projects become more technically and contractually complex, the associated risks are magnified. Thus, timely and adequate risk identification and analysis is paramount in order to enable risk to be adequately managed and administered (Cohen, 2002). Ideally, the identification and analysis of the risks needs to be conducted by considering all the supply chains associated with the construction project. The identification of the risks (or risk topic) should be the identification of the causes of the risk, known as the risk triggers (Schoenherr and Tummala, 2011). This research focuses on identifying the triggers of construction supply chain risks within the Sri Lanka context.

1.2 Background of the Research

Rehan et al. (2016), Sungkon et al. (2015), Panchanan et al. (2015), Abigail et al. (2014), Faisal et al. (2013), Wong (2010), Loosemore et al. (2008), Muya et al. (1999), Ruben et al. (2000), Andrew et al. (2006), Geoffrey et al. (2006), Silas et al. (2006), Boris et al. (2004) have studied construction supply chains, however considerable research still needs to be done. Even though, these authors studied risk topics/risk categories, there was limited research which studied causes of the risks (risks triggers). However the study of risk triggers, will help both proactive and reactive approaches of risk management. There is little research, which has studied risk triggers created by all the major stakeholders of construction supply chains such as construction contractors, consultants (engineers, architects, and quantity surveyors), clients or clients' engineers, construction materials suppliers, sub-contractors, regulatory authorities etc. Further, there is little qualitative or quantitative research, which has studied the interrelationship among these risk triggers created by different stakeholders in construction supply chains. Importantly, there has been no holistic approach to depict the mapping of interrelationship among the supply chain risk triggers created by different stakeholders in construction supply chains. According to Styger (2011), it is important to map the complex supply chains to understand and assess risks and it is important to map the relationship among various supply chain stakeholders and risk triggers. Construction is complex in nature, therefore, any risk to any part of the construction supply chain can create potential negative impacts not only on its upstream or downstream supply chains, but also other construction supply chains linked to the construction project or even construction industry as a whole. For an example, a change in the macro environment of the construction industry can create risk triggers to any of the construction supply chains or supply chain stakeholders. Similarly, a change in the micro environment of a project can create risk triggers at different supply chains, different stakeholders or even the construction industry as a whole. The research gap is determined to be understanding of triggers and their interrelationships in construction supply chains within the Sri Lankan context.

The construction industry in most countries is an extremely competitive with high risks and low profit margins, (Mochtar and Arditi, 2001). According to Mbachu (2014), "being cautious of the priority risks and application of the identified effective risk mitigation measures could help to create accurate budget in responding the risks. Thereby ensuring more satisfactory project outcomes". In this context, this research focus is important to both an academic and practitioner point of view.

1.3 Research Problem

The primary research problem is to identify and study the nature of triggers of construction supply chain risks within the Sri Lankan context.

The specific research problems related to the research questions are;

1. What are the risk topics of construction supply chains?
2. Who are the owners of these risk topics of construction supply chains?
3. What are the triggers of construction supply chain risks;
    a. Generated from construction industry?
    b. Generated from construction contractors?
    c. Generated from client/consultant?
    d. Generated from material supplier and supply environment?
4. What is the risk profile for construction supply chains?
5. What is the relationship among these different risk triggers?
6. What are the deep rooted primary triggers of all the risk triggers?

1.4 Objectives of the Research

The aim of the research is to identify the triggers of construction supply chain risks. The research objectives are;

1. Identify the risk topics of the construction supply chains.
2. Identify the triggers of construction supply chain risks, generated from risk owners such as client, consultant, construction contractors, suppliers and construction industry.
3. Identify the risk profile of the construction supply chains
4. Identify the relationship among the different risk triggers and risk owners
5. Investigate the deep rooted primary triggers of all the above risk triggers.

1.5 Scope of Work

The scope of the work is to investigate the risk triggers created by different construction supply chain stakeholders and understand the interrelationship among the supply chain stakeholders. The research is carried out in the Sri Lankan construction industry context.

1.6 Methodology

As there is only limited research conducted in this area, as such an exploratory natured qualitative research is important in this context. On the other hand, there are significant amounts of research done on supply chain risk management in the global context, in general providing a foundation for deeper quantitative analysis to assign probabilities, impacts and to determine overall risk profiles. Hence, this research uses both a qualitative and quantitative approach. More specifically, this study uses a face to face interview method as a data collection technique to explore the extent of the various risks in construction supply chains, and to get an expert assessment of its risk perceptions.

Preliminary qualitative findings were arrived using one to one interviews of two clients (clients' representative engineers), three consultants (two engineers and an architect), 12 of the largest construction companies, represented by ten project managers, 22 engineers and five quantity surveyors and seven companies supplying construction materials. These interviews were designed as unstructured open ended interviews, so that the risk topics and their triggers were identified and ranked by the industry. The risk triggers were categorized under various risk owners, such as contractor generated, client generated, consultant generated, materials supplier generated and construction industry stakeholder generated.

A Risk Relationship Diagram (RRD) showing the various risk triggers and risk owners were arrived at using a lab test (leading to focus group discussions) with 38 engineers/project managers/quantity surveyors/architects and analysed the results qualitatively. Detailed project information of 38 construction projects were collected, which was completed during 2015 and 2016. The major focus is estimated cost against actual cost and estimated duration against actual construction duration for each of the major step of construction. The reasons for each risks were given and they were further analysed and arrived with 20 different risk cases, which can be generalized. Using the same data, a risk profile, which explains the probabilities and impacts for the risk triggers were established.

Triangulation of RRD qualitatively and quantitatively was carried out using an independent data set collected from 55 independent project managers, engineers, quantity surveyors, architects and managers. By asking these participants to mark the most critical 10 risks factors, the probability and impact for future projects on a scale of 1-5 were indicated and analysing of the risk factors qualitatively, and the RRD is triangulated qualitatively. Using the same data, a risk profile, which explains the futuristic probabilities and impacts for the risk triggers was established, which was known as the risk profile based on predicted probability and impact data. Using both the risk profiles based on past data and predicted data, a forecasted risk profile was proposed. Further, the constructive feedback for the RRD was taken to explore the strengths of the RRD as well as the areas to improve. Additionally, interviewees were asked to constructively criticize the RRD to investigate, how far it can be used to assess construction supply chains risks. Quantitative inputs were taken for each risk topic in the risks relationship diagram with inputs from the same 55 independent project managers, engineers, quantity surveyors, architects and managers. In a lab test (leading to focus group discussions) they were given the RRD and asked to rank each of the risk factor based on their past experience. Mathematical analysis were done to prove the relationships quantitatively, as such, the results were double triangulated.

The RRD was further given to 10 construction materials suppliers to obtain feedback to potential usage of it for forecasting purposes and risk management purposes in the downstream supply of construction materials. Using further qualitative analysis, three deeply rooted primary risk triggers were identified as human generated risks, infrastructure related risks and unavoidable risks.

1.7 Limitations of the Research

The research was conducted in the Sri Lankan context and the fitness of these risk profiles to any other country, needs to be found out through empirical work. However, the findings can be useful to derive the risk profiles and explore the link between the risk triggers of various construction supply chain stakeholders in any other country.

The findings are based on construction supply chains of construction project managed by a large construction contractor, involvement of consultants and sub-contractors. Construction supply chains involving small/medium projects done by small/medium contractor is excluded in this research. Only the main part of risk owners such as the main construction contractors, clients or their engineers, direct material suppliers (business to business) were interviewed. Risk owners such as sub-contractors of the main contractor, upstream suppliers of the material suppliers, financiers or external stakeholders, such as regulatory authorities, politicians, general public etc. were not interviewed directly due to practical limitations. However, the risk triggers created by them were assessed through those who were interviewed. In a construction project performance is measured by the achievement of construction cost, construction duration and construction quality and the risks can affect one or many of them. In this research, the impact of the research was assessed on the impact of the construction cost and construction duration only because they are the only parameters that can be compared with estimates and actual data.

1.8 Structure of the Thesis

The structure of this thesis is as follows:

Chapter 2 discusses the literature on the principles of supply chain management, construction supply chain management, project and business risks, construction supply chain risk management and literature gaps in construction supply chains. It discusses the Sri Lankan construction industry and a comparison of the Sri Lankan construction industry in the global context. It further discusses the challenges and unique problems in the Sri Lankan construction industry, key industry performance measures and the role of the supply chain in the Sri Lankan construction industry.

Chapter 3 discusses the research design and methodology which includes a discussion on different methodologies, identification and justification of the research methodology and the research design.

Chapter 4 presents the discussion and findings of the construction supply chain risks in Sri Lanka including risk topics, risk owners, risk triggers, risk classification, risk focus of construction supply chain stakeholders, risk profile of construction supply chains based on past data, risk profile of construction supply chains based on predicted data.

Chapter 5 depicts the research findings on a model linking the risk owners and risk triggers including the construction of the interaction model known as Risk Relationship Diagram, Risk Cycle, qualitative and quantitative validation of the RRD, deeply rooted primary risks.

Chapter 6 is the conclusion of the work, identifying the contribution to knowledge and recommendation for the further research

Chapter 02

2.0 CRITICAL ANALYSIS OF RELATED LITERATURE

2.1 Introduction

An introduction to this research work is given in chapter 01, where the research questions were discussed, the research objectives were identified and methodological approach was provided. The intention of this research is to study the primary triggers of construction supply chain risks as well as their interactions. This chapter consists of a literature review from 1978 to 2017 that brings together relevant knowledge concerning supply chain, construction supply chain and risk management. Supply chain principles are discussed as the foundation for this research work. Risk definition, risk classification, risk identification and risk management are discussed as they form the essential core elements of this research work. Further supply chain disruptions management, crisis management, supply chain resilience, supply chain sustainability and business continuity planning are discussed because of their overlapping nature to risk management. Construction supply chains and the risk management of the construction supply chains are also discussed. This chapter describes the background, and data to Sri Lankan construction industry. It further provides a comparison of the Sri Lankan construction industry in global context, its challenges and unique problems and summary.

2.2 Principles of Supply Chain Management (SCM)

Construction supply chain management (CSCM) is an emerging area of practice, which has originated from manufacturing supply chain management (MSCM), which was the foundation for developing supply chain management principles (Tran et al., 2012). Supply chain management has been defined by the Council of Supply Chain Management Professionals (CSCMP) as: "*Supply Chain Management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply* *chain management integrates supply and demand management within and across firms. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across firms into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology*"(CSCMP, 2008). Table 2.2-1 provides an overview of various definitions of supply chain management from key authors.

Table 2.2-1: Views on Supply Chain Management

Literature	**Views on Supply Chain Management (SCM)**
Cachon et al. (2017)	Supply chain issues ranging from supply contracts to supply chain coordination, and, more recently, operational issues arising from the sharing economy.
Lariviere (2016)	The research in supply chain management is getting saturated.
Theodore et al. (2011)	"Few companies have yet to take advantage of the stakeholder value opportunity presented through supply chain activities. One primary reason for this lack of progress is that many firms retain a traditional "functional" view of the supply chain, seeing it only as the area responsible for managing trucks, pallets, manufacturing lines and warehouses and thus being unable to make the strategic link between supply chain performance and shareholder value".
Mentzer et al. (2006)	Proposed the additional functions of marketing, production, and operations management into supply chain. The supply chain includes all the operations within a firm as well join all possible firms together involved in a specific good to form the extended supply chain.
Brindley and Ritchie (2004)	Introduced terms such as the "basic supply chain", which "typically focuses on the linkages between a single organization and its immediate supplier and/or immediate customer." An "extended supply chain" looks at additional echelons and includes multiple organizations, while the "ultimate supply chain" incorporates the complete scope all the way from securing raw materials to delivering products to the final customers.
Vachon and Klassen (2002)	Supply chain management includes "all activities associated with the flow and transformation of goods from the raw material through to the end customer".

Literature	Views on Supply Chain Management (SCM)
John et al. (2001)	Defined "direct supply chain," an "extended supply chain," and an "ultimate supply chain. A direct supply chain consists of a company, a supplier, and a customer involved in the upstream and/or downstream flows of products, services, finances, and/or information. An extended supply chain includes suppliers of the immediate supplier and customers of the immediate customer, all involved in the upstream and/or downstream flows of products, services, finances, and/or information. An ultimate supply chain includes all the organizations involved in all the upstream and downstream flows of products, services, finances, and information from the ultimate supplier to the ultimate customer".
Handfield and Nichols 1999	Supply chain management includes "all activities associated with the flow and transformation of goods from the raw material through to the end customer".
Ross (1998)	Supply chain process as the actual physical business functions, institutions, and operations that characterize the way a particular supply chain moves goods and services to market through the supply pipeline.
Tyndall et al.(1998)	"Some authors define SCM in operational terms involving the flow of materials and products, some view it as a management philosophy, and some view it in terms of a management process".
Cooper et al. (1997)	Defined SCM as the management and integration of the entire set of business processes that provides products, services and information that add value for customers.
Towill (1996)	"A system whose constituent parts include materials supplies, production facilities, distribution services and customers linked via the feed forward flow of materials and the feedback flow of information."
Christopher (1992)	Supply chain is the network of organizations that are involved, through upstream and downstream linkages, in the different processes and activities that produce value in the form of products and services delivered to the ultimate consumer. In other words, a supply chain consists of multiple firms, both upstream (i.e., supply) and downstream (i.e., distribution), and the ultimate consumer.

(Source: Author)

Analyzing the content in Table 2.2-1, it can be concluded that supply chain includes all activities involved in the production and delivery of a final product or service, from the supplier's supplier to the customer's customer. Supply chain management integrates supply and demand management within and across companies. In other words SCM includes the management of supply and demand, sourcing of raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, and distribution and delivery to the customer.

It is important to note that research dealing with concepts of risk and disruption in a supply chain context do not always incorporate all of the above areas. Research incorporating the full scope of the supply chain is difficult and rare (Blackhurst et al., 2005).

Table 2.2-2 depicts the insights regarding supply chain implementation. Literature on key concepts such as sharing information, mutual sharing of risks and rewards, cooperation among the supply chain members, supply chain integration, supply chain process orientation and bullwhip effect are presented.

Table 2.2-2: Insights about Supply Chain Implementation

Literature	Insights About Supply Chain Implementation
Wu et al. (2014), Daniel et al. (2012),Cheng (2011), Cai et al. (2010), Kanda et al. (2008),Vicky et al. (2004), Tyndall et al. (1998), Cooper et al. (1997); Cooper et al. (1997), Ellram and Cooper (1990), Novack et al. (1995)	Mutually sharing information among supply chain members is required to implement a SCM.
Srinivasan et al. (2011), Cao et al. (2010), Cheng(2008),Schmid et al. (2008),Nishat et al. (2006),Min et al. (2005), Palaneeswaran et al. (2003) , Mentzer et al. (2001), Tyndall et al.(1998), Cooper et al. (1997); Cooper et al. (1997), Langley and Rinehart(1995), Ellram and Cooper (1990)	Mutually sharing risks and rewards that yield a competitive advantage.
Stadtler (2015), Ballou (2007),Li and Lin (2006), Tan et al. (2001), Mentzer et al. (2001), Chandra and Kumar (2000),Ellram and Cooper, 1990; Tyndall et al. (1998), Anderson and Narus (1990), Heide and John (1990)	Cooperation among the supply chain members is required for effective SCM.
Prajogo (2012), Wong et al. (2011),Flynn et al. (2010) , Kim et al. (2009), Yang et al. (2009), Awad (2010), Yao et al. (2007),Bagchi et al. (2005), Gunasekaran and Ngai (2004), Fawcett and Magnan (2002),Tyndall et al. (1998), Cooper et al. (1997), Cooper et al. (1997) , Ellram and Cooper (1990), Novack et al., (1995)	Integration of processes from sourcing, to manufacturing, and to distribution across the supply chain.
Monczka et al. (2015), Lambert and Garcia-Dastugue (2001), Cooper (2000),Croxton et al. (1998)	To successfully implement SCM, all firms within a supply chain must overcome their own functional silos and adopt a process approach.

(Source: Author)

The points in Table 2.2-2 are explained as follows.

Open sharing of information such as inventory levels, forecasts, sales promotion strategies, and marketing strategies reduces the uncertainty between supply partners and results in enhanced performance (Wu et al., 2014; Daniel et al., 2012; Cheng, 2011; Cai et al. 2010; Kanda et al., 2008; Vicky et al., 2004; Tyndall et al., 1998; Cooper et al., 1997; Cooper, Lambert, and Pagh, 1997; Ellram and Cooper, 1990; Novack, et al., 1995). Risk and reward sharing is important for long-term focus and cooperation among the supply chain members cooperation refers to similar or complementary, coordinated activities performed by firms in a business relationship to produce superior mutual outcomes or singular outcomes that are mutually expected over time (Srinivasan et al., 2011; Cao et al., 2010; Cheng, 2008; Schmid et al., 2008; Nishat et al., 2006; Min et al., 2005; Palaneeswaran et al., 2003; Mentzer et al.,2001, Tyndall et al.,1998; Cooper et al., 1997; Cooper et al., 1997; Langley and Rinehart, 1995; Ellram and Cooper,1990. According to Behnam et al. (2015) supply chain partners work jointly to mitigate SCRs. by risk information sharing and risk sharing mechanisms.

Cooperation starts with joint planning and ends with joint control activities to evaluate performance of the supply chain members, as well as the supply chain as a whole. In addition to planning and control, cooperation is needed to reduce supply chain inventories and pursue supply chain-wide cost efficiencies (Cooper et al., 1997; Dowst, 1988). Furthermore, supply chain members should work together on new product development and product portfolio decisions (Drozdowski, 1986). Design of quality control and delivery systems is also a joint action (Stadtler, 2015; Ballou, 2007; Li and Lin, 2006; Tan et al., 2001, Mentzer et al. 2001; Chandra and Kumar, 2000; Ellram and Cooper, 1990; Tyndall et al., 1998; Anderson and Narus, 1990; Heide and John, 1990; Treleven, 1987).

Integration can be accomplished through cross-functional teams, in-plant supplier personnel, and third party service providers (Olhager, 2012; Wong et al. 2011; Flynn et al. 2010; Kim et al. 2009; Yang et al. 2009; Awad, 2010; Yao et al., 2007;

Bagchiet al., 2005; Gunasekaran and Ngai, 2004; Fawcett and Magnan, 2002; Tyndall et al., 1998; Cooper et al., 1997; Cooper et al, 1997; Ellram and Cooper, 1990; Novack et al., 1995).

All the functions within a supply chain are reorganized as key processes, which include customer relationship management, customer service management, demand management, order fulfillment, manufacturing flow management, procurement, and product development and commercialization (Monczka et al., 2015; Lambert and Garcia-Dastugue, 2001; Cooper, 2000; Croxton et al., 1998).

According to Lee et al. (1997), due to the bullwhip effect, distorted information from one end of a supply chain to the other can lead to tremendous inefficiencies. Companies can effectively counteract the bullwhip effect by thoroughly understanding its underlying causes. Industry leaders are implementing innovative strategies that pose new challenges: 1. integrating new information systems, 2. defining new organizational relationships, and 3. implementing new incentive and measurement systems.

According to Christopher (1992), leading-edge companies have realized the real competition is not company against company, but rather supply chain against supply chain. Cooper et al. (1997) argue that organizational relationships tie firms to each other and may tie their success to the supply chain as a whole. In this context, a supply chain as a whole may have its own identity and function like an independent firm.

Many of the above theories and research findings are based on the manufacturing supply chain management (MSCM), they are applicable in construction supply chains. However, there are also circumstances that inhibit (Briscoe and Dainty, 2005) the development and diffusion of the supply chain concept in construction. According to Eisa et al. (2017), some of the SCM concepts from manufacturing sector may not be directly applicable in construction.

2.3 Construction Supply Chain Management (CSCM)

Construction supply chain management is the core focus of this research and as such an extensive literature survey was carried out. According to Tran et al. (2012), supply chain management is an emerging area of practice in the construction industry worldwide.

Construction Supply Chain Management (CSCM) is defined as "a system where suppliers, contractors, clients and their agents work together in coordination to install and utilize information in order to produce, deliver materials, plant, temporary works, equipment and labour and/or other resources for construction projects" (Hatmoko and Scott, 2010, p.36). The major emphasis of MSCM is on modeling of production volume; whereas CSCM is primarily concerned with the coordination of discrete quantities of materials (and associated specialty engineering services) that must be delivered to specific construction projects (O'Brien et al., 2008).

Four studies were carried out to apply this concept to the construction context (O'Brien, 2009; London et al, 2008; Kara et al, 2008; Yoo et al, 2011). Construction project supply chain may contain contractors; sub-contractors; material and equipment suppliers; engineering and design firms; and consulting firms etc. (Brien, 2001; Taylor et al., 1999). It remains highly fragmented and involves many small and medium size suppliers and subcontractors (Briscoe et al., 2001; Dainty et al., 2001). In most cases, materials have to be imported and supply chain becomes global and more difficult to manage. Further, construction projects need a high level of coordination among various stakeholders, who have conflicting interests (Wong et al., 1999). According to Marzouk et al. (2011), construction supply chains start with design phase and the design phase is generally identified as the phase where the customer's ideas and speculations are conceptualized into a physical model by defining his needs and requirements into procedures, drawings, and technical specifications (Freire et al., 2002). Construction supply chain management (CSCM) includes flows of materials, labour, information, plant, equipment and temporary works, which may originate from various parties (Hatmoko et al., 2010).

There are compelling reasons for the implementation of supply chain management in construction. Table 2.3-1 depicts the importance of construction supply chain management.

Table 2.3-1: Importance of Construction Supply Chain Management (CSCM)

Literature	Importance of Construction Supply Chain Management (CSCM)
O'Brien (2000)	"Supply Chain Management (SCM) as a whole takes a systems view of the production activities of independent production units (subcontractors and suppliers in construction) and try to holistic optimization of these activities. Therefore, the SCM basics is that system performance supersedes individual operation optimization. The system view of SCM contrasts with the hierarchical approach of traditional construction methods, where individual activities such as planning, controlling and contracting for projects are optimized separately." Hence, CSCM is very important.
Spillane et al. (2011)	When materials are not delivered to site as per the project programme, it results in delay in construction projects. Therefore, effective logistical management and supply chain management is essential in the overall material management process.
Agapiou et al.(1998), Poon et al. (2004a)	The benefits of effective material management are well documented, resulting in significant monetary savings and schedule compression where implemented.
Navon and Berkovich (2006)	In the majority of construction projects, materials amount to between 50-60% of the total contract cost, (Song et al., 2006) effective management of this resource can lead to a reduction in costs, resulting in a significant saving. A potential 6% saving on total cost through effective materials management is achievable (Bell and Stukhart, 1987), yet the construction industry invests only 0.15% in materials management and control.
Kini (1999), Formoso et al.(2002)	Based on the possible savings that are achievable through CSCM, the potential for more competitive tendering and increased profit margins are evident. As many of the authors outline, materials management is core to the successful management of a construction project.

(Source: Author)

Supply chain management in construction is both diverse and complex (Hughes, 2009). According to Male and Mitrovic (2005), the practice of supply chain management in construction has two discrete organizational structures; first, a contractor-led supply chain and second, a client-led supply chain. Both supply chains are short, bilateral arrangements (King and Pitt, 2009) that function largely independent of one another (Vrijhoef and de Ridder, 2005).

The contractor-led supply chain has a distinct organizational orientation, with networking arrangements (Eccles, 1981). The contractor-led supply chain is an inventory of sub-contractors and suppliers that the main construction contractor may call upon for the delivery of specialist and general construction services and products. According to Vrijhoef and Koskela (2000) there are four contractor-led supply chain management roles; the operational interface between contractor and suppliers, the operational capacity of the upstream supply chain, transferring onsite construction processes offsite and creating a fully integrated and refined supply chain management structure. In addition to the four contractor-led roles, Vrijhoef and Koskela (2000) also identified a fifth role; the construction client and the role of client-led supply chain management. Government support for client-led supply chain management is unmistakable, given the growing popularity of public sector strategic alliances, public private partnerships and more recently construction framework agreements (Chevin, 2011).

The client-led supply chain is typically the bilateral relationship between the construction client and the first-tier construction contractor. Contrary to the organizationally orientated contractor-led supply chain, the client-led supply chain retains a distinctive project focus (Male et al., 2005). Driven by the construction client, the success of the alliance is arguably governed by the scale of integration and level of corporate interdependency embedded within the client-led supply chain.

2.4 Understanding Risk

As the focus of the research is identification of risk triggers in the construction supply chains, it is important to present the relevant literature on risk in general. This section will start by defining risk and risk management in general, briefly discuss what research is being done in this area, and then focus on risk management in a supply chain context.

Risk has been defined in various ways, depending on the perspective taken. The simplistic view is that risk is the probability of incurring a [financial] loss (Knight 1921). Waters (2007) used a definition of “potential harm from unforeseen events”.

Risk can be "the extent to which there is uncertainty about whether potentially significant and/or disappointing outcomes of decisions will be realized" (Sitkin and Pablo, 1992).

Risk can be categorized into variables. There can be internal and external risks (Waters, 2007). Risk often is defined in the context of what it refers to and the concepts that make it up. In the supply chain literature, sometimes the sources of a crisis are commonly referred to as risks. Sometimes, risk is identified as the sources of disruptions.

In general, risk management is a method used to avoid, reduce, transfer, or share risks (Norrman et al., 2004). Quantifying or prioritizing a risk was shown to be one of the early steps taken in risk management. Efforts to quantify risk have resulted in the idea that the probability of the risk occurring can be multiplied by the effect on business that the risk would have leading to an expected value (Doherty, 2000; Norrman et al., 2004). This is frequently simplified into an impact vs. likelihood chart (Sheffi, 2005). Ogden et al. (2005) used such a two-dimensional matrix with 'likelihood' and 'impact' axes to help place the various supply strategies that firms could employ.

Lockamy and McCormackb (2009) indicated that risks can be defined as a combination of likelihood and outcome. Further, risks are described as the combination of outcome and most relative possibilities. They defined an equation to define risks as;

Risk= $\{(L_1,O_1),(L_2,O_2),\ldots,(L_n,O_n)\}$, Where Li is likelihood and Oi is outcome. The risk has two more dimensions as time and perspective.

Gunasekaran et al. (2012) indicated three elements to describe risk; loss, importance, and probability of appearance. The risk of an event n from probability of loss P ($loss_n$) and the importance of the loss L ($loss_n$) is expressed by the equation.

$$\text{Risk } n = P(loss_n) * L(loss_n) \quad (2.1)$$

2.5 Classification of Risks

Understanding the existing literature on risk classification gives an insight to the research around construction supply chain risk management. To facilitate a systematic and comprehensive risk identification process, several classification schemes can be presented. Categorizing risks not only improves the effectiveness and quality of risk identification, but also supports better communication among the actors involved in the process (Stecke et al., 2009). Table 2.5-1 depicts the supply chain risk classifications.

Table 2.5-1 Supply Chain Risk Classification

Literature	Supply Chain Risk Classification
Heckmann et al. (2015), Jabbarzadeh et al. (2014)	Disruptions are either due to natural risks (e.g. earthquake, floods, fire, and tsunami) or man-made risks (e.g. terrorist attacks, accidents, supplier adulterations, and cyber-attacks) that are inherent to the underlying global supply chains.
Behzad et al. (2012)	Severities and indexes were categorized as catastrophic, critical, marginal and negligible. Further, four risk probability categories such as often, infrequent, rare and extremely rare were developed. Risk factor was calculated by multiplying risk consequence index into risk probability. Risks were categorized into catastrophic, critical, marginal and negligible risks by the calculated risk factors.
Gunasekaran et al. (2012)	Risks were examined in nine categories; disruptions, delays, systems, forecast, rational property, procurement, receivables, inventory and capacity.
Schoenherr and Tummala (2011)	Introduced risk categories as demand risk, delay risk, disruption risks, inventory risks, process break down risks, physical plant risks, supply risks, system risks, Sovereign risks, Transportation Risks.
Blos et al. (2009)	Classified supply chain risks into four categories of vulnerability: financial, strategic, hazard, and operations.

Literature	Supply Chain Risk Classification
Ravindran et al. (2010)	Low-Likelihood, High-Impact disruptions: for example, labor strike, terrorist attack or natural disaster. This class is also termed Value-at-risk (VaR) type disruptions. High-Likelihood, Low-Impact disruptions: for example, late delivery or missing quality requirements. This is frequently called "operational" or "day-to-day" disruptions "Miss the target (MtT) risks".
Malini et al. (2009)	Considered the overall supply chain, which results in different internal/external factor classification. Considered, problem with a supplier could be either an internal factor (e.g. machine breakdown due to the lack of preventive maintenance) or an external factor (e.g. damage at the suppliers' facility due to an earthquake). Crises that are caused by the supply chain operating environment are classified under external sources. Some examples of external sources are disasters (both man-made and natural), market, economy, and legal/regulatory/political issues together with some other miscellaneous factors such as criminal acts and infrastructure.
Thun et al. (2009)	Made a distinction between "internal company" and "cross-company" risks. The latter are further divided into "purchasing risks" (upstream) and "demand risks" (downstream). External supply chain risks are also subcategorized into sociopolitical, economical, technological or geographical disruptions.
Manuj and Mentzer (2008a)	Discussed additional risks to the supply chain such as security, macro (such as exchange rates), and policy risks.
Paulsson (2007)	Divided risk into two parts. One part represents operational or static risks that exist within the product flow. The other includes dynamic risks found outside the product flow, such as inflation, new laws, and terrorism.
Wu et al.(2006)	Proposed an internal/external factor-based classification for inbound supply risk. considered a problem with a supplier as an external factor,
Tang (2006a)	Divided his methods for managing supply chain risk into supply management, demand management, product management, and information management.
Peck (2005)	In this multi-level classification conceptual framework, the sources for supply chain risks are presented in four main levels of "value stream/product or process", "assets and infrastructure dependencies", "organizations and inter-organizational networks" and "environment".

Literature	Supply Chain Risk Classification
Norman et al. (2004)	Introduced three dimensional model, or typology, to categorize risks in the supply. Their three axes are the ‘unit of analysis’ (or scope of the risk within a supply chain), ‘type of risk and uncertainty’ (which they have divided into strategic risks, financial, operational, commercial, and technical), and ‘Risk and Business Continuity Management’ which was meant to display the level of risk management activities in a firm on a continuum from simple risk analysis to complete business continuity planning (BCP).
Chopra et al. (2004)	Introduced risk categories as delays, systems, forecast, intellectual property, procurement, receivables, inventory, capacity, and disruptions as aspects of supply chain risk. It should be noted here that their examples of disruptions include natural disasters, labor disputes, and supplier bankruptcy.
Christopher and Peck (2004)	Considered three categories of risk sources – “Internal to the firm, “external to the firm but internal to the supply chain network”; and “external to the network”. Risk sources “Internal to the firm” are further subcategorized into “process risks” and “control risks”. The category “external to the firm” includes “demand” and “supply” risks. Risk sources “external to the network” or “environmental risks” are exemplified by natural disasters, terrorist attacks and regulatory changes.
Cavinato (2004)	Discussed that identifying risks and uncertainties in supply chains must focus on five sub-chains/networks in every supply chain: Physical, Financial, Informational, Relational and Innovational networks.
Brindley and Ritchie (2004)	Classified under context related and less under a firm’s influence (environmental, industry, and organizational) and those over which the firm has greater influence (problem specific and decision-maker).
Das et al. (1996)	Explained two types of risks that occur in a supply network; relationship risks and performance risks. Relationship risks occur due to relationship failures; continuous defects done by partners, awareness of opportunistic behaviors, lack of understanding between partners, conflict risk, non-learning of skills, loss of core proprietary capabilities cause violation risk. Performance risks occur due to factors such as alliance performance; intensified challenge, changing of government regulations, demand fluctuations, and lack of competence of partner firms.
Ritchie and Marshall (1993)	Included environmental, industry, organizational, problem specific, and decision-maker related categorization

(Source: Author)

Table 2.5-1 explains various risk classifications discussed in the literature. Another location-based classification approach is to categorize the risk sources into “supply” and “demand” (Wagner and Bode, 2006; Sodhi and Lee, 2007; Tang and Tomlin, 2008). This classification can be regarded as offering a “supply chain view” (Sodhi and Lee, 2007). “Supply Risks” are located in the supply base of company (upstream) while “demand risks” are associated with the demand side and activities downstream of the supply chain. For example, second-or third-tier suppliers with which the focal firm has no direct contact can also be part of the firm’s risk management process (Choi et al., 2006; Kull et al., 2008).

Tang et al. (2008) included a “process risk” category which consists of risks associated with in-house operations and in-bound and out-bound logistics. Sodhi et al. (2007) considered a third class of “contextual risks” that include cultural differences in multinational operations, environmental, regulations, and exchange rate risks across countries. Supply risk refers to the risk of supply to the firm being disrupted for any reason. This can happen through bankruptcy, under capacity for production, unconfirmed pricing structures, inadequate quality, inability of the supplier to procure their supplies, and many others.

Another approach called “scale-based classification” suggested in literature categorizes disruptions according to their likelihood and impact. Low-likelihood, High-impact disruptions are named as “catastrophes” or “catastrophic events” by Lodree et al. (2008), Knemeyer et al. (2009) and Huang et al. (2009). High-likelihood, Low-impact disruptions are named as “operational” or “day-to-day” disruptions (Kleindorfer et al., 2005; Huang et al., 2009). A third class of “Medium-likelihood, Medium-impact” is discussed by Oke et al. (2009) and included risk factors like changing regulations which does not occur very frequently, but is normally more frequent than natural disasters.

In addition to categorization approaches discussed here, a number of papers discuss only specific risks or try to identify risks that occur in certain situations. For example, risk sources exacerbated by globalization and offshoring are discussed by

Tan et al. (2006), Colicchia et al. (2010),Deane et al. (2009) and Tsai et al. (2008) studied logistics outsourcing risk; Faisal et al. (2007) identified four types of information risks: information security/breakdown risk, forecast risk, intellectual property rights risks, and IS/IT outsourcing risks; Sanchez-Rodrigues et al. (2010) specifically discuss transportation risks and Roth et al. (2008), Chao et al. (2009) and Pyke et al (2010) focus on product quality and recall problems.

According to Gunasekaran et al. (2012), a risk management process was expressed as risk classification, risk identification, risk calculation, implementation of risk management actions and sometimes risk monitoring in some situations. A conceptual model was introduced as a combination of three steps to manage risks; attitude toward risk, tools used in risk management, techniques to minimize risk in supply networks. Communication and information sharing with partners were believed as an effective ways of managing risks. Malini et al. (2009) classified the crisis management into four primary stages: mitigation, preparedness, response, and recovery.

Schoenherr and Tummala (2011) introduced a general approach to specify supply network risks, assess their likelihood and severity, risk mitigation plans, and implementation process. Furthermore, supply network risk categories and their causes were described. Table 2.5-2 signifies ten different risk categories of supply network with triggers.

Table 2.5-2: Supply Chain Risk Categories and Their Triggers

Risk Category	Causes of Risks
Demand risks	Order fulfillment errors Inaccurate forecasts due to longer lead times product variety, swing demands, seasonality, short life cycles, and small customer base Information distortion due to sales promotions and incentives, lack of supply chain visibility, and exaggeration of demand during product shortage

Risk Category	Causes of Risks
Delay risks	Excessive handling due to border crossings or change in transportation mode, Port capacity and congestion, Custom clearances at ports, Transportation breakdowns
Disruption risks	Natural disasters, Terrorism and wars, Labor disputes, Single source of supply, Capacity and responsiveness of alternate suppliers
Inventory risks	Costs of holding inventories, Demand and supply uncertainty, Rate of product obsolescence, Supplier fulfillment
Process Break Down Risk	Poor quality, Lower process yields, Higher product cost, Design changes
Physical Plant risk	Lack of capacity flexibility, Cost of capacity
Supply Risk	Quality of service, including responsiveness and delivery performance, Supplier fulfillment errors, Selection of wrong partners, High capacity utilization supply source, Inflexibility of supply source, Poor quality or process yield at supply source, Supplier bankruptcy, Rate of exchange, Percentage of a key component or raw material, procured from a single source
System risks	Information infrastructure breakdowns, Lack of effective system integration or extensive system networking, Lack of compatibility in IT platforms among SC partners
Sovereign risks	Regional instability, Communication difficulties, Government regulations, Loss of control, Intellectual property breaches
Transportation risks	Paperwork and scheduling, Port strikes, Delay at ports due to port capacity, Late deliveries, Higher costs of transportation, Depends on transportation mode chosen

(Source: Schoenherr and Tummala (2011), p. 475)

Table 2.5-2 explains the supply chain risk categories and their triggers. However, in the literature there is very limited discussion on risk triggers.

2.6 Supply Chain Risk Identification, Analysis and Management

As one of the core objective of this research is to investigate the supply chain risks in construction supply chains, it is important to analyze the relevant existing literature on risk analysis. One of the most frequently available sources to identify supply chain risks is the expert view. Different methods like surveys (Thun et al., 2009) or brainstorming (Norrman et al., 2004) can be used for this purpose. Adhitya et al.

(2009) explained risk identification as "The first step is to recognize uncertainties and possible sources of disruption to the supply chain operation, both internal and external." Then they explain the consequence analysis as "once the risks have been identified, their consequences have to be analyzed using an appropriate model of supply chain operations".

According to Harland et al. (2003) “The chosen types of risk are assessed for the likelihood of their occurrence, exposure in the network, potential triggers of the risk, at what stage in the life cycle the risk is likely to be realized, and what likely potential losses to whom might occur”.

Table 2.6-1 depicts the risk identification approaches.

Table 2.6-1: Risk Identification and Analysis Approaches

Literature	**Risk Identification and Analysis Approaches**
Zou et al. (2007)	Risk factors may be identified through a data-driven (quantitative) methodology or qualitative process such as interviews, brainstorming, and checklists. It is considered as an evaluation process which involves description of each risk and its impacts or the subjective labeling of risk (high/medium/low) in terms of both risk impact and probability of its occurrence.
Hillson (2002)	Listed “brainstorming and workshops, checklists, questionnaires and interviews, Delphi groups, and various diagramming approaches (e.g. cause-effect diagrams, systems dynamics, influence diagrams, etc.)” as suitable for risk identification. He mentioned that there is no single “best method” for risk identification, and an appropriate combination of techniques should be used.
Schoenherr et al. (2011)	Identification of risks can be completed using supply chain mapping, checklists or check sheets, event tree analysis, fault tree analysis, failure mode and effect analysis, and cause and effect diagrams.
Hallikas et al. (2004), Norrman et al. (2004)	Historical data of past events and review of literature or reports of similar companies can support experts in a better-informed risk identification process. It is also recommended to involve a cross-functional team of employees and a diverse group of experts in the process.
Wiendahl et al. (2008)	Ishikawa Diagram
Adhitya et al. (2009)	Hazard and Operability
Schoeuherr, 2008	Action Research Method

Literature	Risk Identification and Analysis Approaches
Tuncel et al. (2010), Yang (2010), Canbolat et al. (2008), Wu et al. (2006)	Expert Interviews
Norrman and Jansson (2004)	Personal brainstorming
Nerija et al.(2012)	Risk identification is an iterative process because new risks may become known as the project progresses through its life cycle and previously-identified risks may drop out.

(Source: Author)

According to Johnson (2001), supply chain risk management is managing the risks in supply and demand. Norrman et al. (2002) defined supply chain risk management as a procedure "to collaboratively with partners in a supply chain apply risk management process tools to deal with risks and uncertainties caused by, or impacting on, logistics related activities or resources." The concept of mitigation has been used to refer to both pre and post-disruption events. Mitigation should correctly refer to pre-disruption risk management. It can be used to refer either to an effort to reduce the likelihood of a risk occurring or reduce the effect the risk would have on the firm should it occur, as both can be viewed as efforts to lessen risk. The implication is that risk management is primarily a pre-risk activity. It does not deal with post-risk processes of restoring the firm to stability. Instead, the view of Tomlin (2006) is taken, which places these as contingency activities.

Jiho et al (2017) suggested that a combination of upstream and downstream risk mitigation strategies should be jointly considered with supplier selection rather than considering these decisions separately and focusing on applying a sole strategy. They highlighted that the simultaneous consideration of upstream and downstream risk mitigation strategies has the potential for better performance than using each strategy solely. As per Ceryno risk management was generally described as the identification and analysis of risks as well as their monitoring and mitigation (Ceryno, Scavarda, and Klingebiel 2015). A main particularity of SCRM, contrary to traditional risk management, is that it is characterised by a cross-company orientation aimed at the identification and reduction of risks not purely at the company level but instead focuses on supply chains(Jüttner2005). According to Rudolf et al (2018) supply chain is a complex network combined with the adaptive capability of various organizations, cross-organizational teaming is essential for risk identification, assessment and management. One method of reducing supply risk can be to effectively manage supplier behavior (Zsidisin and Ellram, 2003). They find that behaviors such as quality management and supplier certifications can help to manage that risk, as well as control variables such as industry, firm size, and the percentage of sales the purchasing firm has. Early supplier involvement is another means to reducing supply risk. This was found by using a case study approach also with agency theory (Zsidisin and Smith, 2005). Far less research on demand risk and strategies for its reduction has been done (Tang, 2006a). As such, the firm incurs the possibility of lost sales as a customer shops elsewhere. The simplest way for a firm to manage this risk is to have plenty of inventory for every product sold. However, this is commonly known to be an untenable idea. Instead, firms manage this risk more effectively by shifting demand over time, markets, or products (Tang, 2006a).

As Tang (2006a) mentioned, many firms respond to competition by offering greater product variety which increases inventory, design, and manufacturing costs. Managing these costs and associated risks, many firms offer postponement (Manuj et al., 2008a), and may reverse the process sequence of manufacturing where appropriate (Lee et al., 1998; Tang, 2006a).

Managing information related to demand as well as between elements in the supply chain can be an effective way of managing risk. Such strategies as vendor managed inventory (VMI), collaborative forecasting, and managing products with short life cycles with delayed ordering (and thereby more accurate forecasts) are all means of achieving this end. Christopher et al. (2004) advocated that end-to-end supply chain visibility is vital to gaining supply chain confidence and help to manage risks. In the following sections, affiliated research areas of supply chain risk management are discussed as they form an important theoretical and practical insight.

Martin et al. (2004) discuss that the vulnerability of supply chains to disturbance or disruption has increased. It is not only the effect of external events such as wars, strikes or terrorist attacks, but also the impact of changes in business strategy. Many companies have experienced a change in their supply chain risk profile as a result of changes in their business models, for example the adoption of "LEAN" practices, the move to outsourcing and a general tendency to reduce the size of the supplier base.

According to Azhar et al. (2016), the last step in the risk management process is risk response control which includes executing the risk response strategy, monitoring triggering events, initiating contingency plans, and watching for new risks. According to Behnam et al. (2015) while certain supply chain risks can be prevented, other risks can be mitigated so that supply chain operations can be restored quickly after a disruption. Some of the more common strategies for mitigating supply chain risks include managing vulnerabilities through Agility (Lee, 2004), Flexibility (Tang and Tomlin, 2008) and Resilience (Sheffi and Rice, 2005).

According to Behnam et al. natural first step is to define and classify supply chain risks and there is a need to construct frameworks to help make sense of the field. One framework development tactic is to classify works using an evolutionary perspective such as: (1) identifying risks; (2) assessing risks; (3) mitigating risks; and (4) responding to risks (e.g. see Blackhurst and Wu, 2009; Sodhi and Tang, 2010; Zsidisin and Ritchie, 2010).

Supply chain disruption, supply chain sustainability, supply chain resilience, supply chain security supply chain vulnerability, business continuity planning (management) and crisis management are related research topics of supply chain risk management.

Table 2.6-2 depicts literature on related topics of supply chain risk management.

Table 2.6-2: Literature on Related Topics of Supply Chain Risk Management

Topic	Literature
Supply Chain Disruption	Matsuo (2015), Sawik (2014), Sawik (2013), Schmitt and Singh (2012),Zegordi and Davarzani (2012), Tomlin and Wan (2011), Wakolbinger and Cruz (2011), Dowty and Wallace (2010), Yu et al. (2009),Skipper and Hanna (2009), Craighead et al. (2007),Gaonkar et al. (2007), Sheffi (2001), Chapman et al. (2002), Cooke (2002), Koch, (2002), Machalaba and Kim (2002), Mitroff and Alpaslan (2003), Blackhurst et al. (2005), Melnyk et al. (2005), McKinnon (2006 h)
Supply Chain Sustainability	Mota et al. (2015), Penfield (2014), Seuring and Müller (2008), Linton et al. (2007), Kleindorfer et al. (2005), Lee (2004)
Supply Chain Resilience	Bellow (2016), Vecchi and Vallisi (2015), Wieland and Wallenburg (2013), Jüttner and Maklan (2011), Pettit et al. (2010), Datta et al. (2007), Sarathy (2006), Caniato (2003), Rice and Caniato (2003), Sheffi and Rice (2005)
Supply Chain Security	Markmann et al. (2013), Yang (2011), Marucheck et al (2011), Thibault et al. (2006), Russell and Saldanha (2003), Rice et al.(2003)
Supply Chain Vulnerability	Heckmann et al. (2015),Wagner and Neshat (2012), Colicchia and Strozzi (2012), Waters (2011), Thun and Hoenig (2011), Peck (2005), Zinn et al. (2006), Svensson (2000)
Business Continuity Planning (Management)	Wright (2017), Cremonini andSamarati (2012), Warren (2010), Zsidisin et al. (2005), Rice and Caniato (2003), Hiles (2007), Hiles et al.(2001), Norrman et al.(2004), Savage(2002), Barnes (2001), Norrman and Lindroth(2004).
Crisis Management	Boin et al. (2016), Booth (2015),Alfonso, Suzanne (2008), Mitroff and Alpaslan (2003), Pearson et al.(1998), Hale et al.(2006)

(Source: Author)

A supply chain disruption can be anything that affects the flow and supply of raw materials, sub-components, components, and finished goods all the way from origin to the final demand point. Craighead et al. (2007) defined a supply chain disruption as “unplanned and unanticipated events that disrupt the normal flow of goods and materials within a supply chain.” Gaonkar et al. (2007) indicated that there are three levels of these types of risk, namely deviation, disruptions, and disasters.

Sustainability is one of the newest concepts to be linked to risk management and disruptions. It has been defined as “using resources to meet the needs of the present without compromising the ability of future generations to meet their own needs” (Linton et al., 2007).

Resilience is an ability to react to an unexpected disruption and restore normal operations, or network operations (Rice and Caniato, 2003). According to (Sheffi and Rice, 2005), resilience is "the ability to bounce back from a disruption". Supply chain security is defined as not losing product during the production and transportation phase of the supply chain due to human pilferage causes can be divided into physical security, information security, and freight security.

According to Svensson (2000) vulnerability has been defined as "the existence of random disturbances that lead to deviations in the supply chain of components and materials from normal, expected or planned schedules or activities, all of which cause negative effects or consequences for the involved manufacturer…". Chapman et al. (2002) suggested that supply chain vulnerability is "an exposure to serious disturbance, arising from risks within the supply chain as well as risks external to the supply chain".

Business Continuity Planning (BCP) is a "system that has been developed primarily by practitioners to minimize the effects of unanticipated events on the firm's ability to meet customer requirements" (Zsidisin et al., 2005).

As per Pearson et al. (1998), Hale et al. (2006), an organizational crisis is "a low-probability, high-impact event that threatens the viability of the organization and is characterized by ambiguity of cause, effect, and means of resolution, as well as by a belief that decisions must be made swiftly". Pearson and Clair (1998) further defined crisis management as "… involve minimizing potential risk before a triggering event. A crisis can be the extreme end of a disruption in terms of impact".

2.7 Construction Supply Chain Risk Management

There are limited research on the topic construction supply chain risk management. Even though, Vinit et al. (2007) have studied the total construction supply chain in their decision support system for risk management (and they have given some examples about the risk relationship and propagation), they have not studied the holistic approach of risk relationship among the suppliers, contractors, designers, engineers and clients in the overall construction supply chains and they have not studied adequately the primary causes of supply chain risks. Table 2.7-1 depicts the importance of risk management in construction projects.

Table 2.7-1 Importance of Risk Management in Construction Projects

Literature	Importance of Risk Management in Construction Projects
Eisa et al. (2017)	The owners of complex construction projects need to pay greater attention to the integration practices of the supply network and coordinate the interfaces between multiple prime contractors which might significantly save project cost and duration.
Nerija et al. (2012)	Large construction projects are exposed to uncertain environment because of planning, design and construction complexity. Presence of various interest groups (owner, consultants, contractors, suppliers, etc.), various resources (manpower, materials, equipment, and funds) requirements, dynamic environmental factors, the economic and political environment and statutory regulations impact on the uncertainty.
Mbachu (2011)	With a study in New Zealand, the construction industry is subjected to more risk and uncertainty than many other industries and does not have a good track record of coping with risks. Late completion of projects, surpassing their estimated budgets and in some worse instances without even achieving the desired quality and operational requirements, has given a bad name to the industry. These risks are the main cause of rising cases of insolvency and liquidation/bankruptcies of many contracting firms in New Zealand
Zou et al.(2007)	Lengthy construction periods and time pressures, complexity and a very competitive market give rise to so many risks which must be responded.
Baloi et al. (2006)	Poor cost performance of construction projects seems to be the norm rather than the exception, and both clients and contractors suffer significant financial losses due to cost overruns
Dey et al. (2004)	Different participants with different experience and skills usually have different expectations and interests. This naturally creates problems and confusion for even the most experienced project managers and contractors.

Literature	Importance of Risk Management in Construction Projects
Kumar et al. (2007)	Highlighted the importance of risk management in construction project planning. After a construction firm signs the contract to deliver a project, the problem of handling supply chain risk due to unpredictable events is twofold, and has to be tackled at various strategic and operational levels. The first problem is of preventive risk management, in which the contractor has to find out various mechanisms in order to make the supply chain robust and risk resilient. The second problem is of interceptive risk management, where the contractor has to take a decision on the best action that should be taken subsequent to a risk event in order to contain the loss.

(Source: Author)

Mehrdad et al. (2012) studied the collaborative perspective in construction risk management, but they have not considered the risks that collaboration brings to the supply chain or the total supply chain from end to end and its associated stakeholders. Importantly, the primary causes of the risks and the relationship through the supply chain stakeholders are not considered. There has been work on risk management in construction supply chain management globally(Salman et al., 2007; Stuart et al., 2012; Bondinuba et al., 2016; Sharon et al., 2014; Jasper et al., 2014). However, none of these authors have considered total supply chain from end-to-end and its associated stakeholders. Importantly, the primary causes of risk and the relationship of stakeholders is not considered.

Brien et al. (2000) showed a few cases of improper risk prediction and importance of supply chain risk management in construction who describe various causes of delays in construction projects in developing countries.

In the construction industry, the concept of collaborative risk management is relatively new. According to Arashpour et al. (2011), traditional methods do not support the collaborative risks management. According to Arashpour et al. (2011), very few methods have been developed for stakeholder analysis to identify interests and concerns of major stakeholders and consider multi period effects of social relationship on supply chain risks. Active inclusion of all stakeholders is an important influence on the level of success in projects.

Table 2.7-2 depicts risk management and risk identification in construction.

Table 2.7-2: Risk Management and Risk Identification in Construction

Literature	Risk Management and Risk Identification in Construction
Azhar et al. (2016)	Revealed that the use of risk management techniques in Alabama construction industry is low to moderate depending on company size and their risk tolerance level. Most building contractors were found to apply individual intuition, judgment and experience to identify and assess risks. The main barriers preventing implementation of formal risk management practices were found to be lack of knowledge and doubts about the suitability of the risk management techniques, sophisticated nature of techniques compared to project sizes and human/organizational resistance.
Wang et al. (2015)	Reported that contractors usually use three methods to transfer risk in construction projects: 1. through insurance to insurance companies; 2. through subcontracting to subcontractor; 3. through modifying the contract terms and conditions to client or other parties.
Nerija et al. (2012)	Risk identification methods such as experiential or documented knowledge analysis, project documentation reviews, project team brainstorming, analysis of other information resources, experts 'judgment, historical information analysis, performance bond, warranties analysis, resource reserve analysis, insurance, risk transference to another project party and other methods.
Zoysa et al. (2005)	While risk management is a critical activity in construction project management, existing industry practices involve tools like risk registers, risk management spreadsheets, brain storming sessions etc. As a result many risks remain unidentified, and proper risk management becomes impossible
Uher et al. (2004)	Application of risk management tools depends on the nature of the project, organization's policy, project management strategy, risk attitude of the project team members, and availability of the resources

(Source: Author)

There is a need in the construction industry to clearly communicate projects' performance and effects on the stakeholders (Ball, 2002). Collaboration with external and internal stakeholders will provide a continuous stream of support to construction projects. In recent years collaborative approaches in the construction industry have been brought into attention as companies need to decrease their costs and increase their opportunities in the market (Cruz and Liu, 2011). However, there is no published research to date on construction supply chain risk management in Sri Lankan context.

2.8 Construction Project Risk Management

When construction supply chain risk management is discussed, it is important to consider the risk management of construction projects as it is a core part of construction supply chain.

Risks and uncertainties, involved in construction projects, cause cost overrun, schedule delay and lack of quality during the progression of the projects and at their end (Wysocki, 2009; Wang et al., 2003; Simu, 2006). Managing risks in construction projects has been recognized as an important process in order to achieve project objectives in terms of time, cost, quality, safety and environmental sustainability (Zou et al., 2007). Table 2.8-1 depicts construction risk classification.

Table 2.8-1 Construction Risk Classification

Literature	Construction Risk Classification
Arokia et al. (2017)	With respect to the joint venture (JV) construction supply chains In India: Internal risks (Policy changes in partner's parent company, partner's parent company in financial problems, over-interference by parent company of either partner, partner's lack of management competence and resourcefulness, distrust between partner employees, disagreement on allocation of staff positions in JV company/project team, disagreement on allocation of works, disagreement on accounting of profit and loss, Technology transfer dispute). External risks (Inconsistency in government policies, laws and regulations, labor, material and equipment import restrictions, restrictions on fund repatriation, economy fluctuation, Inflation, exchange rate fluctuation, force majeure, pollution, language barrier, different social, cultural and religious background, security problems at project site). Project specific risks (Partners disagree over some conditions in contract, client's excessive demands and variations, client's cash flow problems, poor relationship between JV team and client or consultant, incompetence of local subcontractors and material suppliers, ground settlement, settlement control (structures).
Tah and Carr (2001)	Categorized risks into two groups in accordance with the nature of the risks, i.e. external and internal risks.
Hong et al. (2015)	China's Engineering, Procurement and Construction (EPC)/Turnkey Contract discussed different Risk Categories. 1. Political (war/revolution/social unrest, government instability, discontinuity of government policy, bureaucracy) 2. Social (Social security is low, the diseases and medical facilities, the lack of a legal system, different cultural practices, lack of commercial facilities) 3. Natural Environment (unforeseen geological conditions, bad weather affected, floods, earthquakes and other disasters) 4. Economic (interest rate fluctuations, inflation, tax rates rise, the owners shortage of funds/payment is not in place, supervision delays and deductions, bond forfeiture) 5. Design risk (poor quality design level, whether the design and post-procurement, with the construction, design or description is not specific enough, inaccurate difference norms and standards) 6. Materials procurement and quality defects Risk, 7. Sub-contractors technical level defects, 8. Transport risks, 8. The owners change request, 9. Difficult construction.

Literature	Construction Risk Classification
Al-Baha (1990)	Risks in construction can be classified into six categories as follows: (i) Acts of God, e.g. Floods, hurricanes; (ii) Physical risks, e.g. Labor injuries, fire, damage to equipment; (iii) Financial and economic risks, e.g. Inflation, unavailability of funds; (iv) Political and environmental risks, e.g. Changes in rules and regulations, political uncertainty; (v) Design-related risks, e.g. Defective design, incomplete design; and (vi) Construction-related risks, e.g. Change orders, labor productivity, etc.

(Source: Author)

According to Nerija et al. (2012), Risks include geological or pollution-related conditions, interference with ongoing operations, construction accidents, as well as design and construction faults that may negatively impact the project both in construction and when the project is complete.

According to Arokia et al. (2017), "*The various factors like regulatory approvals, competition at tender stage, less contract duration and flow of finance are the critical factors under the project specific risks are influencing the completion of project. If any changes are made by the owner during the commencement of the work then it makes delays in the project. The continuous revision of the drawings and design details of the project even during the commencement of the work, results in the project delays. Lack of proper data and survey before designing, lack of experience of consultant with regard to type of project are known to cause project delays, which are grouped as architect/consultant related risk factors. The delays due to the huge price variations, Delay in materials delivery, improper selection of equipment, Equipment breakdowns, Shortage of equipment and labours under resource related risks results in increased project cost than what was calculated initially during the project initiation phase. From various risk factors discussed above, the risks related to architect/consultant, project, and resources varies widely with respect to their risk severity level and influences successful completion of project in the Indian construction industry to a much greater extent.*"

There are many possible risks which could lead to the failure of the construction project, and through the project, it is very important to understand what risk factors are acting simultaneously. As stated by Raz et al. (2009) too many project risks as undesirable events may cause construction project delays, excessive spending, and unsatisfactory project results or even total failure.

According to Eskesen et al. (2004), the use of risk management from the early stages of a project, where major decisions such as choice of alignment and selection of construction methods can be influenced. Construction projects can be managed using various risk management tools and techniques. Ahmed et al. (2009) reviewed techniques that can be used for development of risk management tools for engineering projects. Many authors have reviewed problems on time performance in construction projects (Baloi et al., 2001; Assaf et al., 2006; Aibinu et al., 2006). Aibinu et al. (2015) investigated and assessed the causes of delays in building projects in Nigeria. The nine factor categories evaluated include: client, contractor, quantity surveyor, architect, structural engineer, services engineer, supplier, and subcontractor caused delays, and external factors (i.e. delays not caused by the project participants). Finally, ten overall delay factors were identified, namely: contractors' financial difficulties, client' cash flow problems, architects' incomplete drawings, subcontractors' slow mobilization, equipment break-down and maintenance problems, suppliers' late delivery of ordered materials, incomplete structural drawings, contractors' planning and scheduling problems, price escalation, and subcontractors' financial difficulties.

According to Baloi et al. (2001), the construction contractors highlight that delay in payments is common both in private and public projects, with the public sector being the worse defaulter. Moreover, most types of contracts presume compensation clauses for delay in payments, but clients rarely agree to pay the interest due to the contract.

In construction projects, many parties are involved such as the owner, consultant, contractor, subcontractor, and supplier. Each party has its own risks. Risk transfer means the shift of risk responsibility to another party either by insurance or by contract.

According to Nerija et al. (2012) **s**ome of the incidental risks associated with poor project management performance are: 1.Unclear or unattainable project objectives; 2. Poor scoping; 3. Poor estimation; 4. Budget based on incomplete data; 5.Contractual problems; 6. Insurance problems; 7. Delays; 8. Quality concerns; 9. Insufficient time for testing.

Many authors have recognized the value of trust within the project business. Lewicki and Bunker (1996) emphasized that trust is a critical success element to most business, professional, and employment relationships. Trust is argued to improve the inter-organizational relationships among principal actors in project development, such as owners, contractors, and suppliers (Pinto et al., 2009). According by Krane et al. (2012) trust between project owners and project managers is crucial for project success. In business relations, as stated by Kaklauskas et al. (2010), the global economic crisis brought about distrust of other stakeholders. Trust reinforces the relationships of the critical stakeholder that often determine the success of a project (Pinto et al.,2009; Chan et al.,2003; Brewer et al., 2008, Ward et al. 2008) concluded that stakeholders are a major source of uncertainty in construction projects. Smyth et al. (2010) noted that trust provides an important resource for creating greater probability and certainty. Construction projects are tendered and executed under different contract systems and payment methods (Oztas, 2004). Chapman and Ward (2008) argued that the contract choice decisions are central to both stakeholder management and the management of risk and uncertainty.

Nerija et al. (2012) proposed an integrated approach based on a balanced incentive and risk sharing approach to contracting as well as a best practice approach to risk management in terms of the whole project life cycle. Ökmen et al. (2010) proposed a new simulation based model - the correlated cost risk analysis model - to analyze the construction costs under uncertainty when the costs and risk-factors are correlated.

Baloi and Price (2003) determined the most critical risk factors affecting construction cost performance. Twenty risk factors were established to be significant under the internal risks categories by Nerija et al. (2012). Under the design risk category, design errors/omissions and design process delays were the most frequently mentioned risk factors attributed to the contractors. Under the project management risk category, scheduling errors and failure to comply with contractual quality requirements were the most frequently mentioned risk factors. Under the construction risk category, construction cost overruns and technology changes were the most frequently mentioned risk factors attributed to the contractors. Respondents believed that these risk events are responsible for poor quality of work, delays and associated losses. Risks with high impact and high probability, such as design errors and omissions, construction cost overruns, scheduling errors and contractor delays are required further analysis, including quantification, and aggressive risk management.

According to Azhar et al. (2016), risk management is a proactive approach to control the level of risk and to mitigate its effects. It also prepares project managers to take risks when a time, cost, and/or technical advantage is possible. Successful management of project risks gives the project manager better control over the future events and can significantly improve chances of reaching project objectives on time, within budget, and meeting required technical/functional performance (Gray and Larson, 2008).

According to Azhar et al. (2016), there are four typical ways of responding to risks in a construction project, which are: (i) Risk elimination, e.g. by placing preconditions in the bid; (ii) Risk transfer, e.g. hiring subcontractors or buying insurance; (iii) Risk retention, e.g. reducing the impact of risk through preplanned strategies; and (iv) Risk reduction, e.g. training the staff about risk perception and its management (Panthi et al., 2007; Thompson and Perry, 1992).

According to Azhar et al. (2016), majority of contractor's are either risk averse or risk neutral, an organization that is conservative towards risk taking is less likely to be able to respond effectively to the unexpected circumstances. This attitude is one of the main reasons behind less innovation in the construction industry as compared to other industries. An organization with a "risk averse" culture is less likely to realize the improvements in delivery of projects with advances in technology and processes. Risk aversion, personal or organizational, is also a barrier to the effective implementation of the risk management practices. Ahmad and Azhar (2004) found a similar trend in the state of Florida where the majority of companies (over 70%) were found to depend on intuition/judgment/experience to assess risks involved in construction.

Eisa et al. (2017), described strategies to eliminate interface conflicts on the boundaries between multiple prime contractors and to improve supply chain integration of complex construction projects characterized by adversarial short-term relationships and fragmentations in project delivery procedures.

According to Govan, and Damnjanovic (2017) even within an organization, different units represent risks differently, depending on their primary function. As a result, a holistic picture of the risk exposure is often hard to describe and even harder to manage.

According to Eisa et al. (2017), “proactive interface identification (identifying interface events and scheduling interface tasks) is the key to success of interface management and complex supply chain integration. An interface mapping and tracking approach should be promoted in future research in order to provide essential interface knowledge for key participants in the complex construction projects and to visualize potential interface risks during the whole lifecycle of a project”.

Globally, extensive research has been carried out into construction risks, and several risk factors have been identified, even though little research has been carried out into construction supply chain risks. However, little research has been carried out on supply chain construction risks in the Sri Lankan context.

2.9 Construction Risk Analysis and Risk Identification

According to Azhar et al. (2016), risk assessment helps in estimating potential impacts of risk and in making decisions regarding which risks to retain and which risks to transfer to other parties. Table 2.9-1 depicts insights into risk analysis by various authors.

Table 2.9-1 Insights into Risk Analysis

Literature	Insights into Risk Analysis
Behnam et al. (2015)	Quantitative analysis of supply chain risk is expanding rapidly and sustainability risk analysis is an emerging and fast evolving research topic.
Nerija et al. (2012)	Qualitative risk analysis can lead to further analysis in quantitative risk analysis or directly to risk response planning.
Nerija et al. (2012)	Introduced a fuzzy decision framework for a systematic modeling, analysis and management of global risk factors affecting construction cost performance from contractor's perspective and at a project level.
Yang et al. (2011)	Social network analysis is a specific method to analyze the relationships among any kind of stakeholder-risk nodes. It demystifies the underlying knowledge in the network. In terms of risk analysis, a few studies have applied this method to analyses the interdependent risks associated with various stakeholders in construction projects. By this method the interrelations among the risks in the network will be considered. The major advantage is to consider the multi-criteria decision-making behavior of the stakeholders in a given construction.
Abbasi (2009)	Introduced an implicit sensitivity analysis using neural network approaches.
Ismail et al. (2008)	Provided a 'Level-Severity-Probability' approach to determine the critical risk source and factors.
Zwikael et al. (2007)	Although organizations appreciate the benefits of managing risks in construction projects, formal risk analysis and management techniques are rarely used due to lack of knowledge and to doubts on the suitability of these techniques for construction projects. There are four alternative strategies – risk avoidance, risk transfer, risk mitigation, and risk acceptance, for treating risks in a construction project.

Literature	Insights into Risk Analysis
Modarres (2006)	Quantitative risk analysis attempts to estimate the frequency of risks and the magnitude of their consequences by different methods such as the decision tree analysis, the cost risk analysis, and Monte Carlo simulation.
Aramvareekul et al. (2006)	The Cost-Time-Risk diagram (CTR) proposed helps project managers consider project risk issues while monitoring and controlling their project schedule and cost performance in one diagram.
Pai et al. (2003)	Risk analysis involves three broad aspects namely vulnerability assessment, consequence analysis and implementation.
Nasir et al.(2003)	Analyzed schedule risks and developed a comprehensive construction schedule risk model is referred to as Evaluating Risk in Construction–Schedule Model (ERIC-S). The ERIC-S model provides decision support to project owners, consultants, and researchers as a project delay prediction tool.
Carr et al. (2001)	Introduced a hierarchical risk breakdown structure (HRBS), and the HRBS represents a formal model for qualitative risk assessment.
Tah et al. (2001)	Used a Knowledge Engineering approach and present a qualitative risk analysis framework using object modeling for managing supply chain risks in construction projects.
Dey and Ogunalana (2001)	Appreciated probabilistic analysis by Monte Carlo simulation.
Hatush and Skitmore (1997)	Appreciated deterministic analysis by: Project Evaluation and Review Technique (PERT).
Lorterapong (1996)	Used Fuzzy set approaches for risk management.
Woodward (1995)	Used explicit sensitivity analysis using regression or correlation between risk variables.
Bahar et al. (1990)	Used Monte Carlo Simulations to analyze and evaluate construction project risks.

(Source: Author)

The application of the quantitative risk analysis allows the construction project exposure to be modeled, and quantifies the probability of occurrence of the identified risk factors as well as their potential impact. Various risk management tools are available, but unfortunately they are not suitable for many industries, organizations and projects (Zwikael et al., 2007). As stated by Hillson (2009), risk mitigation and risk response development is often the weakest part of the risk management process. The proper management of risks requires that they be identified and allocated in a well-defined manner. This can only be achieved if contracting parties comprehend their risk responsibilities, risk event conditions, and risk handling capabilities (Perera, 2009).

Both quantitative and qualitative techniques are available for risk assessment. The quantitative methods rely on probability distribution of risks and may give more accurate results than the qualitative methods, if the available data is strong and reliable. On the other hand, qualitative methods depend on personal judgment and past experiences of the analyst and the results may vary from person to person. Hence the quantitative methods should be given precedence if both choices are available (Ward et al, 1997).

2.10 Background to Sri Lankan Construction Industry

The construction industry has been a key sector in the Sri Lankan economy for many years. According to the Central Bank Annual Report of Sri Lanka (2016), "*The value added of construction activities rebounded during the year recording a substantial growth of 14.9 per cent in 2016 recovering from 2.7 per cent contraction recorded in 2015."* The Table 2.10-1 depicts the growth in the construction sector during 2016 compared to 2015.

Table 2.10-1 Growth of Construction Related Variables during 2016

Aspect in the Construction Sector	**Growth during 2016 Compared With Year 2015**
Value addition to the economy	14.90%
Local production of cement	17.80%
Import of cement	29.50%
Import of investment goods	20.00%
Import of building materials	22.90%
Credit granted by private banks to the construction activities	27.10%
Number of completed condominium units	24.50%

(Source: Central Bank Annual Report, 2016)

Large scale construction projects such as Colombo International Financial City, extension of Southern Expressway, Phase III of Colombo Outer Circular Highway project and emerging condominium apartments largely contributed to the expansion in construction activities (Central Bank Annual Report 2016). The main construction projects initiated by the government are the construction of expressways and roads (The Southern Expressway Expansion project, the Outer Circular Highway and the Central Expressway that enhance the connectivity between Western, Southern, North Central and Central Provinces, the i-ROAD programme, Priority Roads Project, Northern Road Connectivity Project and several bridge construction projects), railroad construction, urban and town center development and irrigation systems etc. Furthermore, the government launched its flagship project, the Western Region Mega polis Master Plan, in 2016 with an anticipated cost of US dollars 40 billion which was targeted to resolve issues related to urbanization, such as traffic congestion, poor housing conditions, waste disposal and access to basic utility services by improving essential infrastructure, such as information and communication, personal housing construction activities as well as large-scale private construction activities such as hotel projects and apartment complexes also play a significant role in the Sri Lankan construction industry (Central Bank Annual Report, 2016).

The Annual Survey of Construction Industries (2015), estimated the total value of work done by all types of construction activities in Sri Lanka was USD 522 million in 2015. The highest contribution to this value has been made by the building construction sector which accounted for 48.0 % of the total value of work done. The major share of the value of work done by the building construction sector (which amounted 250 million Sri Lankan Rupees) has come from the private and public sector. High way and roads construction was the second highest contributor to the value of work done, amounting to 32.6% of the total value.

The construction industry accounts for 7.2% of the total work force in the country, which amounts to around 570,000 persons. The percentage of professional, technical, operator and craft categories are 11%, 12%, 6% and 71% respectively. Almost 97% of total persons employed were males with 75% falling in the 25-45 age-group. 52% were with experience of less than five years. Engineers fall in to the category of professionals and 97% of them are male (Department of Census and Statistics, Government of Sri Lanka, 2015).

The success factors for any construction project are in time completion, within specific budget and requisite performance (technical requirement). Dey (2011); Dey et al. (2002); Patrick et al. (2007) explained the key performance areas in terms of cost, time, quality, safety, environmental sustainability and stakeholder satisfaction.

There is no specific literature found regarding how to compare two construction industries in the context of studying construction supply chains. However, based on the general literature, it can be reasonably argue that the comparison of the Sri Lankan construction industry in the global context can be done in two ways. One is the comparison of the constituent, methodology and process of construction and construction supply chains. Other one is the comparison of the challenges of Sri Lankan construction industry/projects within a global context. The comparison of the construction industries is important because the findings of this research is based on Sri Lankan construction industry and may be useful for a construction industry with similar supply chains and challenges. Even for the construction supply chain challenges which are significantly deviating from the Sri Lankan construction industry, the findings can be used with suitable modifications.

2.10.1 Comparison of the Constituent, Methodology and Process of Construction and Construction Supply Chains.

Based on the overall literature review, the constituent of the Sri Lankan construction industry is similar to construction industries in many other countries. There are many similarities in the construction process, design work, construction project management activities, materials used, machinery used, people employed as well as construction supply chains. However, there can be country specific or project specific variations.

2.10.2 Comparison of the Challenges of Construction and Construction Supply Chains.

According to the literature, some of the major challenges of the construction industry includes time and cost overruns, productivity issues, quality problems and associated root causes. The following section discusses some typical issues commonly discussed in the literature both in global context and Sri Lankan context.

2.10.2.1 Time and Cost Overrun

According to Kaming et al. (1997) and Trigunarsyah (2004), time overrun is the extension of time beyond planned completion dates usually traceable to contractors. Elinwa and Joshua (2001) defined it as the time lapse between the agreed estimation or completion date and the actual date of completion. Bramble and Callahan (1987) described time overrun as the time during which some part of construction project is completed beyond the project completion date or not performed as planned due to an unanticipated circumstance.

Numerous studies relating to causes of time or cost overruns have been conducted worldwide in developed countries such as the USA and UK (Xiao and Proverbs, 2002), and developing countries such as Nigeria (Okpala and Aniekwu, 1988; Mansfield et al., 1994; Dlakwa and Culpin, 1990), Saudi Arabia (Assaf et al., 1995), Thailand (Ogunlana et al., 1996), Malaysia (Wang, 1992) and Jordan (Al-Momani, 2000).

Frimpong et al., (2003); Alaghbari et al. (2007); Sweis et al. (2008); Fugar and Agyakwah-Baah, (2010) established that the problem of project delays and cost overrun are caused by financing and payment for completed works. Ogunlana et al., (1996); Ojo et al., (1999) emphasized poor contract management as a main cause of time and cost overrun. Changes in site conditions (Mansfield et al. (1994), Al-Momani, (2000)), shortage of materials (Ogunlana et al., (1996)), design changes (Mansfield et al. (1994), Xiao and Proverbs (2002)), weather condition (Frimpong et al., (2003)), also were recognized as main factors of time and cost overruns.

The Table 2.10-2 depicts some literature explaining the reasons of time/cost overruns related to some countries including Sri Lanka.

Table 2.10-2: Literature Depicting the Reasons for Time and Cost Overruns

Literature	Country	Reasons for time/cost overruns
Nadarajapillai et al. (2012)	Sri Lanka	Availability of materials, labour shortage
Oko (2012)	Nigeria	Inadequate funds for the project, inadequate planning before project take off, inadequate tools and equipment's, delay in delivery of materials, contractors' financial difficulties, the project owners' cash flow problems, incomplete drawings, subcontractors' incompetency, equipment breakdown, late delivery of materials, planning problems, price escalation and subcontractor's financial problems
Fugar and Agyakwah-Baah (2010)	Ghana	The inability of clients (building owners) to honour payments on time
Frimpong et al. (2003)	Ghana	Financial problems are the main factors
Alaghbari et al. (2007)	Malaysia	List of thirty-one (31) factors, clients, contractors and consultants agreed that financial problems were the main factors causing delay.
Sweis et al. (2008)	Jordan	Financial difficulties faced by the contractor and too many change orders
Abd El-Razek et al. (2008)	Egypt	Financing irregularity by contractor

(Source: Author)

Al-Momani (2000) conducted a survey on 130 public projects in Jordan and found delays occurred in 106 (82%) of the projects studied. Frimpong et al. (2003) observed that 33 (70%) out of 47 projects in Ghana were delayed. Ogunlana et al.'s (1996) study in Thailand and Kaming et al.'s (1997) study in Indonesia found that most projects became delayed because of contractor's issues. Abd. Majid and McCaffer (1998) found that 50% of the delays to construction projects can be categorized as non-excusable delays, for which the contractors were responsible.

Construction cost has increased drastically during the last 5 years in Sri Lanka; increased costs of inputs including that of human resources, have contributed to this situation. Dolage et al. (2013), Dolage et al. (2015), Kesavai et al. (2015), Risath (2016) discussed time overruns and noted that it is a major problem in the Sri Lankan construction industry. Shanumgan et al. (2006) and Silva et al. (2016) discussed the cost overruns in the Sri Lankan construction industry and noted that it is a problem to address. Hence, time and cost overrun are common problem to the construction sectors in any country.

2.10.2.2 Productivity Issues

Productivity is defined as a ratio between an output value and an input value used to produce the output (Borcherding et al., 1986). Output consists of products or services and input consists of materials, labour, capital, energy, etc.

Table 2.10-3 depicts the reasons for productivity issues in different countries.

Table 2.10-3: The Reasons for Productivity Issues

Literature	Country	Reasons for productivity issues
Nayanathara et al. (2005)	Sri Lanka	Disruption of work, due to non-availability or frequent breakdown, of equipment, poor management of cash flow, resulting from payment delays, escalation of prices of inputs, lapses on the part of consultants too have contributed to disruption of work and wastage or idling of resources in projects, leading to low productivity.
Gunawardena et al.	Sri Lanka	Low quality of materials; lack of skilled labour; incompetent subcontractors; lack of commitment and capability of site staff; incorrect construction methods; and lack of site supervision.
Perera et al. (2003)	Sri Lanka	Corporation among the client, architect, civil structural, electrical and mechanical engineers are not sufficient in Sri Lankan context in delivering maximum value to a construction project.
Makulsawatudom et al. (2004)	Thailand	Lack of materials, incomplete drawings, incompetent supervisors, lack of tools and equipment, absenteeism, poor communication, instruction time, poor site layout, inspection delay and rework.
Enshassi et al. (2007)	Gaza Strip	Factors that impact negatively on labour productivity as material shortages, lack of experience of labour, lack of labour surveillance, and alteration of drawings/specification during execution.
Ameh and Odusami (2002)	Nigeria	Low wages, lack of materials and unfriendly working atmosphere as having key impact on productivity

According to Perera et al. (2003), costs of quality (COQ) in construction are estimated to between 8% and 15% in Sri Lanka. According to COQ models, there are three types of costs: prevention costs, appraisal costs, and failure costs. The failure costs are usually regarded as avoidable and if minimized through preventive measures, they could lead to substantial reduction in appraisal costs. The prevention costs associated with such approaches are comparatively low and previous research studies suggest that through spending 1% more in prevention costs, the failure costs can be reduced in the order of 8% of the construction costs (Roberts, 1991).

According to Nadarajapillai et al. (2012), a problem, due to a vacuum created in the human resources supply caused by migration of competent labour, resulting in low productivity and poor quality, has been identified in the industry. Contribution by skilled and unskilled labour to the Industry in Sri Lanka, is primarily through informal means. This has been identified as a factor affecting the labour productivity in the industry. Poor and irregular turnout, shifting and migration, of labour causing disruption of work has been observed. The construction industry suffers from inadequate supply of professionals, less skill levels of fresh graduates and skilled labour force. High demand for the professionals in many countries and low level of salary in the local industry may reduce the number of professionals retained in the local construction industry. According to 14th Construct conference held in 2008, organized by ICTAD, a need that has been identified in improving the productivity of skilled personnel in the industry, is to have a higher level of basic education and literacy of the persons who intend joining the occupation. Hence, productivity is a common problem to construction in any country.

2.10.2.3 Issues of Fund Supply and Financial Management

As explained in the Table 2.1, Oko (2012), Fugar and Agyakwah- Baah (2010), Swies et al. (2008), Abd El-Razek et al. (2008), Alaghbari et al. (2007) discussed the impact of financial problems and cash flow issues to the cost and time overruns.

With the knowledge gathered in the expert interviews, in the Sri Lankan context, many construction projects suffered due to fund supply related issues even though research has not carried out in this area. Hence, issues of fund supply are issue to construction in any country.

2.10.2.4 Customer Satisfaction

According to Muya et al. (1999), customer requirements in the construction industry has increased and as such construction companies have to add greater value, improve quality, reduce cost and reduce construction schedule. As such supply chain management in construction is an important area. He pointed out that there is a trend towards supply chain integration in the UK construction industry. It is revealed that entrenched practices and attitudes among UK contractors still impede full supply chain integration in the supply of construction materials. According to Nadarajapillai et al. (2012), the customer orientation of the Sri Lankan construction contractors is below average.

2.10.2.5 Issues on the Construction Supply Chains

Construction supply chains comprises of many different supply chains such as materials supply chains, equipment and machinery supply chains, supply of other services, supply of funds, supply of labours etc.. Patil et al. (2012) have discussed the importance of supplier selection in construction productivity. Thunberg et al. (2013) have mentioned "The construction industry is experiencing poor productivity, resulting from an inability of contractors, subcontractors, and suppliers to cooperate efficiently. Research in logistics in construction lacks a holistic perspective and tends to focus on one activity at a time".

The supply of construction materials has been estimated to: control 80% of the project schedule from initial materials acquisition to delivery of the last item (Kerridge, 1987). According to Muehlhausen (1991) and Stukhart (1995) enhancing efficiency in the supply of construction materials can result in major cost savings in utilization of construction resources. According to The Business Roundtable, (1983) (*More Construction for the Money: Summary of the Construction Industry Cost Effectiveness Project),* improvements in materials supply lead to an estimated 6% increase in labour productivity. In a case study involving structural steel erection, poor materials management led to a project schedule overrun estimated at 18% (Thomas et al, 1989). These and numerous other findings have led to the recognition that the way to control project costs and schedules in construction is via an integrated total construction materials procurement cycle (Berka et al., 1994 and Marquardt, 1994) According to Nadarajapillai et al. (2012) availability of materials are the main factors which hinder planned progress of housing reconstruction in Sri Lanka where planning of material requisition and pre-demand for construction workers were identified as remedies to overcome challenges identified in housing reconstruction. Fearne and Fowler (2006) suggested that the fragmented and temporary nature of the construction industry supply chain has caused productivity problems. Fernie and Thorpe (2007) emphasized the proper use of supply chain management (SCM) principles can mitigate the effects of the problems. Vidalakis et al. (2011), suggested that builders' merchants should receive greater influence in the management of the supply chain, as they possess a natural linkage between the suppliers and the contractors. Ruben et al. (2000) discussed that the construction supply chain has a large quantity of waste and problems. Ruben et al. (2000) further discussed that the waste and problems are largely caused by obsolete, myopic control of the construction supply chain. With the knowledge gathered in the expert interviews, in the Sri Lankan context, many construction projects suffered due to construction supply chain related issues even though research has not carried out in this area.

2.11 **Critical Analysis**

Rehan et al. (2016),Sungkon et al. (2015),Panchanan et al. (2015),Abigail et al. (2014), Faisal et al. (2013),Wong (2010),Loosemore et al. (2008), Muya et al. (1999), Ruben et al. (2000),Andrew et al. (2006), Geoffrey et al. (2006), Silas et al. (2006), Boris et al. (2004) have studied construction supply chains, however considerable research still needs to be done. Even though, these authors studied risk topics/risk categories, there was limited research which studiedcauses of the risks (risks triggers). However the study of risk triggers, will help both proactive and reactive approaches of risk management. There is little research, which has studied risk triggers created by all the major stakeholders of construction supply chains such asconstruction contractors, consultants (engineers, architects, and quantity surveyors), clients or clients' engineers, construction materials suppliers, sub-contractors, regulatory authorities etc. Further, there is little qualitative or quantitative research, which has studied the interrelationship among these risk triggers created by different stakeholders in construction supply chains. Importantly, there has been no holistic approach to depict the mapping of interrelationship among the supply chain risk triggers created by different stakeholders in construction supply chains.

2.12 **Literature Gaps**

The literature search identified significant work in the context of understanding construction supply chains. The majority of research pertaining to CSCM has been limited to logistical issues of the supply chain, with a smaller number of studies exploring other issues such as relationships between client, consultant, contractor, subcontractor, supplier and other external stakeholders as well as external impacts. Even though many research identified risk topics, the triggers of the risks and their interrelationships are not researched adequately.

Moreover, all this research has considered a limited part of the supply chain. Typically, little work has been considered around end-to-end supply chains starting from client and the client's engineer to the final construction contractor as well as raw materials supplier to the final construction contractor. Additionally, most research limits how the stakeholders such as designers, consultant engineers, client, contractor, sub-contractors, materials suppliers and other external stakeholders are interlinked in generating construction supply chin risks. Further, these studies lack the impact of macro level, local or global factors such as economic policies, global trends, and environmental concerns as well as natural and/or man-made disasters that could impact construction supply chains. Additionally, there is no risk classification system which will help to assess the construction supply chain risks and thereby help manage the risk within construction supply chains in mind.

Even though, Vinit et al. (2007) have studied the total construction supply chain in their decision support system for risk management (and they have given some examples about the risk relationship and propagation), they have not studied the holistic approach of risk relationship among the suppliers, contractors, consultant engineers and other professionals and clients in the overall construction supply chains. Further, none of the researchers have studied adequately the primary causes of construction supply chain risks. With respect to the Sri Lankan context, no research was carried out on construction supply chains. Hence, identification of risk topics, risk profiles for Sri Lankan context were also considered as a research gap.

2.13 **Summary of the Chapter**

This chapter discussed the principles of supply chain management, risk identification and analysis, risk categorization and management of risks in general. More specifically, the chapter discussed construction supply chains, construction project risk management in detail. Further, the chapter presented the existing literature on construction supply chain risks management, whilst identifying the research gaps.

This section further discussed the Sri Lankan construction industry, key industry performance measures and comparison of Sri Lankan construction industry within the global context. Cost and time overruns, productivity issues, issues regarding funding supply, customer satisfaction related issues and issues related to construction supply chains are common in both the Sri Lankan construction industry as well as global context. The next chapter discusses the methodology and research design.

Chapter 03

3.0 RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The previous chapter provided and discussed a critical review of the relevant literature on Supply Chain Management, Risk Identification, Analysis and Management and Construction Supply Chains, Background to Sri Lankan Construction Industry and then the research gaps were identified. This chapter provides a review of research methodologies, rationale for the selection of the methodology and research design for the work.

The research methodology is proposed to achieve desired objectives of the research study in the best level and it is selected with a careful study of the nature of the research and information gathered from the methodologies of related literature. The methodology selected was mixed method of research.

This methodology helps to answer the main research question "what are the triggers of construction supply chain risks and their interrelationships?".

3.2 Discussion on Different Research Methodologies

The following section discusses different research methodologies which are applicable in supply chain research.

3.2.1 Quantitative, Qualitative and Mixed Methods

Quantitative methods, qualitative methods and mixed methods are three of the methods used in research.

Quantitative research is used to explain phenomena by collecting numerical data that are analyzed using mathematically based methods. Examples of quantitative methods are surveys, laboratory experiments, formal methods such as numerical methods and mathematical modeling. Quantitative data may be collected using various methods such as survey questionnaires and a pre-existing database etc. (Denzin, 1989; Kimchi et al., 1991; Thurmond, 2001; Casey and Murphy, 2009). Quantitative methods include statistical analysis of outcomes or questionnaires collected by standardized scales or measures and expressed numerically (Risjord et al., 2001).

Qualitative methods are explanatory and textual, and include passive observation, participant observation and open-ended interviews or analysis of appropriate records (Risjord et al., 2001). It is used to gain an understanding of underlying reasons and opinions. It provides insights into the problem or helps to develop ideas or hypotheses for potential quantitative research (Denzin, 1989; Kimchi et al., 1991; Thurmond, 2001; Casey and Murphy, 2009).

There are two primary ways to collect qualitative data. One is through a case study approach, and the other is through interviews. In-depth interviews and case studies, are optimal for collecting data on individuals'/organizations' histories, perspectives, and experiences, particularly when sensitive topics are being explored. The other qualitative research method is participant observation, which is appropriate for collecting data on naturally occurring behaviors in their usual contexts. Richardson et al., (2000) provided strong arguments for using qualitative research as a complement to traditional quantitative research in a way to frame research questions and explain particular results.

Figure 3.1 explains the relationship among the different research methodologies.

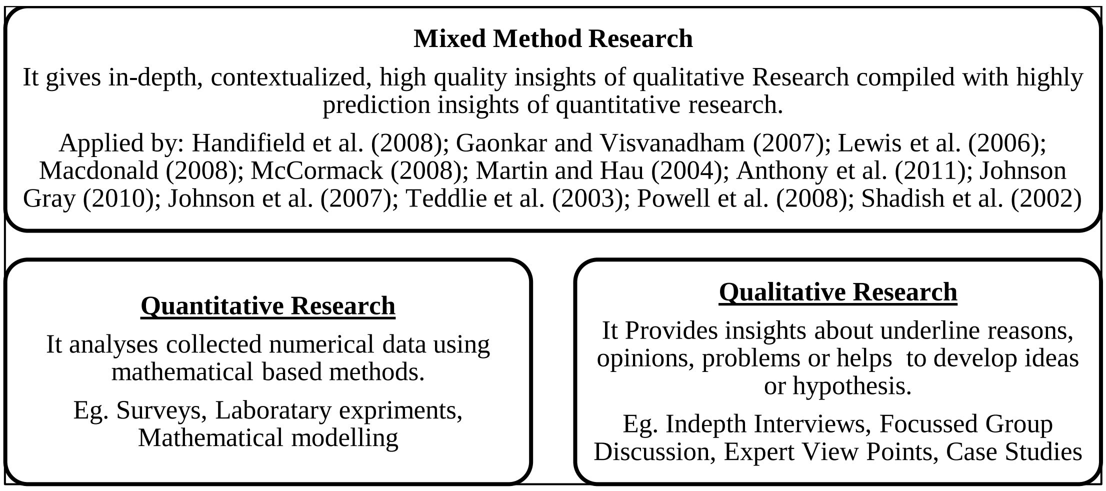


***Figure 3.1*: Relationship among the Different Research Methodologies (Source: Author)**

Mixed methods research is used to tackle a given research question from any relevant angle, making use, where appropriate, of previous research and/or more than one type of investigative perspective. Sometimes referred to as mixed methodology, multiple methodology or multi-methodology research, mixed methods research offers in-depth, contextualized, and natural but more time-consuming insights of qualitative research coupled with the more-efficient but less rich or compelling predictive power of quantitative research (Creswell, 2009; Denzin, 1989; Johnson, Onwuegbuzie, and Turner, 2007; Tashakkori and Teddlie, 2003).

Many different approaches and definitions of mixed methods have been described in the research literature, including combinations of data, methods, methodologies, theories and/or research communities (Creswell, 2009; Denzin, 1989; Johnson, Onwuegbuzie, and Turner, 2007; Tashakkori and Teddlie, 2003).

Although mixed methods research existed in the early twentieth century (Johnson Gray, 2010), it has only been institutionalized as a distinct methodological orientation since approximately 1990 (Greene, 2006, 2008; Teddlie and Johnson, 2009). According to Anthony et al. (2011), "compared to the mono method traditions of quantitative research and qualitative research, the formal use of mixed methods research is relatively new".

As stated by Risjord, Dunbar and Motoney, (2002), completeness and confirmation constitute the principal types of methodological triangulation in mixed methods design. "Completeness" refers to the combination of different research methods in order to obtain comprehensive and complementary data. It is claimed that reciprocal influence of different methods enriches the data (Morse and Field, 1995). Johnson and colleagues (2007) argue that researchers should design and conduct studies based on validity considerations to improve mixed methods research.

Shadish et al. (2002) mentioned that, qualitative and quantitative methods represent complementary approaches to generate knowledge. Atle et al. (2012) further indicated "all researchers have to substantiate their findings, a process in which reliability and validity issues are fundamental. Reliability and validity issues are equally important in qualitative and quantitative research, and therefore a combination of methodologies may be a feasible way to expand our understanding". Atle et al. (2012) suggested that combining qualitative and quantitative methods may solve some construct validity issues in the study.

3.2.2 Triangulation

Triangulation involves using multiple data sources in an investigation to produce understanding. The main reason to triangulate is that a single method can never adequately shed light on a phenomenon and using multiple methods can help facilitate deeper understanding. With triangulation, researchers use two research methods to decrease the weaknesses of an individual method and strengthen the outcome of the study. Rather than seeing triangulation as a method for validation or verification, qualitative researchers generally use this technique to ensure that an account is rich, robust, comprehensive and well-developed. Triangulation is seen as a method for confirming findings and as a test for validity (Denzin, 1978; Sharif and Armitage, 2004).

Figure 3.2 explains different triangulation methods and related literature.

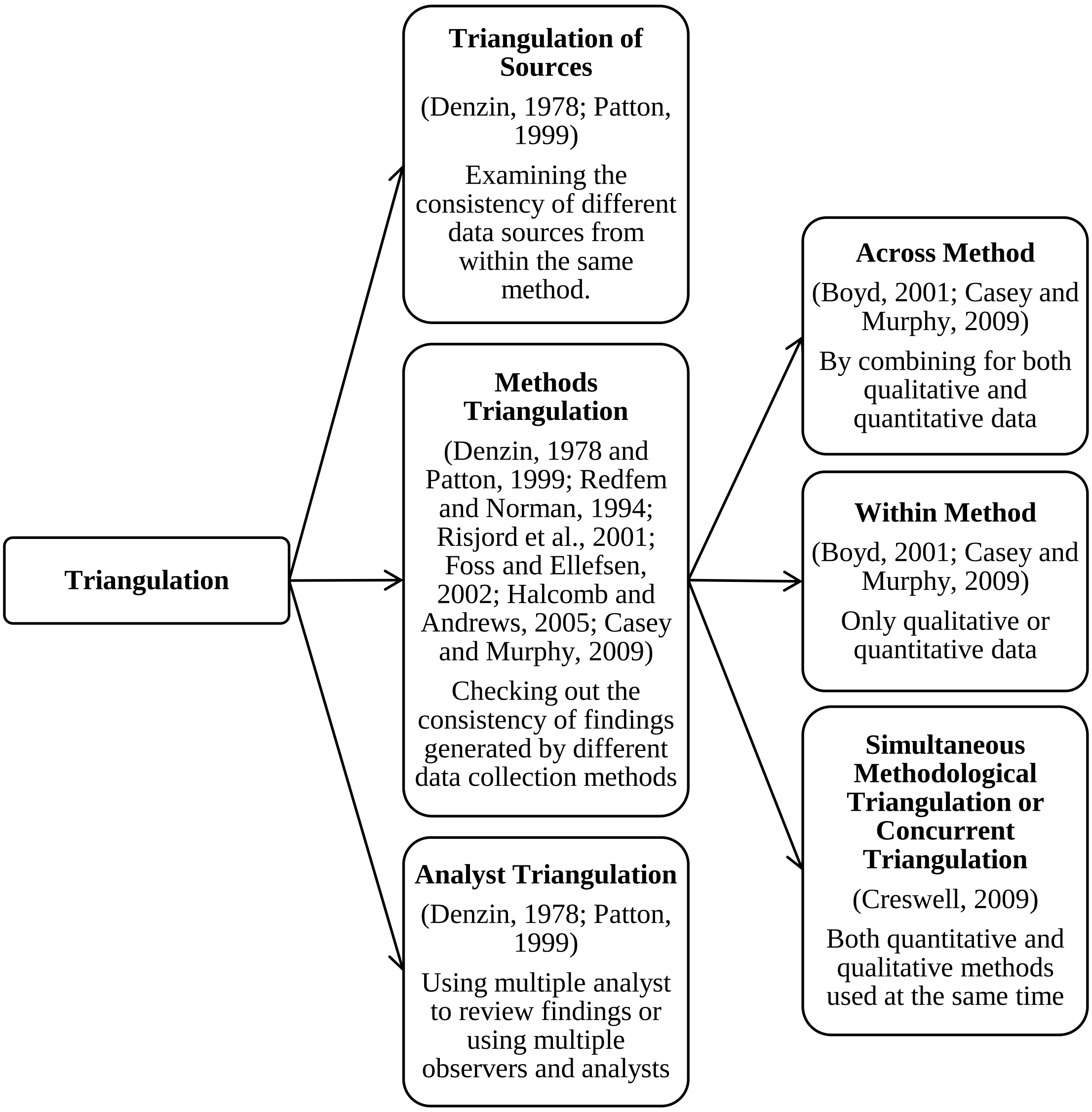


***Figure 3.2*: Different Triangulation Methods and Related Literature (Source: Author)**

Denzin (1978) and Patton (1999) identified different types of triangulation such as methods triangulation, triangulation of sources and analyst triangulation methods triangulation checks out the consistency of findings generated by different data collection methods. It is common to have qualitative and quantitative data in a study. These explain the complementary aspects of the same phenomenon. These data give most insights to the qualitative researcher. Triangulation of sources examines the consistency of different data sources from within the same method at different points in time in public vs. private settings comparing people with different viewpoints. Analyst triangulation uses multiple analyst to review findings or using multiple observers. The goal is not to seek consensus, but to understand multiple ways of seeing the data (Denzin, 1978) and Patton, 1999).

Theory/perspective triangulation uses multiple theoretical perspectives to examine and interpret the data. Methodological triangulation or mixed-methods research uses more than one kind of method to study a phenomenon (Risjord et al., 2001; Casey and Murphy, 2009). There are two types of methodological triangulation: 'across method' and 'within method'. Across-method studies combine quantitative and qualitative data-collection techniques (Boyd, 2001; Casey and Murphy, 2009). Methodological triangulation has been found to be beneficial in providing confirmation of findings, more comprehensive data, increased validity and enhanced understanding of the studied phenomenon (Redfem and Norman, 1994; Risjord et al., 2001; Foss and Ellefsen, 2002; Halcomb and Andrews, 2005; Casey and Murphy, 2009). Simultaneous methodological triangulation or concurrent triangulation (Creswell, 2009) is characterized by qualitative and quantitative methods used at the same time. For example, a researcher may want to use qualitative interviews or focus groups, and at the same time collect data using a questionnaire. In simultaneous methodological triangulation, “there is limited interaction between the two data sets during the data collection, but the findings complement each other at the end of the study” (Morse 1991, p. 120). However, researchers may experience difficulties with discrepancies that arise when comparing the results, a problem that may be typical in the simultaneous triangulation process. This may be solved by additional data collection (Creswell, 2009).

3.3 Identification and Justification of the Methodology for the Research

Even though, there is a considerable amount of research on construction supply chains in the global context, there is very little research carried out to identify the triggers of construction supply chain risks and their interrelationships. As a result, there could be specific risk categories and risk triggers that need to be explored. Further, there is very little research on considering all of the important supply chain risk owners of the construction supply chains such as construction contractors, materials suppliers, consultants, client and construction industry other stakeholders as a whole.

Exploratory natured qualitative research is important in this context. A background study is an important element of exploratory research and findings from the background study can be subsequently used to enhance the quality of the main research. A stepwise process where each stage builds on the previous one (Creswell, 2009), where "the results of one method are essential for planning the next method" According to Morse (1991) sequential exploratory strategy is where qualitative data collection and analysis are followed by quantitative data collection and analysis. Moving from one stage to the next through the research process may also be described as a cumulative validation process, where results from previous studies stimulate and direct new steps in the research process. The cumulative and sequential nature of the research process thus strengthens the validity of the study (Morse, 1991).

The scope of this research is Sri Lankan construction supply chains. There is significant amount of research on supply chain risk management in the global context and such knowledge can be used as a foundation to go into in depth quantitative analysis to find the probabilities, impacts and overall risk profiles in Sri Lankan construction supply chains. Hence, approaching this research question using both qualitative and quantitative approach is important, which can be taken as mixed methods, because these approaches are more comprehensive than approaching a problem from only one type of methodology. This mixed-mode is deemed a suitable way to proceed as the research questions require multi-modal approach to investigate the existence of the various risk triggers in construction supply chains. Further, many researchers have explored and applied the relative merits of qualitative and quantitative research methods in strategic risk management (Hoskisson et al., 1999; Horlick-Jones and Rosenhead, 2002; Phillips et al., 2008; Eppler and Aeschimann, 2009). In addition, how decision makers implement their mitigation responses have received significant attention in the risk and uncertainty management literature using the combination of qualitative and quantitative approaches (Zhao, 1991; Elliot, 2000; Horlick-Jones and Rosenhead,2002; Wood, 2002; Kallman and Maric, 2004; Baldwin et al., 2006; Kewell, 2007; Nilsen and Olsen, 2007; Cairns et al., 2008; Keegan and Kabanoff, 2008; Bea et al.,2009; Corvellec, 2009; Eppler and Aeschimann, 2009; Jarzemskiene, 2009; McKelvey and Andriani, 2010; Zhu, 2010). This clearly shows the potential benefit of adopting a qualitative and quantitative methodology for a risk-related study.

Applying this mixed-mode may provide alternative perspectives on the perception of possible risk profile. Combining qualitative and quantitative approaches provides the benefits of synergizing the strengths of both. Considering all the above points, mixed method is suggested for this study.

Figure 3.3 depicts the proposed mixed method research approach

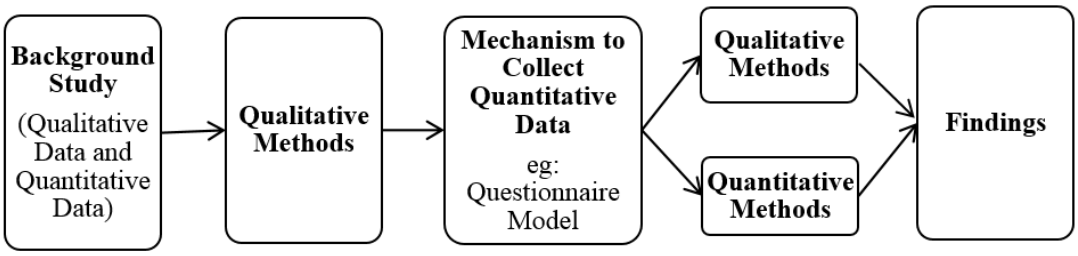


***Figure 3.3*: Proposed Mixed Method Research Approach (Source: Author)**

Figure 3.3 explains the proposed mixed method and how qualitative and quantitative methods are appropriately used.

3.4 Theory Behind the Research Design and Methodology

A research design is described as the planning stage of collecting and analyzing research units and variables that provide relevancy, causation, and integration according to research objectives (Selltiz, et al., 1976; Gable, 1994; Hitt et al., 1998; Lakshman et al., 2000; Zikmund, 2007; Ketchen et al., 2008; MacDonald, 2008; Jarzemskiene, 2009). It is also recognized as being the arrangement of conditions for the collection and analysis of data in a manner that aims to combine relevance to the research purpose" (Gable, 1994, p. 116).

The research design in this thesis enables the experiences of respondents, and their understanding of the various risks topics and their triggers as a basis for identifying the risk profile, to be discussed and analyzed in depth. In order to do so, the research process is designed to give a detailed description according to the research questions. In doing so, various factors that may prompt supply chain risks in the upstream and downstream chains of the construction supply chains that can be explored. The likelihood of future potential risk events in construction supply chains are investigated by probing historical experiences of senior engineers, project managers and other professionals such as architects, quantity surveyors and senior managers. Then the previous and existing mitigation strategies are explored and measured from qualitative and quantitative perspectives Risk identification methods are two folds as the generic approach and the specific approach identified by Behzad et al. (2012). The generic approach includes the literature review, personal brainstorming, expert interviews and expert view surveys. Wu et al. (2006), Canbolat et al. (2008), Yang (2010) have used literature review to identify the risks. Based on the literature review, the risk topics and risk triggers are identified.

Zhi (1995) broken down the risk concept into two main criteria, which is probability (ex: occurrence of a cost overrun), and the impact, which is the degree of seriousness. Therefore using a mathematical description, a risk is described as,

$$R = P \times I \qquad (3.1)$$

Where, R is the degree of risk, within 0 and 1; P is the probability of the risk occurring, within 0 and 1; I is the degree of impact of the risk, within 0 and 1. It can be interpreted that the greater the figure impact is high. Adhitya et al. (2009) explained risk estimation as "risk is usually quantified in financial terms and/or ranked according to some pre-defined criteria. Two different dimensions need to be considered: its frequency/probability and its severity/consequence, taking into account the effects of mitigating actions and safeguards, if any".

Zhi, (1995) described two ways to assess probabilities, subjective judgement and objective analysis. Subjective judgement means estimating the probability of risk factor directly. This is more practical for construction projects. Probability of risk factor is analysed using historical data.

Vose (2000) discussed how risk analysis models build probability distributions, and count on probability and statistical tools. In probability, using of conditional probability, Venn diagrams, and more other probability theories such as strong law of large numbers, central limit theorem, binominal theorem, Bayes' theorem, etc. were explained.

The first step of risk identification is the selection of the system of study. To start the process for handling risks and disruptions, it is important to carefully define the system, delimit its boundaries and give a clear description of the system structure (Wiendahl et al., 2008). After the decision on the system of study has been made, a map of the system, which describes the system elements and their interdependencies should be provided. Mapping the system might also incorporate a description of key risk management measures that are currently in place (Harland et al., 2003). Behdani (2012) described the objectives and supply chain performance measures as very important. Galway (2004) discussed that project over schedule, over run of the budget and goal satisfaction are the three key concerns in construction risks identification.

Behdani (2012) explained that extensive lists of potential risks can be generated by analysis of past losses, intensive literature review or insurance company checklists. This extensive list might be narrowed down to key potential risks by interviewing employees or meetings with experts (Canbolat et al., 2008; Yang, 2010). Subsequently, for each potential risks/disruptions, a causal pathway, which describes the main causes leading to the event, needs to be developed (Norrman and Jansson, 2004; Ritchie and Brindley, 2007). As stated by Behdani (2012), the "Supplier Failure to Deliver On-time" might be because of "Supplier Production Constraints" which itself might be caused by "Human Resource Problems (e.g. strike in its plants)", "Permanent Closure of a Production Plant", "Temporary Production Stop in a Plant", "New Customers for Supplier". This causal pathway can serve as a basis to estimate the likelihood of a Potential risk or disruption ranking in the "Risk

Quantification" step especially, for the cases in which there is not enough data to make a quantified estimation of risk likelihood.

Wu et al. (2006) indicated "The primary purpose of classifying risk is to get a collective viewpoint on a group of factors, which will help the managers to identify the group that contributes the maximum risk. This can enable supply managers to give the required level of importance (in the risk management process) for every group/type of factors".

Harland et al. (2003) mention that "The supply network to be mapped would be defined by the problem or concern. For example, the network might be the product supply network for a particular product, where it is felt there is some exposure to risk. In this stage a diagrammatical representation of the supply network enriched with appropriate data is created. Mapping this supply network is likely to involve understanding who owns what, and what are the key measures currently in place, i.e. clarity of role and responsibility within the network". According to Knemeyeret et al. (2009) "The first step in the planning process is to identify key supply chain locations. A location is considered key if interruption of its operations results in a major disruption in the flow of goods in the supply chain". Furthermore, according to Knemeyeret et al. (2009) "At the conclusion of the first step of the proactive planning process, management will have developed a list of key locations with an associated specification of potential catastrophic events that should be considered for each key location. The next step is to estimate probabilities for each potential catastrophe for each key location". Norrman and Jansson (2004) discussed that "Initially, Ericsson identifies and analyzes its supply chain risks by mapping the supply chain upstream, looking at suppliers as well as products/services. An in-depth analysis is carried out of the suppliers and sub suppliers of critical products to see what the probability and impact of the risks are."

Using the same data, risk profile which explains the probabilities and impacts for the risk triggers were listed, which was known as risk profile based on historical data. Sinha et al. (2004) mentioned the existing process and existing risk awareness is transformed by the activity 'identify risks' into foreseen and perceived risks.

Foreseen risks are predicted through statistical data and steps can be carried out to mitigate them. Perceived risks are identified based on intuition (Sage and White, 1980), where there are no data or statistical proof that the desirable/undesirable event may occur. These outcomes are grouped under identified and categorized risk according to their similarities. Further, indicated by Sinha et al. (2004), "The assessment process can be intuitive or analytical. The goal is to determine the root cause or the source of the undesirable/desirable event. Furthermore, it facilitates identifying the direct and indirect impact. The identified and categorized risks are transformed by the activity 'assess risks' into identified controllable (risks, which are within the scope of the company's control) and uncontrollable risks (risks, which are not within the scope of the company's control)".

Manuj and Mentzer (2008b) performed in-depth interviews using focus groups. Focus groups method is effective in generating broad overviews of issues of concerns. Interviews with many firms (without the specific focus on one case study firm) have also been used to gather data. Interviews with multiple firms tend to provide more breadth on a topic (Craighead et al., 2007).

More specifically, this study applied a face-to-face interview methodology, focused group discussions and laboratory experiments as a data collection technique to explore the extent of the various risks in construction supply chains, and how the impact and probability of the risks can be explained by the quantitative manner and the qualitative risk perceptions .

The Figure 3.4 depicts the Approach for the data collection.

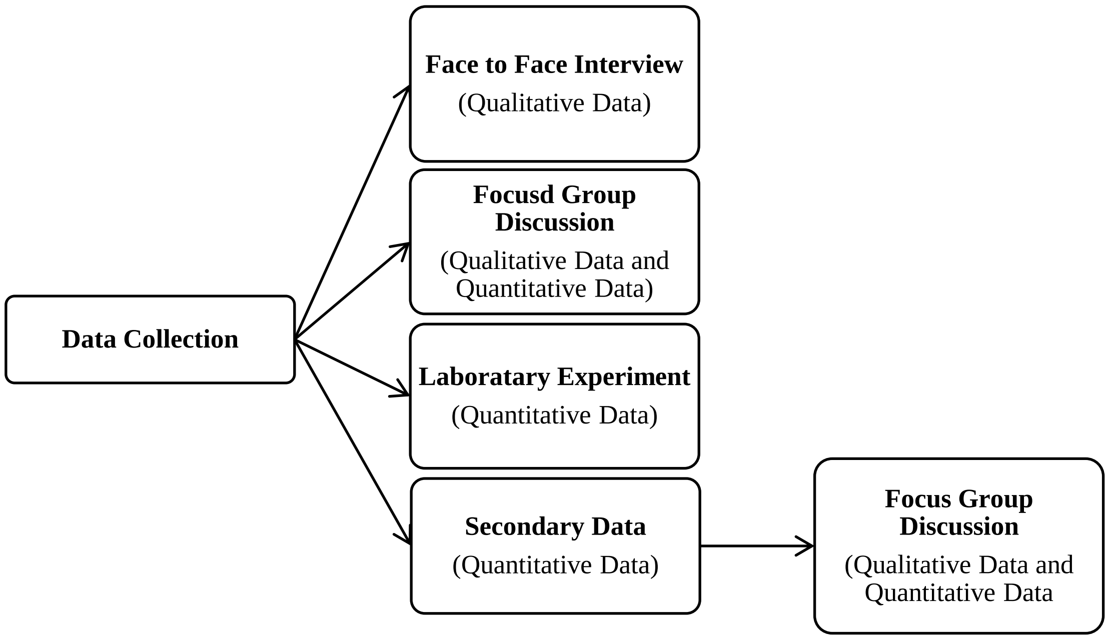


***Figure 3.4*: Approach for the Data Collection (Source: Author)**

As depicted in the Figure 3.4, face-to-face interviews, focus group discussion, laboratory experiments and secondary data were used to gather data which is explained in details in the relevant parts of the methodology. Data were analyzed both qualitatively and quantitatively. In the quantitative analysis, a regression analysis was used appropriately.

Black, et al., 2007 discussed usage of regression analysis in risk analysis, where a multiple variable model can be developed to fit any set of data. Once the model is created, a regression model helps to predict the unseen decision in many areas. Broadie and Du (2015) introduced a regression-based nested simulation method to calculate the financial risk in an organization.

3.5 Map of the Rxzcesearch Design and Methodology

The foundation for this research is double triangulation approach depicted in Figure 3.5

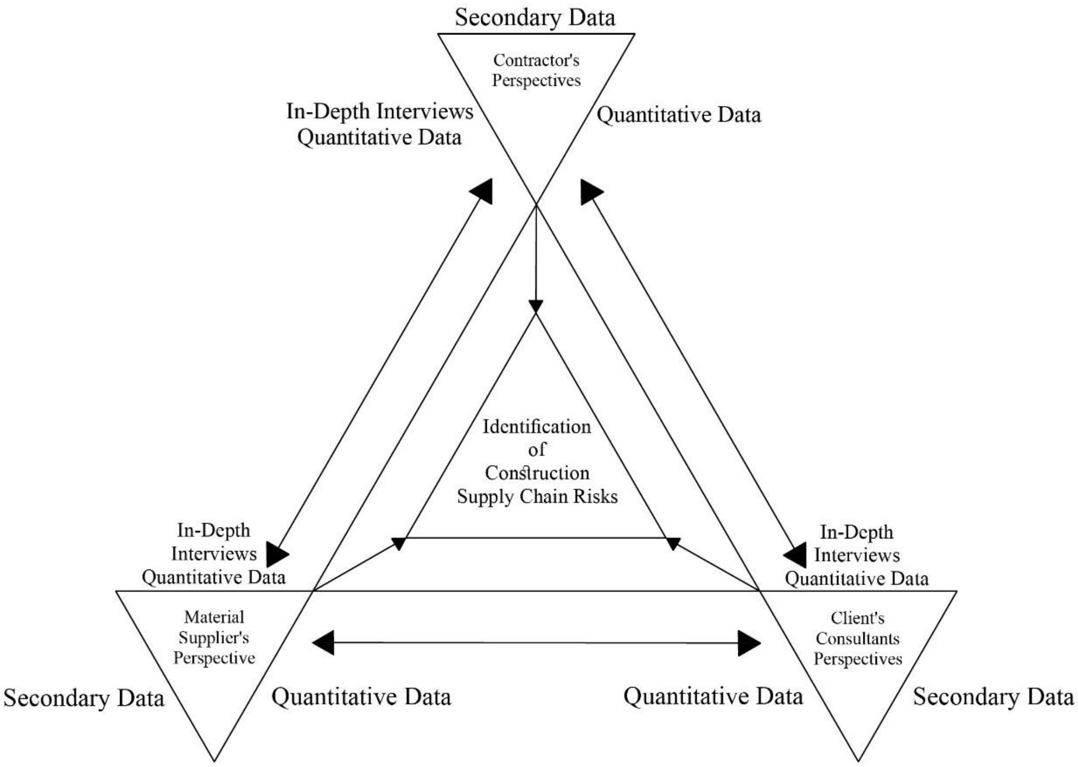


***Figure 3.5*: Triangulation Road Map (Source: Author)**

Denzin (1978), Patton (1999), Risjord et al.(2001), Casey and Murphy (2009), Boyd (2001), Denzin (1989), Kimchi et al.(1991), Thurmond (2001), Redfem and Norman (1994), Risjord et al.(2001), Foss and Ellefsen (2002), Halcomb and Andrews (2005), Creswell (2009) and Atle et al. (2012), suggested triangulation as an effective research tool which was discussed in length under Section 3.2.2. In triangulation, the general acceptance is, it is the best to use one additional data source or method to validate the conclusion. However, in the Double Triangulation Methodology is developed with the suggestion that it is compulsory to validate the results using a minimum of two other different data sets/two other approaches (qualitative and quantitative both) and as such will validate the results with high accuracy. The Double Triangulation Methodology introduced in this research can be applied in other research as a viable research methodology. This will help a researcher to conclude the findings more accurately.

Figure 3.5 explains, the application of the Double Triangulation Methodology in the context of construction supply chains. Data were proposed to collect from three major stakeholders namely client/consultant, contractor and materials supplier both qualitatively and quantitatively. The secondary data was used to increase the validity further.

The summary of the methodological approach as against the five respective objectives of the research are depicted below.

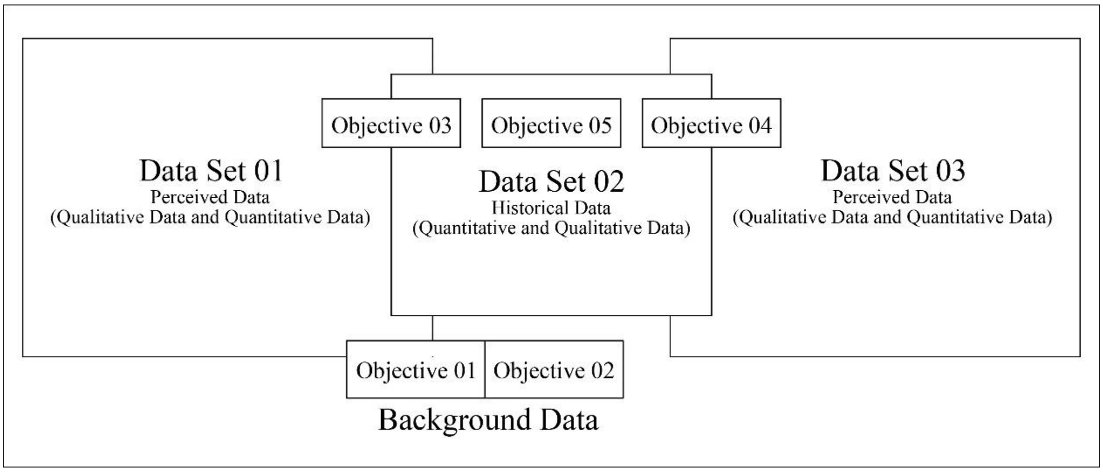


***Figure 3.6*: Summery of Data Sets and Objectives Achieved (Source: Author)**

The Figure 3.6 explains how different objectives are achieved from different data collection process both qualitative and quantitative manner. Background data is collected by face to face interview of two clients each from government and private sectors (owners of the project and their representative engineers), three consultants (two engineers and one architect), 12 large construction companies (mix of semi government and private sectors) of Grade C1 (10 project managers, 22 engineers and 5 quantity surveyors) and 7 leading construction materials supply companies (private sector local and multinational) into cement, steel, paints, ceramic tiles and bitumen. Data set 1 and 3 are collected from intuitive judgment of focus group of 55 respondents. Data set 2 is collected from past construction project details of randomly selected 38 projects by 38 respondents from another focus group. The details of the data and the methodological approaches are explained below.

3.5.1 Achieving Objectives 01 and 02

The objectives 01 and 02 are identification of the risk topics of the construction supply chains and identification of the triggers of construction supply chain risks, generated from risk owners such as client, consultant, construction contractors, suppliers and construction industry respectively. The following methodology was carried out to achieve the objectives.

3.5.1.1 Background Study

The approach of achieving objectives 01 and 02 are indicated in figure 3.7. This is more holistic approach to understand all the risk topics from different directions, so that all the possible risks are investigated.

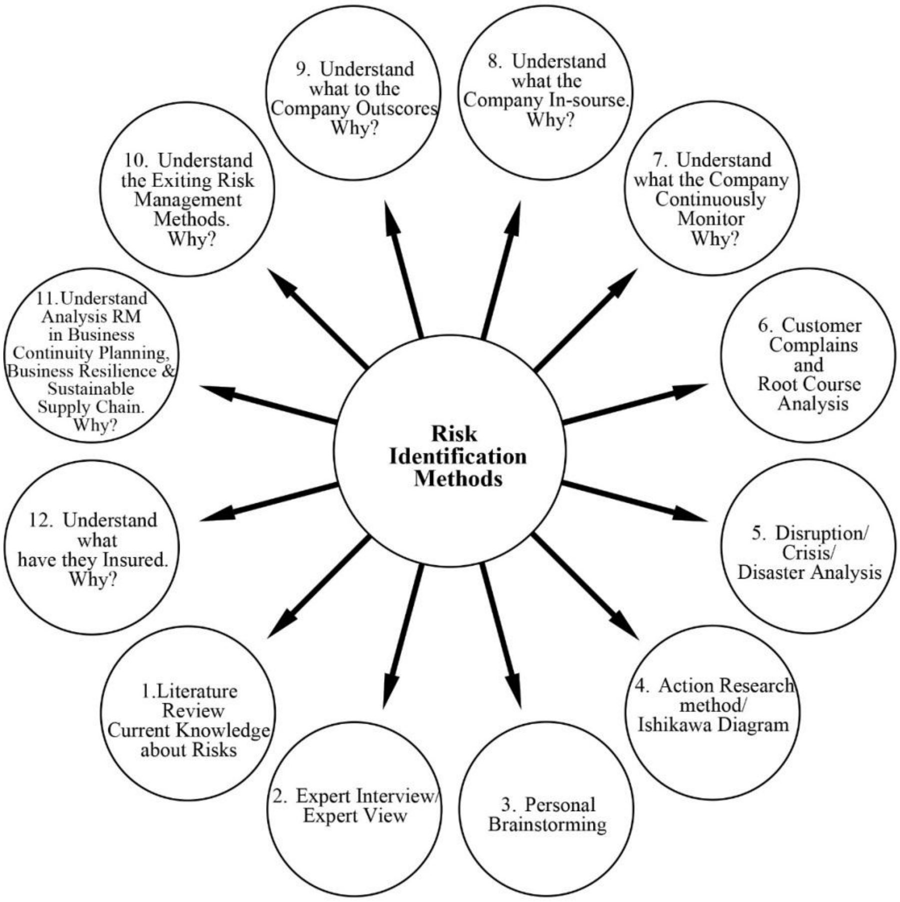


***Figure 3.7*: Risk Topic Identification Methods (Source: Author)**

As indicated in the figure 3.7, by using both the literature review and in-depth interviews in the background data collection, the 12 approaches are presented as risk identification methods. According to the literature, literature review, expert interview, personal brainstorming were most commonly accepted and used methods. Action research method/Ishikawa diagram, disruption/crisis/disaster analysis were accepted, but used occasionally in the risk identification process.In addition to already five approaches described above, the following seven approaches are proposed as risk identification methods. They are:

i. Customer/stakeholder complaints and their root cause analysis,
ii. Understanding and analyzing what each of the risk owner is continuously monitoring,
iii. Understanding and analyzing what each of the risk owner is sourcing,
iv. Understanding and analyzing what each of the risk owner outsourcing,
v. Understanding and analyzing existing risks management methods,
vi. Understanding and analyzing risk management methods in business continuity planning/business resilience/sustainable supply chains,
vii. Understanding what is insured by each of the risk owners,

This holistic approach with twelve risk identification methods can be used simultaneously in identifying the risk triggers in construction supply chains. Method 01, completed literature review is presented in Chapter 2. The questions in 3.5.1.4 are derived based on the above approaches.

3.5.1.2 Sample Selection

Preliminary qualitative findings were arrived using face-to face expert interviews of two clients (owners of the project and their representative engineers), three consultants (two engineers and one architect), 12 large construction companies of Grade C1 (10 project managers, 22 engineers and 5 quantity surveyors) and 7 leading construction materials supply companies into cement, steel, paints, ceramic tiles and bitumen.

All of the respondents were chosen so that they have the attributes of an expert. The respondents were highly qualified in their chosen fields both academically (all the respondents were qualified with Bachelors and Masters Degrees) and professionally (Chartered Engineers, Chartered Architects, Chartered Quantity Surveyors). They had minimum 15 years of working experience, together with a high image in their organization due to the expertise. In fact they represent a mix of government, semi government, private and multinational organizations.

3.5.1.3 Structured and Un-Structured Interviews

Wu et al. (2006), Canbolat et al. (2008), Tuncel and Alpan (2010), Thun and Hoenig (2009), Yang (2010) have emphasized the importance of expert interviews as one of the methods of risk identification.

These interviews were structured as well as unstructured open ended interviews to initially explore the responses on the construction supply chain risks. Having the feedback, the risk topics were identified and ranked. Using the risk topics, the risk triggers were derived and they were categorized into common groups based on their characteristics. The risk triggers were also categorized under various risk owners such as contractor generated, client generated, consultant generated, materials supplier generated and construction industry stakeholder generated.

3.5.1.4 Questions Asked at Structured Interviews

The following questions were asked to obtain viewpoints of the experts interviewed whilst suitable un-structured questions were asked where necessary to clarify the viewpoints

1. Ask them their perspective about supply chain risks
2. Ask them to name the most frequent risk topics
3. Ask them to explain the root causes of these risks to arrive at risk triggers
4. Ask them to group the risk triggers under common names
5. Ask to explain some examples of the risk associated incidents.

6. Ask to explain crisis and disaster experience which happened during last two years.
7. Check what they currently monitor in the operations.
8. What are the recent customer complaints and why it happened?
9. What elements are insured in the company?
10. What are the risks they take into account in the business planning process?
11. Why don't they outsource some specific supply chain elements?
12. Why do they always outsource some specific supply chain elements?
13. What do they in-source?
14. Do they have risk management committee in their organization?

    Further exploratory unstructured questions were asked based on the answers given by the respondents.

Figure 3.8 explains the map of the methodology to achieve the research objectives 01 and 02.

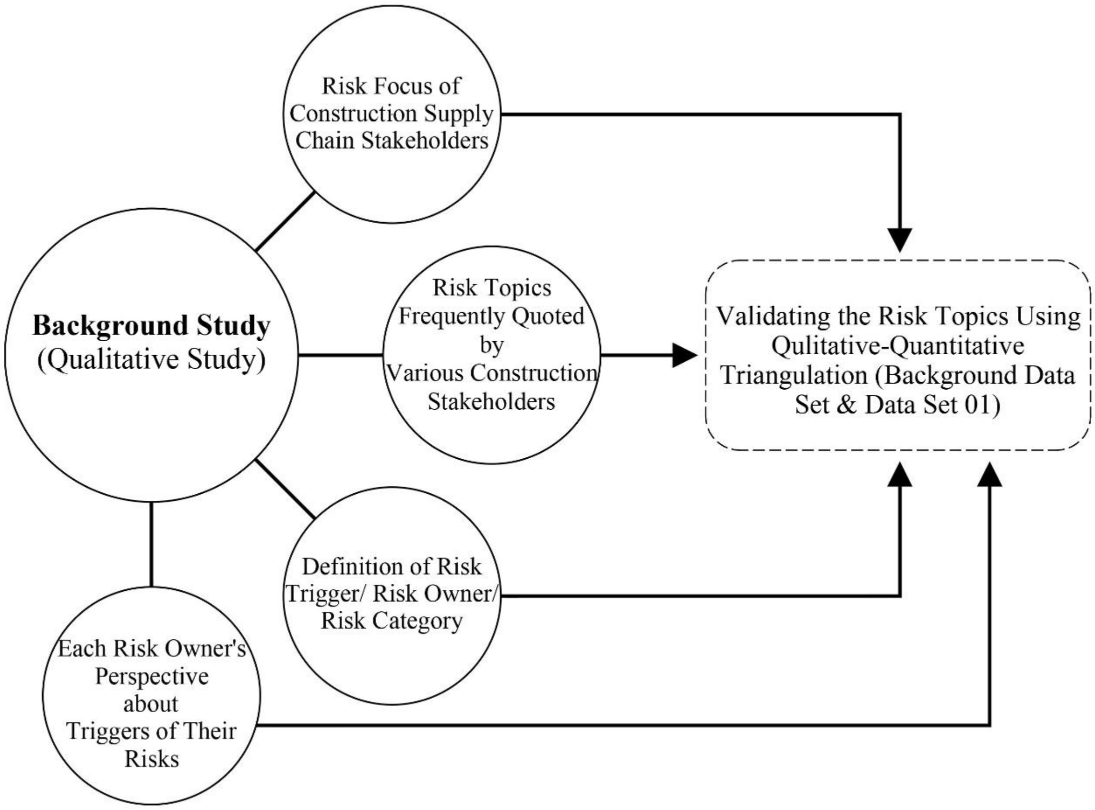


***Figure 3.8*: Map of the Methodology to Achieve Objectives 01 and 02 (Source: Author)**

Figure 3.8 explains how the data collected were linked to the objectives of the research.

3.6 Achieving Objective 03

Objective 03 was the identification of the risk profile for construction supply chains. This was attained by analyzing data set 01 and data set 02. Data set 01 was collected using the intuitive judgment of the focused group of 55 respondents. Data set 02 was collected from the past construction project details of 38 projects given by another 38 respondents from a focused group. Based on the results of both perceived data and historical data, the risk profile was developed. Figure 3.9 depicts the approach diagrammatically.

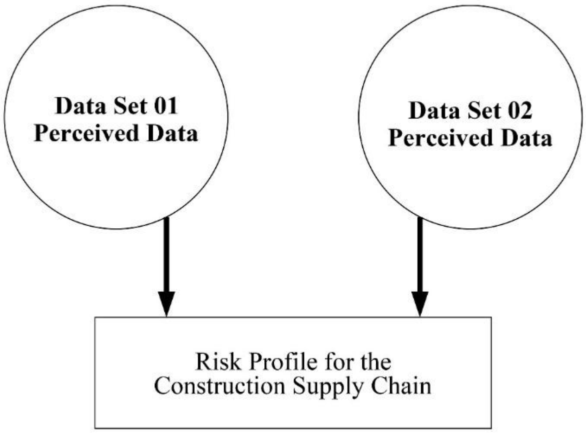


***Figure 3.9*: Data Usage to Achieve Objective 03 (Source: Author)**

Figure 3.9 clearly explains as to how the data collected were linked to the objectives of the research.

3.6.1 Achieving Step 01 of Objective 03 – From Perceived Data (Data Set 01)

Qualitative and quantitative data were collected by a face to face interviews, using structured open and close ended questions.

3.6.1.1 Sample Selection

The focus group of 55 respondents were selected from two Masters in Construction Management programs from two recognized universities. The focus groups were chosen based on their academic qualifications and experience. In fact, they represent a mix of government, semi government and private sectors and some of them have worked overseas. All of the participants had a first degree in engineering/quantity surveying and architecture and all of them were members of respective professional body such as Institution of Engineers/Architects/Quantity Surveyors Sri Lanka. Sample consisted of 55 respondents including clients (Owners of the project or their representative Engineers), Consultants (Engineers and Architect), Construction Companies (Project Managers/Engineers/Quantity Surveyors) and Figure 3.10 and 3.11 describes the sample distribution with respect to designation and years of experience. Among the respondents, 89%, 7% and 4% respectively are from construction companies, consultants organizations and client's organizations. Among the respondents, 10% respectively have experience beyond 21 years, 9% have 16 to 20 years of experience, 23% have 11 to 15 years of experience, while the majority 58% have 5 to 10 years of experience.

3.6.1.2 Data Collection

Qualitative and quantitative data were collected by a face-to-face interviews, using structured open and close ended questions.

Quantitative and quantitative structured questions given to them were as follows:

1. Designation of the respondent.
2. Working experience of the respondent.
3. List 20 key construction supply chain risks from the working experience.
4. Mark probability of occurrence of the listed risks;
   Very High – 5, High – 4. Reasonable – 3, Low – 2, Very Low – 1
5. Mark the degree of impact of the listed risks;
   Very High – 5, High – 4. Reasonable – 3, Low – 2, Very Low – 1
6. Calculate the risk of each trigger listed using equation 3.1;

$$R = P \times I$$

3.6.1.3 Map of the Methodology

Figure 3.10 depicts the map of the methodology to achieve step 1 of objective 3, the approach from perceived data.

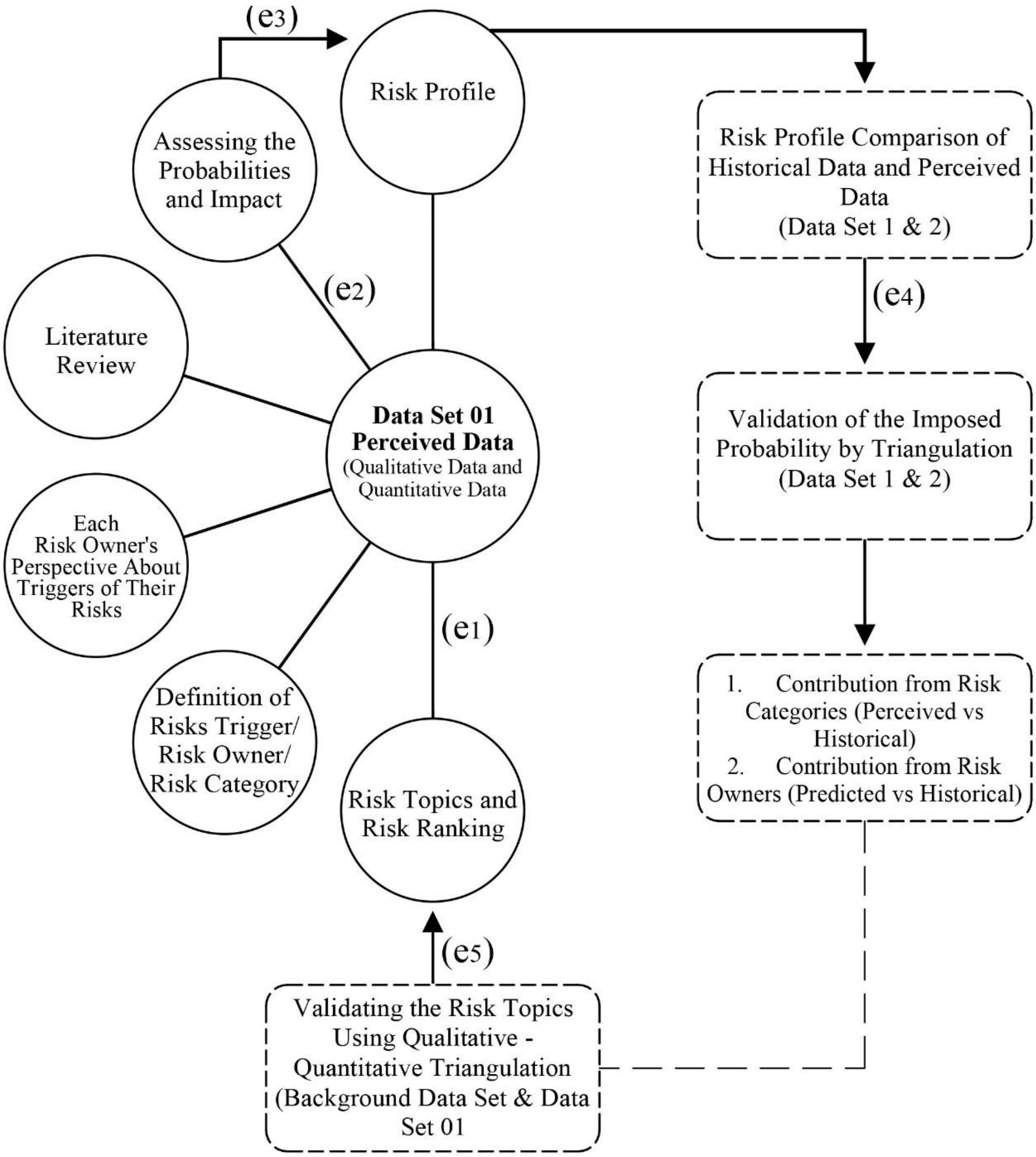


***Figure 3.10*: Map of the Methodology to achieve step 1 of Objective 3- Data Set 1**

(Source: Author)

Figure 3.10 explains as to how the data collected were linked to the objectives of the research.

In the Figure 3.10, the relevant mathematical formulas are presented as (e1), (e2) etc. By analyzing the Data set 01 qualitatively part of the Objective 05, which was to investigate the deep rooted primary triggers of all the above risk triggers were also achieved.

3.6.1.4 Data Analysis

With the risk topics list provided by each respondents, the most common risk topics were evaluated (See Appendix III). After the ranking, average probability and impact were calculated for individual risk topics, given that the risk was calculated using equation 3.1.

(e1)

$$\mathrm{n = frequency\ of\ common\ risk\ topics\ indicated} \ldots\ldots\ldots\ldots\ldots(3.2)$$

(e2)

$$\mathrm{P = Mode\ of\ p\ Values}\ \text{(p: Probability)}\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

$$\mathrm{I = Mode\ of\ i\ Values}\ \text{(i: Degree of impact)}\ldots\ldots\ldots\ldots\ldots(3.4)$$

Where, (Mode is more accurate value to be taken as the data were collected from a scale as ordinal data (Velleman and Wilkinson, 1993).

(e3) Equation 3.1

$$\mathrm{R = P \times I}$$

R: Risk; P: Probability of Occurrence; I: Degree of Impact.

(e4)

Compare Risks from Perceived Data Vs Risks from Historical Data

(e5)

Risk Ranking from Data Set 1 Vs Risk Topics from Background Data

3.6.2 Achieving Step 2 of Objective 03 and Step 1 of Objective 04 and Part of Objective 05 from Historical Data (Data Set 02)

Objective 03 was to identify the risk profiles of construction supply chain and in this step, it was carried out by using the historical data. Objective 04 was to identify the relationships among different risk triggers and risk owners, and in this step was carried out using a qualitative approach. Objective 05 was to investigate the deep rooted primary triggers of all the above risk triggers and part of that is carried out using the historical data.

3.6.2.1 Data Collection

Data was collected by collecting detailed project information about 38 construction projects, which was completed during 2015 and 2016. A focus group of 38 respondents were selected from another Masters in Construction Management programs from one university. In fact, they represent a mix of government, semi government and private sectors and some of them have worked overseas. One of the major information focused were estimated cost against actual cost and estimated duration against actual construction duration for each of the major task of each construction project. The major tasks are foundation work, super structure etc. and the reasons for the variations has to be given by the respective respondents. The reasons for each variation/risk were given, and they were further analyzed and arrived with different risk cases which was finally generalized. This was then planned to be presented as a Tree Diagram, which lead to the diagram known as Risk Relationship Diagram (RRD).

3.6.2.2 Sample Selection

The focused group explained in 3.6.2.1 were chosen based on their academic qualifications and experience. In fact, all of them were having first degree in engineering/quantity surveying and architecture and all of them were members of respective professional body such as Institution of Engineers/Architects/Quantity Surveyors Sri Lanka. They included clients (owners of the project or their representative engineers), consultants (engineers and architect), and construction companies (project managers/engineers/quantity surveyors). Among the respondents, 75%, 15% and 10% respectively are from construction companies, consultants organizations and client's organizations. Among the respondents, 64%, 24% and 12 % respectively have experience 5 to 10 years, 10 to 15 years and beyond 20 years.

The data were used as historical data to triangulate the risk profiles identified by Data set 1. Twenty Nine (29) projects disclosed the names (See Appendix IV), while nine remained enclosed.

3.6.2.3 Structured Questions Asked at the Lab Test.

I. Designation:
II. Year of experience:
III. Project Name:
IV. Client Name:
V. Consultant’s Name:
VI. Contractor's Name:
VII. Break down of the project into major project tasks such as foundation, structure, finishing etc
VIII. Estimated cost (Rupees) to complete each of the project task.
IX. Actual cost (Rupees) to complete each of the project task.
X. Estimated Time (Days) to complete each of the project task.
XI. Actual (Days) to complete each of the project task.
XII. Reasons for each of the variation/risk in each of the major project task known as risk triggers

3.6.2.4 Map the Methodology

Figure 3.11 depicts the methodology to achieve Objectives 03, Step 1, of Objective 04 and part of Objective 05, using Data Set 2.

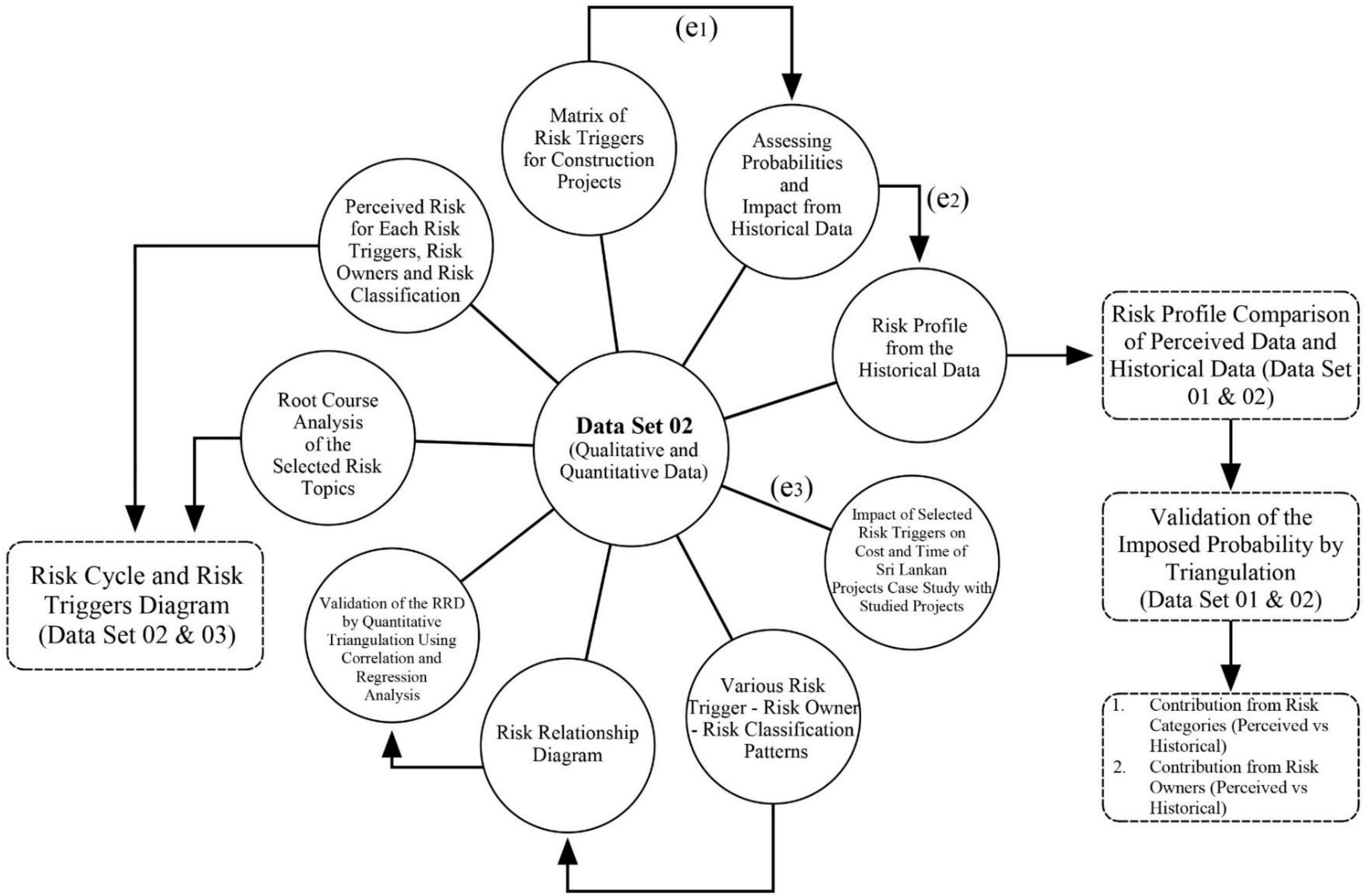


***Figure 3.11*: Methodology to Achieve Objectives 03-Step 1, 04 and part of 05-Data Set 2 (Source: Author)**

Figure 3.11 explains as to how the data collected were linked to the objectives of the research.

3.6.2.5 Data Analysis

Data were analyzed quantitatively using the Equations;

(e1)

$$P = \frac{n}{38} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.5)$$

Where, P is the Probability and n is the frequency

(e2)

$$\text{Cost Impact} = \left(\sum \frac{\text{Esitimated Cost} - \text{Actual Cost}}{\text{Estimated Cost}}\right) / \text{n} \ldots\ldots\ldots (3.6)$$

Where n is the frequency

$$\text{Time Impact} = \left(\sum \frac{\text{Esitimated Time} - \text{Actual Time}}{\text{Estimated Time}}\right) / \text{n} \ldots\ldots\ldots (3.7)$$

Where, n is the frequency

$$\text{Average Impact} = \frac{\text{Cost Impact} + \text{Time Impact}}{2} \ldots\ldots\ldots\ldots (3.8)$$

And the equation 3.1

$$R = P \times I$$

Where, R; Risk, P: Probability of Occurrence, I: Degree of Impact

(e3)

Cost and time behavior of risk triggers were examined using correlation and regression analysis.

$$\text{Dependent Variable} = \text{f (Independent Variable)} \ldots\ldots\ldots\ldots(3.9)$$

3.6.3 Achieving Step 2 of Objective 04 from Perceived Data (Data Set 03)

Objective 04 was identification of the relationship among different risk triggers and risk owners and in this step it was carried out using a quantitative approach.

3.6.3.1 Sample Selection

Qualitative and quantitative data were gathered from the same sample used in Data Set 1. Feedback were collected from 55 respondents, who were asked to comment qualitatively on the Risk Relationship Diagram and then quantitative provide Risk profiles, using their working experience.

3.6.3.2 Questions

I. Comment the pros and cons about the RRD Diagram.
The constructive feedback for the RRD was taken to explore the strengths of it as well as the areas to improve. Additionally they were asked to constructively criticize the Risk Relationship diagram to investigate how far it can be used to assess the construction supply chains risks.

II. Indicate the risk amount for each Risk Trigger, using expertise experience. Quantitative inputs were taken for each risk topic in the risks relationship diagram with inputs with the same 55 independent project managers, engineers, quantity surveyors, architects and managers. In a lab test they were given the risk relationship diagram and asked to mark a number for each of the risk factor based on their past experience. Regression analysis were done to prove hypothesis and relationships quantitatively. With all the above triangulation methods, the results are multiply triangulated.

3.6.3.3 Map the Methodology

Figure 3.12 depicts the methodology to achieve step 2 of objective 4.

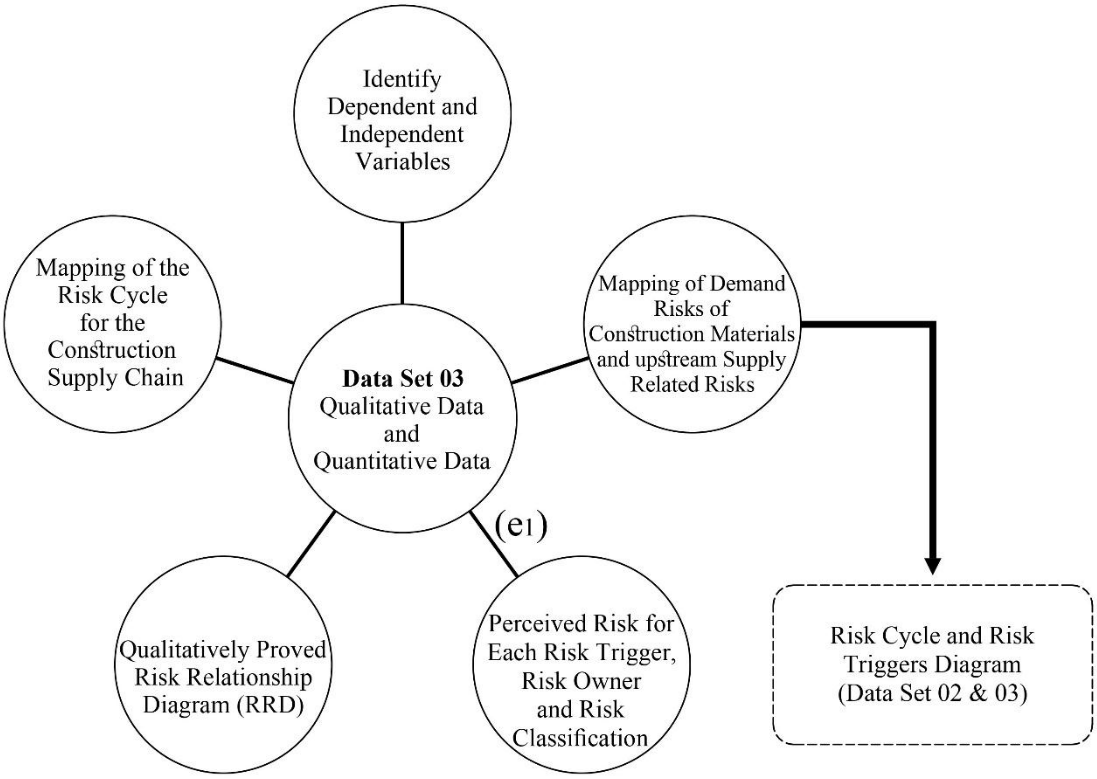


Figure 3.12**: Methodology to Achieve Step 2 of Objective 04 - Data Set 3 (Source: Author)**

Figure 3.12 clearly explains as to how the data collected were linked to the objectives of the research.

e1. Calculating the Risk for each Risk Trigger using;

$$\text{Risk} = \text{Average of Risk Amount} \ldots\ldots\ldots\ldots\ldots\ldots (3.10)$$

3.6.3.4 Descriptive Analysis

Descriptive analysis was conducted to understand the data. Mean, Mode, Standard Error, Standard Deviation, Variance, Median, Range, Skewness, and Kurtosis were evaluated for each Risk Trigger (Appendix VII).

3.7 Summary

The summary of the methodological approach as against the five respective objectives of the research are explained in the chapter.

The chapter explained the theory behind the entire research design together with primary and secondary data collection plans. Double Triangulation approach is suggested as the research and verification methodology.. The next chapter discusses the findings of the construction supply chain risks in the Sri Lankan context.

Chapter 04

4.0 FINDINGS AND DISCUSSION 1 - RISK TRIGGERS AND RISK PROFILES OF THE CONSTRUCTION SUPPLY CHAINS

4.1 Introduction

The previous chapter discussed the methodology and design of this research work that included the methodological steps to achieve the research objectives. This chapter presents the analysis, findings and discussion on the objectives 1, 2 and 3 of the research. Risk topics, risk triggers, risk owners, risk classifications, risk probabilities, risk impacts as well as risk profiles of the construction supply chains are also presented.

4.2 Exploration the Risk Topics, Risk Owners and Risk Triggers

As explained in Section 3.5.1, by carrying out a background study, preliminary qualitative findings were arrived using face to face interviews of two clients (clients' representative engineers), three consultants (two engineers and one architect), 12 largest construction companies (project managers, engineers and quantity surveyors) and seven construction materials supply companies. These interviews are unstructured open ended interviews to initially explore the respondents' views on construction supply chain risks.

The outcome of these interviews revealed the following general findings. (See Appendix I for the summary of the data collected from the interview).

1. Respondents revealed surface level risks or only the immediate reason for those risks. These are identified as risk topics throughout this thesis.
2. The term construction supply chain was not comfortable with the majority of the respondents initially, but once terminology was explained, the respondents were able to link the discussion to it.

3. Initially most of them did not fully comprehend that a supply chain risk that can generate at any point of the chain and which can impact some other different point/points in the supply chain.
4. When the respondents were probed, they started going beyond the immediate reasons and started exploring issues in the rest of the construction supply chain.
5. There was no prominence given to construction supply chain risks in the Sri Lankan context.
6. Some risks are identified proactively, however most of the risks are reactively managed.
7. Risk identification tools used in the current context are mostly intuitive judgements.

Azhar et al. (2016) also revealed similar findings and contractors were found to apply individual intuition, judgment and experience to identify and assess risks in Alabama construction industry.

In the construction supply chains, the meaning of the risk for various stakeholders are different from each other. In the perspective of materials suppliers, the risks are the factors that affect the sales volumes and profitability in the short and medium term. However, in the medium to long term, the risks are the factors that affect sustainability of the supply to a particular construction contractor. In the perspective of the contractor, the risks are the factors that affect the cost, quality and time targets. Contractor's cost targets are important to achieve the expected profitability and long term survival. Contractor's quality targets are important to satisfy the client. It is important in the short term to be paid for the work done by the client and in the long term to sustain the brand image of the construction company to secure future projects. Contractors' time targets are important to satisfy the client short term to long term needs, which has an impact on profitability and sustainability. Based on the interview feedback, each construction supply chain stakeholders' (risk owners) risk focus is depicted the Table 4.2-1.

Table 4.2-1 is arrived by analysing the data in Appendix I. It explains the risk focus of the construction supply chain stakeholders specifically, the client, consultant, contractor and materials supplier.

Table 4.2-1: Risk Focus of Construction Supply Chain Stakeholders

Client's Risk Focus	Consultant's Risk Focus
1. Factors that negatively impact the real requirement from the construction outcome. It can be due to poor design by an architect, or poor engineering inputs from engineers or poor construction quality of the contractor or time overruns of the contractor. 2. Factors that negatively impact the budget, which is the estimated total construction cost. Cost overrun can be due to price escalation, various type of variations, unavoidable circumstances such as unexpected ground conditions etc.	1. Factors that negatively impact the image and income. 2. Construction factors that trouble the consultant and the designs.
Contractor's Risk Focus	**Material Supplier's Risk Focus**
1. Factors that affect the cost, quality and time targets. 2. Cost targets are important to achieve the expected profitability and long term survival. 3. Quality targets are important to satisfy the client. This is important in the short run to be paid for the work done by the client and in the long run to sustain the brand image of the construction company to secure future projects. 4. Time targets are important to satisfy the client short term to long term which has an impact on the profitability and sustainability.	1. Factors that affect sales volumes and profitability in the short and medium run. 2. Factors that affect sustainability of the supply to a particular construction contractor.

(Source: Author)

The Table 4.2-2 discusses the risk topics frequently quoted by various stakeholders. These risk topics are in line with the findings of Arokia et al. (2017) on Indian construction industry, Hong et al. (2015) on the Chinese construction industry, Aibinu et al. (2015) on the Nigerian construction industry, Alaghbari et al. (2007) on the Malaysian construction industry, Nayanathara et al. (2005) on the Sri Lankan construction industry, and Makulsawatudom et al. (2004) on the Thailand construction industry except for sand/soil/gravel/ABC/sub base unavailability.

Table 4.2-2 is arrived by analysing the data presented in Appendix I. According to table 4.2-2, some of the risk topics are quoted by more than one stakeholder.

Table 4.2-2: Some of the Risk Topics Frequently Quoted by Various Construction Stakeholders (Risk Owners)

Risk Topics Frequently Quoted by Clients	**Risk Topics Frequently Quoted by Consultants**
Contractors' issues Consultants' issues Unforeseen site conditions Government regulations Political changes Approval issues Problems from general public Climatic risks such as rain, flood, drought Political influence	Contractors' poor performance Contractors slowness Contractors' quality issues Material quality issues Clients' issues
Risk Topics Frequently Quoted by Contractors	**Risk Topics Frequently Quoted by Materials Suppliers**
Consultants' issues Frequent changes to the designs Scope changes Clients' issues Climatic risks such as rain, flood, drought Government regulations Sand, gravel and aggregate issues Inadequate labour supply and lack of Skilled labour Site security problems Cash flow issues of the contractor Sub-contractors performance issues	Consultants rejecting their materials Order cancellation Competitor initiatives Government regulations Climatic risks such as rain, flood, drought

(Source: Author)

Based on the interview feedback, each risk owner's perspective about their risks are mostly external as depicted in the Table 4.4-2. They mostly attributed their risk to the immediate upstream and downstream partners and they fail to recognize the internal risks created by themselves, as well as risk coming from the extended supply chain both upstream and downstream.

4.3 Validating the Risk Topics Using Qualitative- Quantitative Triangulation

As explained in the Chapter 3.6.1, in data set 1, fifty five (55) project managers/engineers/quantity surveyors were asked to name 20 most important risks in construction supply chains. As explained in the Appendix III, the most frequently quoted risks are identified and presented in Table 4.3-1 Risk Topic and Risk Rank.

The ranking of this is not always similar to the rankings suggested by Aibinu et al. (2015) on the Nigerian construction industry however, almost all 20 risk topics are common except sand/soil/gravel/ABC/sub base unavailability and shortage of labour.

Table 4.3-1: Risk Topic and Risk Rank

Risk Topic	Rank
Drawing delays/modifications, poor communication of client and consultant	1
Rain	2
Lack of money/cash flow issues of the contractor	3
Sand/soil/gravel/ABC/sub base unavailability	4
Shortage of machines/equipments	5
Shortage of labour	5
construction engineering defects and quality risks	5
Health and safety risks	8
Shortage of materials cement/steel/bricks	9
Quality shortfall of materials	10
Poor construction program	11
Change/Resignation of project manager/key engineer	11
Political influence	11
Site security related problems	14
Problems from the general public	14
Shortage of engineers, technical officers etc.	16
Utility such as water, electricity delays/problems	17
Approval delays from authorities	18
Clients financial problems/Delayed payments	19
Transport issues	20
Poor performance of sub-contractors	20
Price escalation of materials	20
Policy and regulatory changes	20

(Source: Author)

Comparing the Table 4.2-2and Table 4.3-1, all the risk appear in each other. As such the risk topics can be validated by triangulation.

4.4 Deriving the Risk Triggers

Analyzing the risk topics depicted in Table 4.2-2 and 4.3-1, each risk owner's perspective about triggers of their risks are depicted in the Table 4.4-1. These triggers were found as a result of the in depth discussion held with the respondents of the background study (Appendix I) and data set 1 (Appendix III).

Table 4.4-1: Each Risk Owner's Perspective about Triggers of Their Risks

Client's Perspective	Consultant's Perspective
1. Contractors' planning issues 2. Contractors' sub-contractor issues 3. Contractors' communication issues 4. Consultants' communication issues 5. Consultants delays 6. Unforeseen site conditions 7. Government regulations 8. Political changes 9. Rain and flood	1. Contractors' planning issues 2. Contractors' slowness due to cash flow issues 3. Contractors quality issues 4. Material quality issues 5. Clients' financial problems 6. Clients' scope changes 7. Clients' communication issues
Contractor's Perspective	**Materials Supplier's Perspective**
1. Consultants giving inaccurate designs and BOQs 2. Frequent changes to the designs 3. Scope changes created by client and consultants 4. Clients cash flow issue and bankruptcy 5. Climatic risks such as rain, flood, drought 6. Regulatory initiatives by the government 7. Sand, gravel and aggregate issue 8. Inadequate labour supply and lack of skilled labour 9. Cash flow issues of the contractor 10. Subcontractors performance issues 11. Unavailability of quality materials 12. Material price issues and delivery issues 13. Unforeseen site conditions 14. Machinery break downs	1. Consultants rejecting their materials 2. Order cancellation due to changes in construction plan 3. Competitor initiatives 4. Government regulations 5. Rain and flood 6. Contractors' poor planning 7. Contractor's cash flow issues 8. Forecasting errors

(Source: Author)

There is only limited literature on risk triggers (causes). Even though, Schoenherr and Tummala (2011) have studied risk triggers, it was not in the context of construction supply chains.

In order to analyse the whole supply chain and the impact of each of the risk to the other areas, it is very important to classify the risk triggers. Some of the risk triggers are generated by client, consultant and contractors which can be put to a broad topic as stakeholder generated risks. Risk on communicating the scope of work and risk on supply of funding are classified under client generated risks. Risk trigger of submitting accurate designs and estimates is categorized under consultant generated risks. Risk triggers associated with contractors' decision making risk, communication risk, sub- contractor risk, financial risks and planning risk can be categorized as contractor generated risks. Some of the risk triggers such as materials supply related quality risks, availability risks, on time delivery risks, price risks which can be put into a broad topic as material supply related risks. Sand problem, regulations related risks, seasonal trends related risks and labour problem can be put under construction industry specific risks.

In analyzing the risk topics, it is important to understand the definition of each terminology. The definitions for risk triggers, risk owners and risk categories given by the author is depicted in the Table 4.4-2.

Table 4.4-2: Definition of Risk Trigger/Risk Owner/Risk Category

Risk Trigger (RT)/Risk Owner(RO)/Risk Category(RC)	**Definition**
Construction Industry Specific Risks- (RC)	All type of risks from the construction industry/country/globe, which are broken to regulation risks, sand problem, risk on labour supply and seasonal trends.
Regulation Risk- (RT)	All types risks coming from rigidities/flexibilities in the regulations and policies (some of the legal risks, approval delays, labour laws, environmental concerns, inflation, exchange rate fluctuations, rights of the general public) as well as weakness in the regulations and policies (Ex: political influences, unethical behaviors, public protests etc.).
Sand Problem- (RT)	All types of risks related to earth materials availability, quality and excavation approval. Earth materials includes sand, soil, aggregates, etc.).
Risk on Labour Supply - (RT)	Skilled and unskilled labour supply risk. Skilled labour includes professionals such as engineers, project managers, quantity surveyors, architects, land surveyors as well as others such as technical officers, technicians, electricians, masons, bar benders, plumbers, machine operators etc.

Risk Trigger/Risk Owner/Risk Category	Definition
Seasonal Trends- (RT)	All type of climatic/natural risks such as rain, drought, flood, tsunami, wind, land-slides, etc.
Stakeholder Generated Risks- (RO)	Contractor generated risks plus client generated risks plus consultant generated risks.
Client Generated Risks - (RO)	Risks that can be generated from client or his engineer/architect/quantity surveyor/project manager/adviser. These can be summarized to risk on communicating the scope of work plus risk on supply of funding.
Risk on Communicating the Scope of Work- (RT)	Client or client's engineer/architect generated risks on clearly explaining the scope of the work.
Risk on Supply of Funding- (RT)	Client's or client's supplier of funding (e.g. bank, investor) related risks or cash flow issues.
Consultant Generated Risks- (RO)	Risks generated by consultant designated as architects/all type of engineers/quantity surveyors or consultants third party employees.
Risk on Submitting Accurate Designs and Estimates- (RT)	Consultant generated risks on submitting accurate designs and estimates as well as site supervising, advising and approving.
Contractor Generated Risks- (RO)	Risks that can be generated by the owner/directors/advisers/consultants/top level managers/project managers/engineers/quantity surveyors/accountants and other professionals, technical officers/electricians and all the other skilled/unskilled labour/sub- contractors working for a contractor. This includes decision making risks, communication risks, sub-contractor risks, financial risks and planning risks.
Contractor Generated Decision Making Risks- (RT)	Decision making risks of contractor/contractor's employees or contractor's consultants. This includes all the decisions made by a top level manager/engineer to a site worker employed by the contractor.
Contractor Generated Communication Risks-(RT)	Communication risks of contractor/contractor's employees or contractor's consultants. This includes communication planning to actual delivery as written, verbal communication and in the form of drawings etc.

Risk Trigger/Risk Owner/Risk Category	Definition
Contractor Generated Sub-Contractor Risks- (RT)	Risks of selecting and managing all type of sub-contractors (including supply of equipments and machinery) by contractor/contractor's employees or contractor's consultants.
Contractor Generated Financial Risks- (RT)	Contractor's cash flow issues and profitability issues.
Contractor Generated Planning Risks- (RT)	Planning risks of contractor/contractor's employees or contractor's consultants. This includes all the planning made by a top level manager, engineer, site worker to sub-contractor employed by the contractor.
Material Supply Related Risks- (RO)	All type of material supply related risks including price risks, quality risks, availability risks and on time delivery risks.
Price Risks-(RT)	Risks of increasing the price due to various reasons.
Quality Risks-(RT)	Risks of not achieving expected quality levels due to various reasons.
Availability Risks-(RT)	Risks on non-availability of materials due to various reasons.
On Time Delivery Risk-(RT)	Risks of not delivering on time.

(Source: Author)

As explained in the Table 4.4-2, three risk categories are introduced namely construction industry specific risks, stakeholder generated risks and materials supply related risks. The risk owners introduced are contractor generated risks, consultant generated risks, client generated risks and material supply related risks. Using the above definitions, any risk topic can be analyzed for tier 1, tier 2 triggers and a sample of such analysis is depicted below in Table 4.4-3 (See Appendix VIII).The original risks revealed by the respondents are presented under the original risk topics. The conversion of the risk topics to a suitable grouping based on the causes of the risks is presented under tier 1 risk triggers. The possible causes/influences of the tier 1 risk triggers are presented under tier 2 risk triggers. For an example, 'no proper construction plan for contractor' can be considered as planning issues at management level or project manager level or engineer level or even technical officer or sub-contractor level which can be commonly termed as contractor generated planning risk presented in tier 1. Moreover, consultant generated problems on submitting accurate design and estimate, client's problems on communicating the scope of the work can negatively impact the contractor generated planning and it is presented in tier 2. 'Shortage of cement' is due to materials supply related problem which is presented as tier 1. Moreover, the problem of shortage of cement can be negatively influenced by contractor generated various risks such as planning, decision making and communication which is presented in tier 2. Similarly, the other original risk topics are analyzed under tier 1 and tier 2. There is no literature found on similar type of analysis for construction supply chains.

Table 4.4-3: Analysis of the Selected Risk Topics to Assess the Risk Triggers

Original Risk Topic	Tier 1	Tier 2
No proper construction plan for contractor	Contractor generated Planning Risks	Consultant generated Risk on submitting accurate design and estimate, Client's Risk on Communicating the Scope of the Work
Congested programme	Contractor generated Planning, Decision Making Risks, Contractor Risks, Communication Risks, Financial Risks	Consultant and Client Generated Risks, Regulation risks, Material supply risks, Other service supply risks (such as machines, equipment)
Delay in construction drawings submission	Client's Risk on Communicating the Scope of the Work	
Concrete cracks due to no proper thermal insulation	Contractor generated Planning, Decision Making Risks,	Consultant Generated Risk on submitting accurate design and estimate
Shortage of sand	Sand Problems	Contractor generated Decision Making, Planning and Communication and sub-contractor Risks, Regulatory Risks
Shortage of cement	Materials Supply Related Availability Risks	Contractor generated Decision Making, Planning and Communication and sub-contractor Risks,
Cash flow issues	Contractor generated Decision Making, Planning and Communication Risks	Client Generated Risks, Consultants Generated Risk

Original Risk Topic	Tier 1	Tier 2
Quality problem	Contractor generated Decision Making, Planning and Communication Risks	
Shortage of labour	Labour problem	Contractor Generated Decision making, Planning, Communication and sub-contractor risk
Political influences	Regulation Risks Risk	
Government policy changes	Regulation Risks Risk	

(Source: Author)

Construction industry specified risks are further classified into the following risk triggers.

1. Sand problem
2. Regulations
3. Seasonal trends
4. Labour problem

Figure 4.1 depicts construction industry specific risks derived using the above explanation.

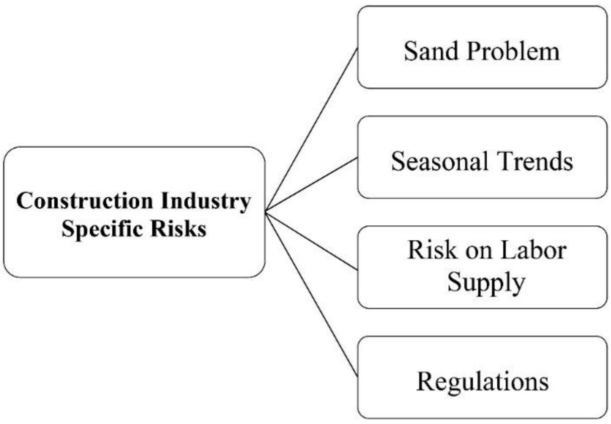


***Figure 4.1*: Construction Industry Specific Risks - Tree Diagram (Source: Author)**

Stakeholder generated risks are further classified into the following risk triggers.

1. Contractor generated risks
2. Consultant generated risks
3. Client generated risks

Materials supply related risks are further classified into the following risk triggers.

1. Materials supply related quality risks
2. Materials supply related availability risks
3. Materials supply related on time delivery risks
4. Materials supply related price risks

Figure 4.2 depicts the materials supply related risks and a "tree diagram" is derived based on the above description.

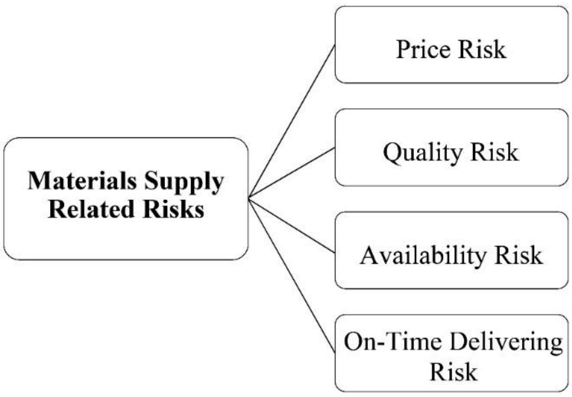


Figure 4.2**: Materials Supply Related Risks - Tree Diagram (Source: Author)**

Contractor generated risk triggers are,

1. Decision making risks
2. Communication risks
3. Sub-contractor risks
4. Financial Risks
5. Planning Risks

Client generated risk triggers are,

1. Risk on communicating the scope
2. Risk on supply of funding

Consultant generated all the risk triggers can be attributed to

1. Risk on submitting accurate designs and estimates

Figure 4.3 depicts the stakeholder generated risks derived from the above description.

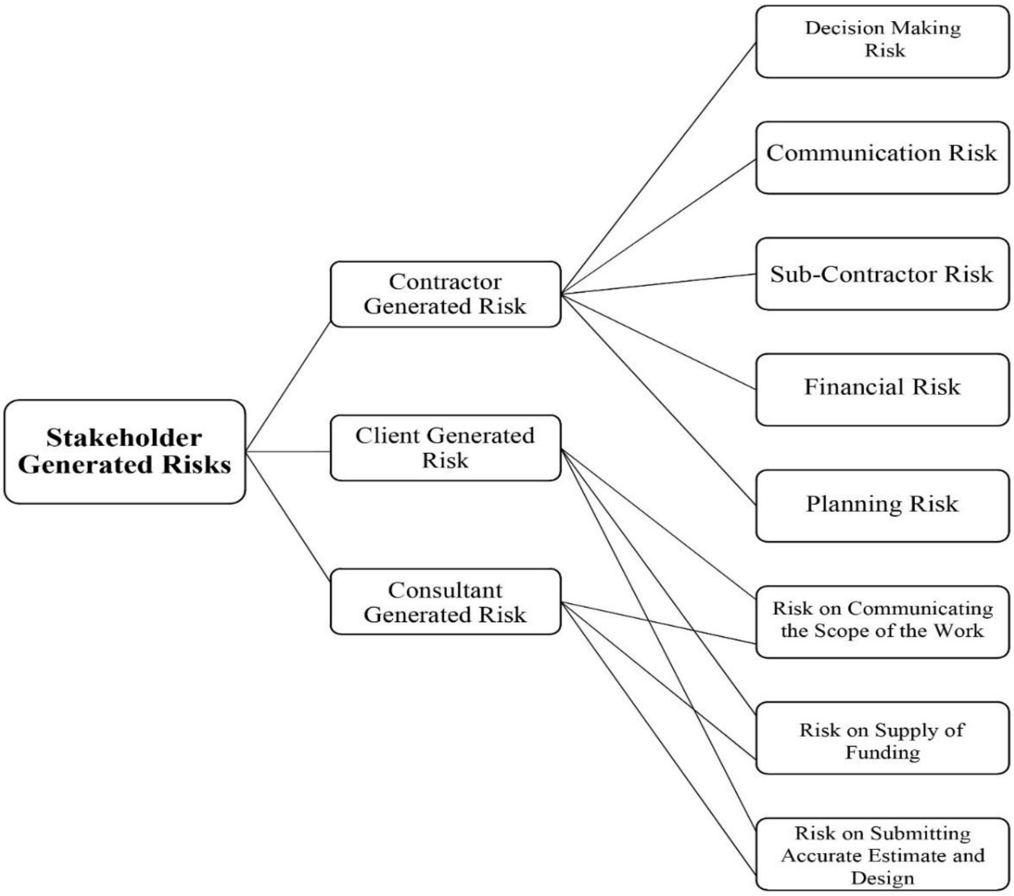


Figure 4.3: **Stakeholder Generated Risks – Tree Diagram (Source: Author)**

In order to analyse the different risks in the whole construction supply chain and the impact of each of the risk at the different points of the construction supply chain to the other areas of the supply chain, three major risk classification system were introduced as: construction industry specified risks, stakeholder generated risks, materials supply related risks. The risk classification methods already available in the literature are explained in Table 4.5-1 and this type of holistic risk classification is new to the literature. Moreover, risk classification using the risk owners are explained in the literature, however risk classification based on the triggers of the risks is new to the literature.

4.5 Assessing the Probabilities and Impact from Historical Data

As per the methodology explained in Chapter 3.3, detailed project information of 38 construction projects were collected which was completed during 2015 and 2016. Data set 2, the major information focused is the risk triggers occurred in each project. The results are depicted in Table 4.5-1 and based on the historical probabilities are derived from each risk trigger (See Appendix VIII).

Cost Impact Index and Time Impact Index of the risks were calculated by dividing the variance value (Actual value – Budgeted value) by budgeted value. Average of these two indices represents the average impact index from historical data as depicted in Table 4.5-1.

Table 4.5-1: Matrix of Risk Triggers for 38 Construction Projects

	Construction Industry Specific Risks				Material Supply Related Risks				Contractor Generated Risks					Client Generated Risks		Consultant Generated Risks
Project	Sand Problem	Regulations	Seasonal Trends	Labour Supply	Quality Risks	Availability Risks	On-time delivery Risks	Price Risks	Decision Making Risks	Communication Risks	Sub-contractor Risks	Planning Risks	Financial Risks	Risk on Communicating the Scope of the Work	Risk on supply of funding	Risk on Submitting Accurate Design and Estimate
1				1					1	1	1	1	1			
2		1	1	1					1	1	1	1	1	1		1
3		1	1	1					1	1	1	1	1	1		1
4						1			1	1	1	1	1	1	1	1
5									1	1	1	1	1	1	1	1
6														1		
7				1										1		
8				1		1	1		1	1	1	1	1	1		1
9									1	1	1	1	1	1		1
10	1			1			1		1	1	1	1	1	1		1
11			1	1					1	1	1	1	1	1		1
12			1						1	1	1	1	1	1		1
13																
14				1	1		1		1	1	1	1	1	1		1
15			1	1					1	1	1	1	1			1

	Construction Industry Specific Risks				Material Supply Related Risks				Contractor Generated Risks					Client Generated Risks		Consultant Generated Risks
Project	Sand Problem	Regulations	Seasonal Trends	Labour Supply	Quality Risks	Availability Risks	On-time delivery Risks	Price Risks	Decision Making Risks	Communication Risks	Sub-contractor Risks	Planning Risks	Financial Risks	Risk on Communicating the Scope of the Work	Risk on supply of funding	Risk on Submitting Accurate Design and Estimate
16							1		1	1	1	1	1	1		
17		1	1	1		1			1	1	1	1	1	1		1
18	1	1			1				1	1	1	1	1	1		1
19									1	1	1	1	1	1		1
20				1	1	1	1		1	1	1	1	1	1		1
21									1	1	1	1	1	1		1
22								1	1	1	1	1	1	1		1
23								1	1	1	1	1	1	1		1
24								1	1	1	1	1	1	1		1
25		1	1	1					1	1	1	1	1	1	1	1
26									1	1	1	1	1			1
27																1
28																
29																
30			1	1						1	1	1	1	1		1
31										1	1	1	1	1		1

	Construction Industry Specific Risks				Material Supply Related Risks				Contractor Generated Risks					Client Generated Risks		Consultant Generated Risks
Project	Sand Problem	Regulations	Seasonal Trends	Labour Supply	Quality Risks	Availability Risks	On-time delivery Risks	Price Risks	Decision Making Risks	Communication Risks	Sub-contractor Risks	Planning Risks	Financial Risks	Risk on Communicating the Scope of the Work	Risk on supply of funding	Risk on Submitting Accurate Design and Estimate
32								1		1	1	1	1	1		1
33	1	1					1			1	1	1	1	1		1
34																
35																
36		1	1			1				1	1	1	1	1		
37		1	1	1			1			1	1	1	1	1		1
38		1				1				1	1	1	1	1		
Count	3	9	10	14	3	6	7	4	23	30	30	30	30	29	3	27
Probability	**0.091**	**0.273**	**0.303**	**0.424**	**0.091**	**0.182**	**0.212**	**0.121**	**0.697**	**0.909**	**0.909**	**0.909**	**0.909**	**0.879**	**0.091**	**0.818**

$(P = \frac{n}{38};$ Where P is the Probability and n is the frequency$)$

(Source: Author)

Equations Used in Section 4.5 (Described in Chapter 3.6.2.4)

$$\text{Cost Impact} = \frac{\left(\sum \frac{\text{Esitimated Cost} - \text{Actual Cost}}{\text{Estimated Cost}}\right)}{\text{n}}$$

Where n is the frequency

$$\text{Time Impact} = \frac{\left(\sum \frac{\text{Esitimated Time} - \text{Actual Time}}{\text{Estimated Time}}\right)}{n}$$

Where n is the frequency

$$\text{Average Impact} = \frac{(\text{Cost Impact} + \text{Time Impact})}{2}$$

$$\text{R} = \text{P} \times \text{I}$$

The Table 4.5-2 depicts the risk profile from the historical data (See Appendix IX for the calculations). According to Table 4.5-2, the highest overall risk came from contractor's risks such as communication, sub-contractor, financial and planning risk followed by the risk of communicating the scope of work generated at client's end risk of submitting accurate designs and estimates generated at consultant's end. The highest time impact was created by sand problems followed by regulation risks. Material related risks such as availability risk and quality risk made considerable impact on time risk. The highest cost impact was made by contractor generated risks followed by seasonal trends. Client generated risks and consultant risks also affected the cost significantly.

Table 4.5-2: Risk Profile from the Historical Data

R = P × I Where, R; Risk, P: Probability of Occurrence, I: Degree of Impact					
Risk Trigger	**Probability**	**Cost Impact**	**Time Impact**	**Average Impact from Historical Data**	**Risk**
Risk on Sand Problem	0.09	0.11	1.88	0.99	0.09
Regulations Risks	0.27	0.13	1.25	0.69	0.19
Risks on Seasonal Trends	0.30	0.30	0.69	0.50	0.15
Risk on labour supply	0.42	0.18	0.56	0.37	0.16
Price Risks	0.12	0.12	0.30	0.21	0.03
Quality Risks	0.09	0.28	0.89	0.59	0.05

Risk Trigger	Probability	Cost Impact	Time Impact	Average Impact from Historical Data	Risk
Availability Risks	0.18	0.28	0.89	0.59	0.11
On-time delivery Risks	0.21	0.19	0.44	0.32	0.07
Decision Making Risks	0.91	0.31	0.69	0.50	0.35
Communication Risks	0.91	0.31	0.69	0.50	0.45
Sub-contractor Risks	0.91	0.31	0.69	0.50	0.45
Financial Risks	0.91	0.31	0.69	0.50	0.45
Planning Risks	0.91	0.31	0.69	0.50	0.45
Risk on communicating the scope of the work	0.88	0.29	0.64	0.47	0.41
Risk on supply of funding	0.09	0.21	0.19	0.20	0.02
Risk on submitting accurate design and estimate	0.82	0.26	0.61	0.44	0.36

(Source: Author)

Figure 4.4 depicts the probability and impacts diagrammatically from the historical data.

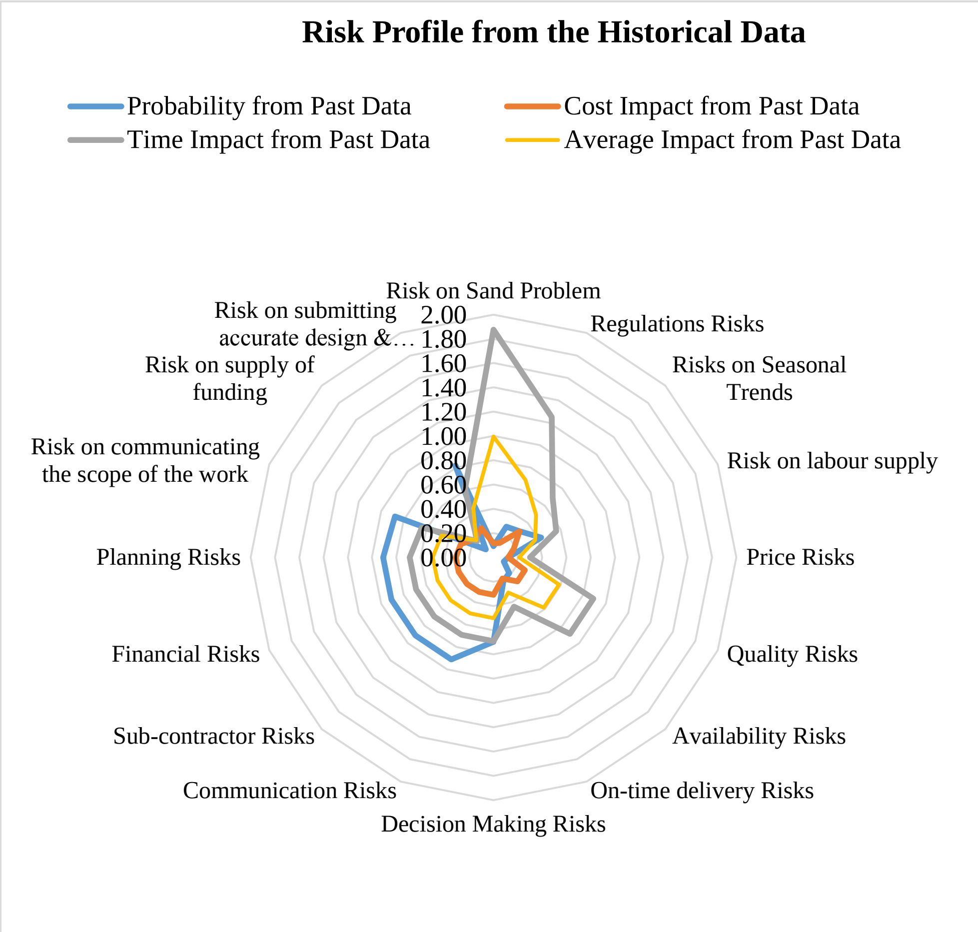


***Figure 4.4*: Risk Profile from Historical Data (Source: Author)**

4.6 Assessing the Probabilities and Impact from Perceived Data

As explained in Section 3.6, fifty five (55) project managers/engineers/quantity surveyors were asked to name 20 most important risks. Data set 1, they were further asked to indicate the total risk in a scale of 1-5 (1- lowest and 5- highest). The results are indicated in Table 4.6-1.

Equations used in Section 4.6 (Described in Chapter 3.6.2.5)

$$\text{n} = \text{frequency of common risk topics indicated}$$

$$P = \frac{\sum_1^n p}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.1)$$

Where, P: Probability, p: probability from perceived data, n: frequency

$$I = \frac{\sum_1^n i}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.2)$$

Where, I: Probability, i: probability from perceived data, n: frequency

$$R = P \times I$$

Where, R; Risk, P: Probability of Occurrence, I: Degree of Impact

Table 4.6-1 depicts the risk profile from the perceived data. For each of the risk triggers probability, impact and risks are shown (Figure 4.2 shows the results diagrammatically.

Table 4.6-1: Risk Profile from the Perceived Data

$R = P \times I$ Where, R; Risk, P: Probability of Occurrence, I: Degree of Impact n = 55			
Risk Triggers	**Probability**	**Impact**	**Risk**
Risk on labour supply	0.8	1.0	0.80
Sand Problem	0.8	0.8	0.64
Decision Making Risks	0.8	0.8	0.64
Financial Risks	0.8	0.8	0.64
Seasonal Trends	0.6	0.8	0.48
Availability Risks	0.6	0.8	0.48
On-time delivery Risks	0.6	0.8	0.48
Sub-contractor Risks	0.8	0.6	0.48
Planning Risks	0.6	0.8	0.48
Risk on communicating the scope of the work	0.6	0.8	0.48
Risk on submitting accurate design and estimate	0.6	0.8	0.48
Quality Risks	0.6	0.6	0.36
Communication Risks	0.6	0.6	0.36
Regulations	0.4	0.8	0.32
Price Risks	0.4	0.8	0.32
Risk on supply of funding	0.4	0.8	0.32

(Source: Author)

Figure 4.5 depicts the probability and impacts diagrammatically from the perceived data.

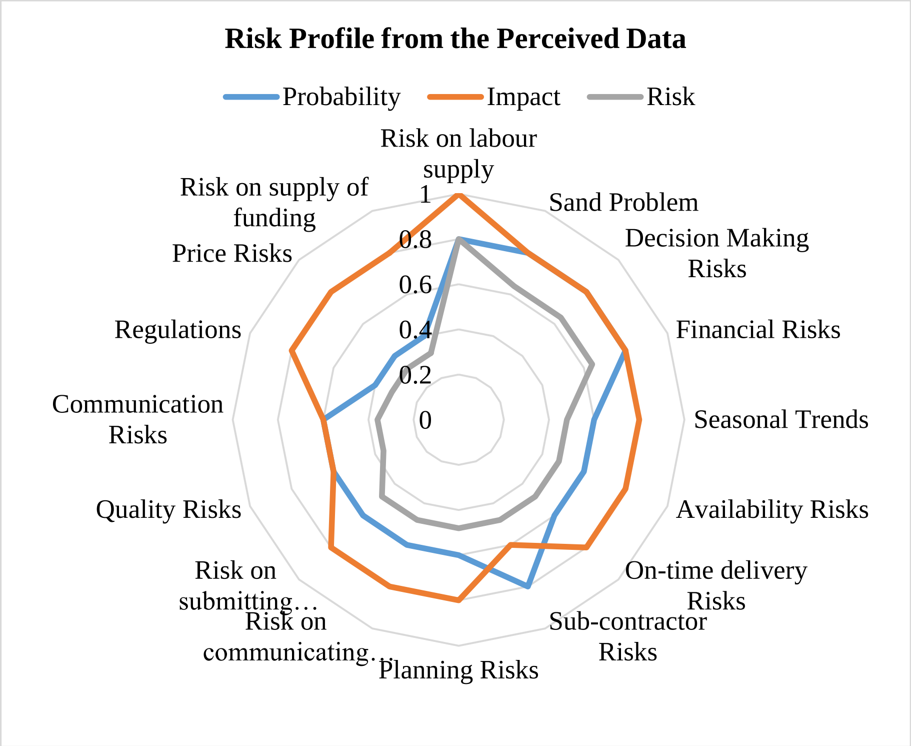


***Figure 4.5*: Risk Profile from Perceived Data (Source: Author)**

Based on Table 4.5-2 and Table 4.6-1, Table 4.6-2 was derived, which shows the risk profile comparison of historical data and perceived data for 16 risk triggers, three risk categories and five different risk owners.

Table 4.6-2: Risk Profile Comparison of Historical Data and Perceived Data

	Perceived Data		Historical Data				
Risk Triggers	Probability from Perceived Data	Impact from Perceived Data	Probability from Historical Data	Cost Impact from Historical Data	Time Impact from Historical Data	Average Impact from Historical Data	Risk
Risk on Sand Problem	0.8	0.8	0.09	0.11	1.88	0.99	0.09
Regulations Risks	0.4	0.8	0.27	0.13	1.25	0.69	0.19
Risks on Seasonal Trends	0.6	0.8	0.30	0.30	0.69	0.50	0.15
Risk on labour supply	0.8	1.0	0.42	0.18	0.56	0.37	0.16
Price Risks	0.4	0.8	0.12	0.12	0.30	0.21	0.03
Quality Risks	0.6	0.6	0.09	0.28	0.89	0.59	0.05
Availability Risks	0.6	0.8	0.18	0.28	0.89	0.59	0.11
On-time delivery Risks	0.6	0.8	0.21	0.19	0.44	0.32	0.07
Decision Making Risks	0.8	0.8	0.70	0.31	0.69	0.50	0.35
Communicatio n Risks	0.6	0.6	0.91	0.31	0.69	0.50	0.45
Sub-contractor Risks	0.8	0.6	0.91	0.31	0.69	0.50	0.45
Financial Risks	0.8	0.8	0.91	0.31	0.69	0.50	0.45
Planning Risks	0.6	0.8	0.91	0.31	0.69	0.50	0.45
Risk on communicating the scope of the work	0.6	0.8	0.88	0.29	0.64	0.47	0.41
Risk on supply of fundng	0.4	0.8	0.09	0.21	0.19	0.20	0.02
Risk on submitting accurate design and estimate	0.6	0.8	0.82	0.26	0.61	0.44	0.36
Risk Categories							
Stakeholder Generated Risks	0.61	0.77	0.72	0.27	0.57	0.42	0.30

	Perceived Data		Historical Data				
Risk Triggers	Probability from Perceived Data	Impact from Perceived Data	Probability from Historical Data	Cost Impact from Historical Data	Time Impact from Historical Data	Average Impact from Historical Data	Risk
Construction Industry Specified Risks	0.65	0.85	0.27	0.30	1.09	0.70	0.19
Materials Supply Related Risks	0.55	0.75	0.15	0.21	0.67	0.44	0.07
Risk Owners							
Contractors	0.72	0.72	0.87	0.31	0.69	0.50	0.44
Client	0.50	0.80	0.48	0.25	0.42	0.34	0.16
Consultants	0.60	0.80	0.82	0.26	0.61	0.44	0.36
Construction industry	0.65	0.85	0.27	0.30	1.09	0.70	0.19
Material Supplier	0.55	0.75	0.15	0.21	0.67	0.44	0.07

(Source: Author)

Based on Table 4.6-2, Figure 4.6 compares the probability from perceived data and probability from historical data.

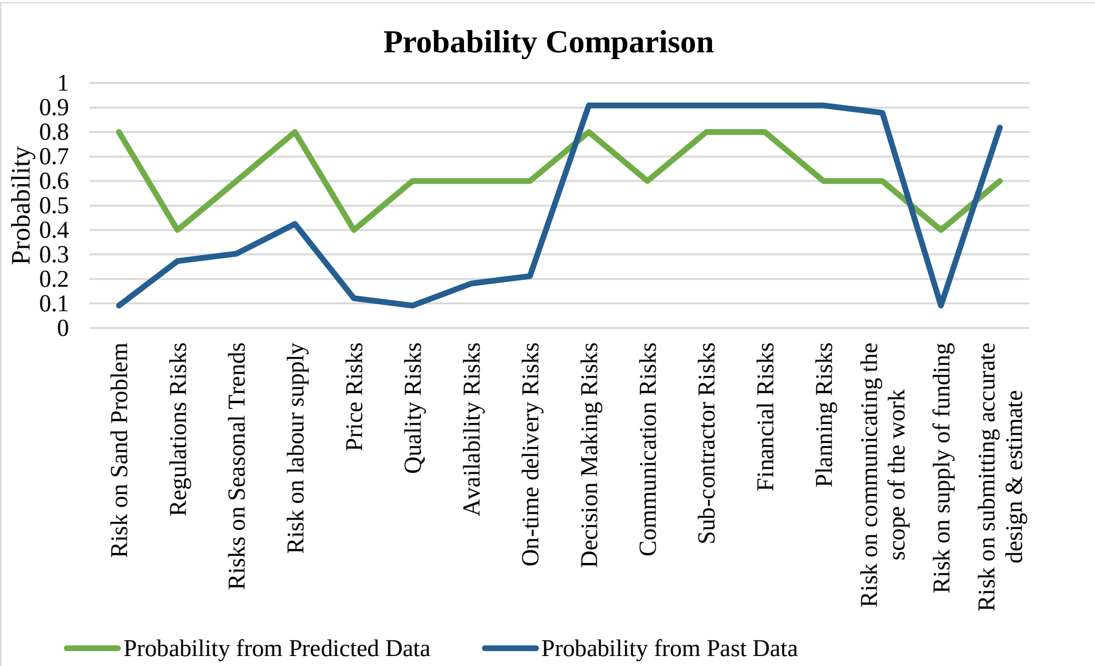


***Figure 4.6*: Probability Comparison (Source: Author)**

In general, the probability of historical data is less than that of perceived data except in the risk triggers connected to contractor, consultant and sand problems. The reason can be that risk owners have managed the risk reasonably well. Sand problem was not a high risk in the historical data, but due to the scarcity of sand resources and strict regulations on extracting sand, the risk is increasing, and it is clearly noted in the diagram. When it comes to contractor generated risk triggers and consultant generated risk triggers, the probability from historical data is higher than the perceived data. The reason can be contractors and consultants have underestimated their own risk in the perceived data but in actual historical cases, the probabilities associates with consultants and contractor are higher.

Figure 4.7 explains the impact from perceived data and historical data based on Table 4.6-2.

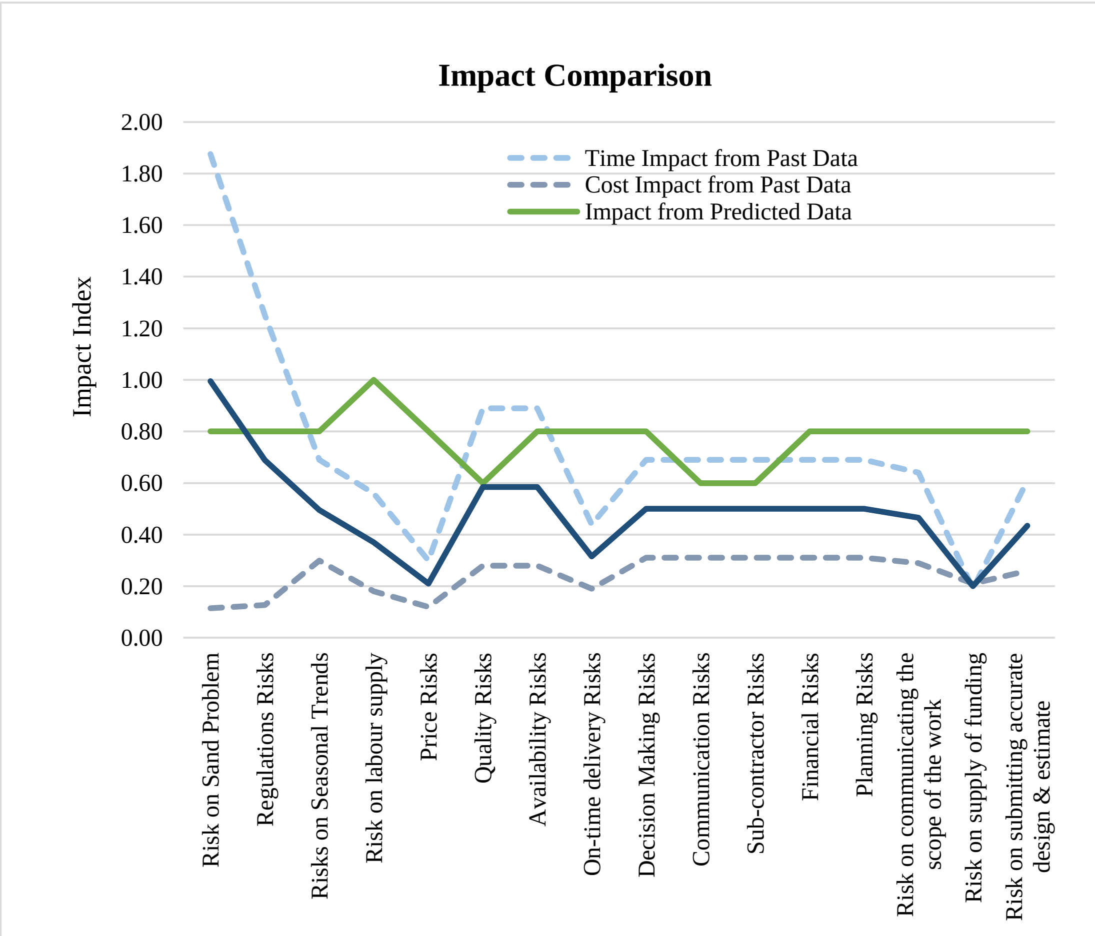


***Figure 4.7*: Impact Comparison (Source: Author)**

Impact from perceived data is generally higher than that of historical data. It shows that the contractors have managed the risks reasonably well. However, the impact may evolve with time as external and internal factors change. This is a limitation of the study as construction is a dynamic industry.

4.7 Deriving an Accurate Probability for Each Risk Trigger

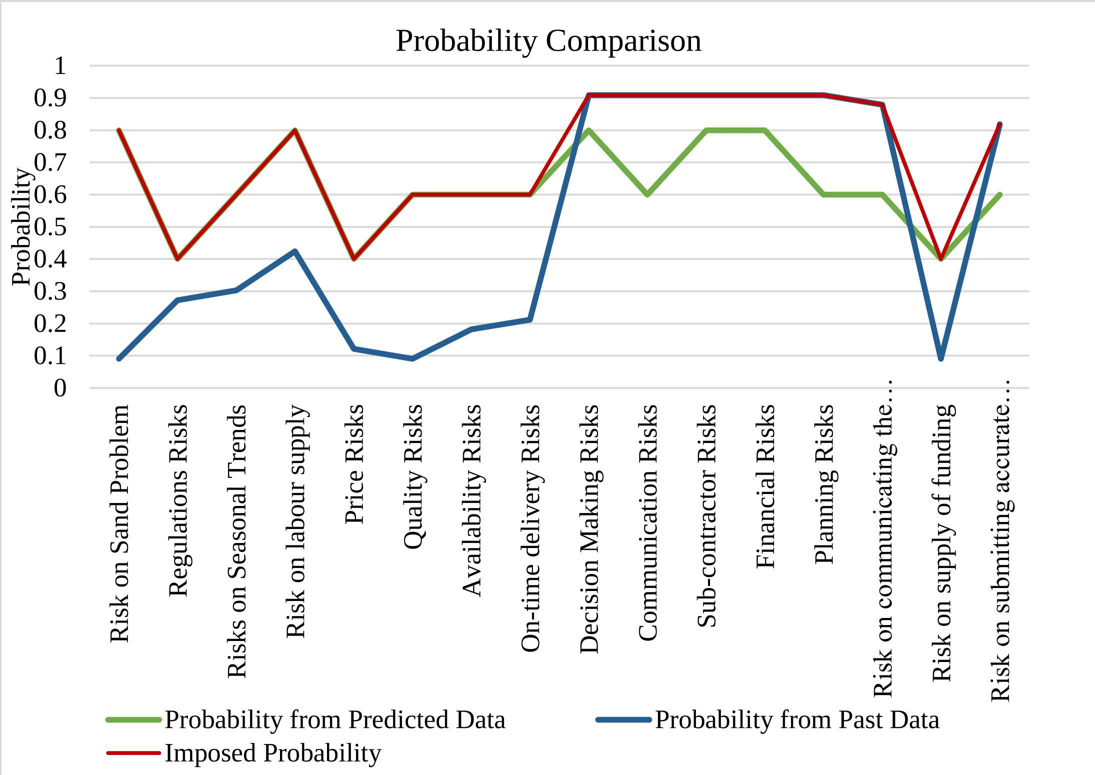


Figure 4.8**: Validation of the Imposed Probability by Triangulation (Source: Author)**

When assessing the forecasted probability it is logical to use perceived data except in risk triggers associated with contractors and consultants. However, it is logical to use the historical probabilities for the forecasted probabilities in risk triggers associated with contractors and consultants because the contractors and consultant can underestimate the risk triggers generated by them in the perceived data.

4.8 Contribution from Risk Categories (Perceived Vs Historical)

Based on the Table 4.6-2, probability contribution from three risk categories for both historical and perceived probabilities are depicted in Figure 4.9.

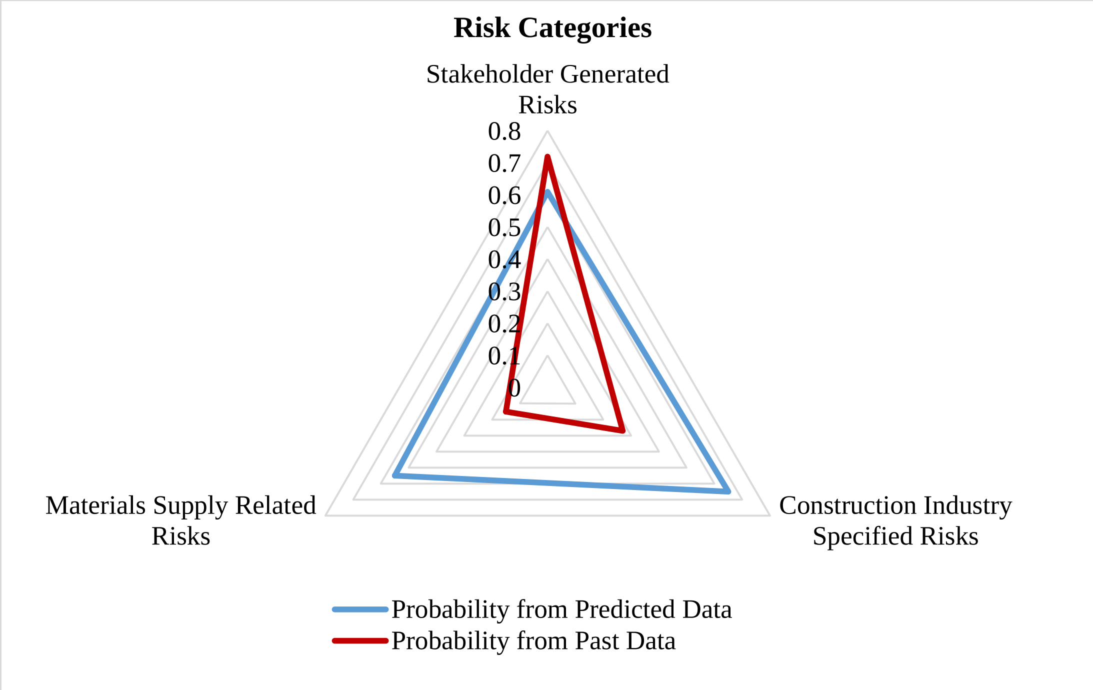


Figure 4.9**: Probabilities of Risk Categories (Source: Author)**

According to the above figures, perceived probabilities are higher for materials supply related risks and construction industry specific risks. However, perceived probabilities are lower than that of historical data for stakeholder risks.

4.9 Contribution from Risk Owners (Perceived Vs Historical)

Based on Table 4.6-2, probability contribution from five risk owners for both historical and perceived probabilities are depicted in Figure 4.10.

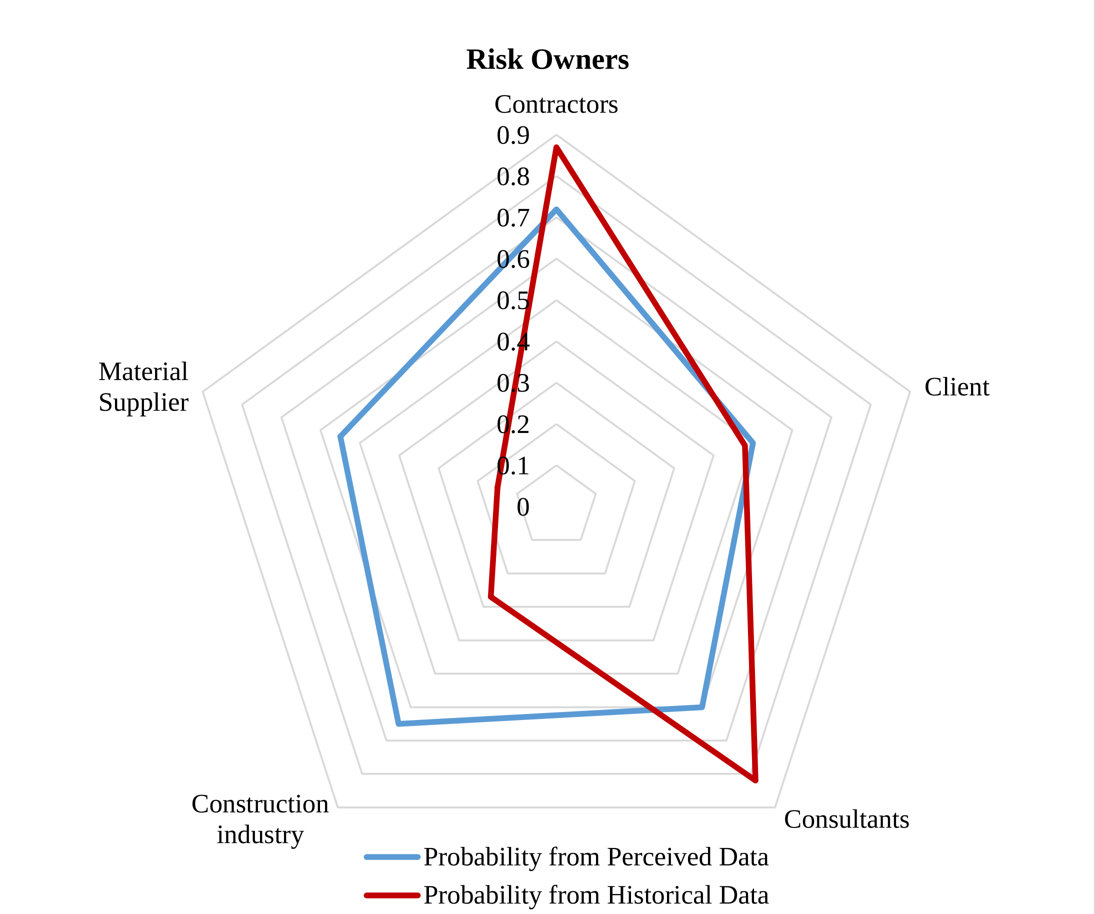


Figure 4.10**: Probabilities of Risk Owners (Source: Author)**

According to the above figures, perceived probabilities are higher for materials suppliers and construction industry. However, perceived probabilities are lower than that of historical data for contractors and consultants. This clearly shows stakeholders such as contractors and consultants have overestimated the perceived data.

4.10 Impact of Selected Risk Triggers on Cost and Time of Sri Lankan Projects- Case Study with 38 Projects

As explained in Section 4.7, detailed project information of 38 construction projects (See Appendix IV) were collected which was completed during 2015 and 2016. Average cost of a project was USD 13.9 Million and average cost of a task (break downs of the project) is USD 1 Million. Average duration of a project was 1100 days and average duration per task was 82 days. In each project, for the major task breakdowns such as foundation work, super structure, finishing etc., the respective actual cost and estimated cost were collected together with the reasons for variation if any. Each task break downs of the project were taken as individual data points. Estimated Cost vs. Actual cost and Estimated Time vs. Actual Time were used to conduct the quantitative analysis in order to study different risk triggers. (See Appendix V) Risks measured in money value and days were identified. Risk were categorized as positive risk and negative risk. Risk was negative when the actual cost/days were more than the estimated values (cost/time overruns) and risk was positive, when the actual cost/days were lesser than the estimated values.

Negative risk related to cost (cost overruns) in construction projects is only 40%, where 60% of the projects managed saving whereas negative time risk (time overruns) of construction projects is 64%, where only 36% have finished work before the estimated schedule. Cost overrun is 37.5% and time overrun is 63.9%, where a time overrun is higher than the cost overrun. This shows project managers when making risk management plans, high focus to safeguarding their profits by minimizing the negative impacts to costs, but they are less bothered about the time targets which mainly affect the clients. However, in the long run it affects to the contractor also as the contractor has to unnecessarily retain resources such as machines and equipment, people and etc. which the contractor could have put into a new project. A regression analysis was conducted to understand the relationships among the estimated cost/time and risk of cost/time. The regression analysis was conducted only for the cases with more than 20 data points as a measure to maintain the model accuracy.

4.10.1 Regression Analysis – Historical Data

Cost and time behavior of few risk triggers were examined using correlation and regression analysis.

Where,

$$\text{Dependent Variable} = \text{f (Independent Variables)} \ldots\ldots\ldots\ldots\ldots (4.2)$$

Table 4.10-1: Dependent and Independent Variables

Dependent Variable	Independent Variables
Risk (Rupees)	Estimated Cost
Risk (Days)	Estimated Time

4.10.2 Case 01: Cost and Time Impact of Labour Supply Risks

In this case, 41% of the construction project's individual tasks was managed within the estimated budget, though 59% had cost overruns due to labour supply risks. Time overrun is 82%, while 18% of construction individual tasks was managed below the budgeted time. It can be reasonably concluded that contractors' risk mitigation plans focus more on achieving the cost targets rather than the time targets. A regression analysis was conducted for both the negative and positive risks (cost and time) generated due to construction labour supply risk.

Negative Risk

Regression Model – Cost

The regression equation is,

$$\text{Construction Industry Specific Negative Risks on Labour Supply in Rupees} = 0.262 \text{ Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

Regression Model - Time

The regression equation is,

$$\text{Construction Industry Specific Negative Risks on Labour Supply in Days} = 0.471 \text{ Estimated} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (4.4)$$

Positive Risk

Regression Model – Cost Saving

The regression equation is,

$$\text{Construction Industry Specific Positive Risks on Labour Supply in Rupees} = 0.494\ \text{Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.5)$$

4.10.3 Case 02: Cost and Time Impact of Seasonal Trends Risks

In this case 62% of the construction projects' individual tasks were managed within the estimated budget, though 38% individual tasks had cost overruns due to seasonal trends. Time overruns of individual tasks were 92%, whilst 8% of individual tasks were able to be within the schedule. This also shows that contractors' risk mitigation plans focus more on achieving the cost targets rather than the time targets. A regression Analysis was conducted for the negative and positive risks (Cost and Time) generated due to construction specific seasonal trends.

Negative Risk

Regression Model - Cost

The regression equation is,

$$\text{Construction Industry Specific Negative Risks on Seasonal Trends in Rupees} = 1.40\ \text{Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

Regression Model - Time

The regression equation is,

$$\text{Construction Industry Specific Negative Risks on Seasonal Trends in Rupees} = 1.40\ \text{Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.7)$$

Positive Risk

Regression Model – Cost Saving

The regression equation is,

$$\text{Construction Industry specific Positive Risks on Seasonal Trends in Rupees} = 0.977\ \text{Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.8)$$

4.10.4 Case 03: Cost and Time Impact of Client/consultant Generated Risk on Communicating the Scope of the Work

In this case; 69% of the construction project individual tasks were managed within estimated budget, though 31% had cost overruns due to client/consultant generated risk on communicating the scope of the work. Among the individual tasks, 92% had time overruns, whilst 8% of construction individual tasks were managed within the schedule. This also shows that contractors' risk mitigation plans focus more on achieving the cost targets rather than the time targets. A regression Analysis was conducted for the negative and positive risks (cost and time) generated due to client/consultant generated risk on communicating the scope of the work.

Positive Risk

Regression Model – Cost Saving

The regression equation is,

$$\text{Client and Consultant Generated Positive Risks on Communicating the Scope of the Work in Rupees} = 1.40 \text{ Estimated Cost} \quad \text{(4.9)}$$

Negative Risk

Regression Model - Time

The regression equation is

$$\text{Client and Consultant Generated Negative Risks on Communicating the Scope of the Work in Days} = 0.791 \text{ Estimated Days} \quad \text{(4.10)}$$

4.10.5 Case 04: Cost and Time Impact of Client/Consultant Generated Risk on Submitting Accurate Design and Estimate

In this case; 35% of the construction project individual tasks were managed within the estimated budget, while 65 % of the individual tasks had cost overruns due to client/consultant generated risk on submitting accurate design and estimate. Among the individual tasks, 99% had time overruns, whilst 1% of construction project individual tasks were managed within the schedule. This shows that contractors' risk mitigation plans focus more on achieving the cost targets rather than the time targets. A regression Analysis was conducted for the negative and positive risks (Cost and Time) generated due to client/consultant generated risk on communicating the scope of the work.

Negative Risk

Regression Model – Cost

$$\text{Client and Consultant Generated Negative Risks on Submitting Accuate Design and Estimate in Rupees} = 0.0928 \text{ Estimated Cost} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.11)$$

Regression Model - Time

The regression equation is,

$$\text{Client and Consultant Generated Negative Risks on Submitting Accuate Design and Estimate in Days} = 11.8 + 0.199 \text{ Estimated Days} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.12)$$

Regression model for the positive risk generated due to client/consultant generated risk on submitting accurate design and estimate is not significant (Appendix XI). The Table 4.10-2 depicts a summary of the risk behaviors of studied cases.

Table 4.10-2: Summary of the Risk Behaviors of Studied Cases

	Case 01				**Case 02**				**Case 03**				**Case 04**			
	Cost Risk		Time Risk		Cost Risk		Time Risk		Cost Risk		Time Risk		Cost Risk		Time Risk	
	Positive	Negative	Positive	Positive	Negative	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Risk Behavior	41 %	39 %	82 %	18 %	62 %	38 %	92 %	8%	69 %	31 %	92 %	8%	35 %	65 %	99 %	1%

(Source: Author)

4.11 Summary

Chapter 4 discussed risk topics, risk owners and risk triggers with respect to the Sri Lankan construction industry. In the Sri Lankan context, some of the construction supply chain risks are identified proactively, however most of the risks are reactively managed and this is line with many other construction industries in the global context. Most of the risk owners perspective about their risks are mostly external and they attribute their risks to the immediate upstream and downstream partners and they fail to recognize the internal risks created by themselves, as well as risk coming from extended supply chain both upstream and downstream. Chapter 4 further ranks the risk topics and except the 'sand, soil, gravel, aggregate,sub base unavailability' the remaining risk topics appeared in many other research in the global context. It discussed the probabilities and impacts of risk triggers from historical data as well as perceived data and derived the risk profile for the Sri Lankan construction industry. In the global context, there were no research outputs to compare the risk profile derived from both historical data and perceived data approach used in the Sri Lankan context. It further describes the risk contribution from different risks categories as well from different risk owners. Finally it discussed the impacts of different risks triggers on project cost and project duration in the Sri Lankan context. The approach explained in the research can be used to calculate the risk contribution from different risk categories as well as risk owners for a country with different socio economic context, however the equations explained in the chapter may not be applicable as it. The next chapter discusses the findings on interaction model linking the risk owners and risk triggers.

Chapter 05

05. FINDINGS AND DISCUSSION 2 - INTERACTION MODEL LINKING THE RISK OWNERS AND RISK TRIGGERS

5.1 Introduction

The previous chapter discussed the risk topics, risk triggers, risk owners and the risk profiles of the construction supply chains in Sri Lankan context. This chapter presents the analysis, findings and discussion on objectives 4 and 5 of the research. According to Styger (2011), *"Complex supply networks are not mapped sufficiently. Moreover, the dynamic nature of supply networks are not recognized and risk mitigated accordingly. Importantly, if it is not possible to map, then it is not possible to measure supply participants (suppliers, customers, stakeholders, society in general etc.) and if it is not possible to measure supply participants then it is not possible to know supply participants and in turn not possible to know the supply network. Lack of supply network mapping embeds significant risk into complex supply networks; however, this factor is typically not acknowledged either in academic and commercial circles*". Hence, it is important to map the interaction among the different construction supply chain partners.

This chapter discusses the interaction model of the Sri Lankan construction industry stakeholders and it is to derive the Risk Relationship Diagram (RRD). The risk triggers are mapped and validated the using double triangulation methodology (See Section 5.4 and 5.5).

5.2 Arriving at Risk Relationship Diagram

As explained in Section 3.6.2.1, focus group discussions, with 38 engineers/project managers/quantity surveyors/architects, were carried out and each of the respondents was asked to bring details about a project that they were personally involved. Detailed project information on 38 construction projects were collected which were completed during 2015 and 2016. One of the major information focused were estimated cost against actual cost and estimated duration against actual construction duration for each of the major task of construction such as foundation work, superstructure etc., and the reasons for the variations. Two hundred sixty three (263) variations from the budget and basic reasons for each variation were presented by 38 respondents from 38 construction projects. Some risk topics such as rain, delays of submitting accurate drawings, sand shortage, construction project management issues etc. were repeated in each project as a reason for cost and time overruns. For each of the major tasks of construction, the reason for cost risk as a percentage of estimated cost and time risk as a percentage of estimated duration were calculated and major reasons for such risks were written from the facts available to each respondents. The given answers were further analyzed as risk category 1, risk category 2 and risk category 3 and used the terminology presented in Section 4.4.

After analyzing all the 263 cases of variations, the risk topics combination for each risk occurrence were coded under risk triggers, such as risk on labour supply, client generated risk on communicating the scope of work, sand problems, etc. as introduced in Chapter 4. In many cases, there were combinations of risk triggers and risk owners. For an example, in one case the foundation cost and time are increased due to unforeseen flooding and a decision making mistake in construction planning. Subsequently, each variation were further categorized under various owners such as contractor generated, client generated, consultant generated, etc. and finally they were classified under a main risk classification (Construction Industry Generated, Stakeholder Generated and Material Supplier Generated) as introduced in Chapter 4. Afterwards, the similar risk-trigger, risk-owner and risk-classification patterns are identified and frequency of appearing each of the patterns are counted and calculated as a percentage. This is presented in Table 5.2-1 as various risk trigger- risk owner-risk classification pattern and their response percentage.

Table 5.2-1: Various Risk Trigger- Risk Owner- Risk Classification Patterns and Their Response Percentage

Risk Category 1	Risk Category 2	Risk Category 3	Responses %
Construction Industry specific Risks on Labour Supply		Construction Industry Specified Risks	5.32
Client and Consultant Generated Risk on Communicating the Scope of the Work	Client and Consultant Generated Risks	Stakeholder Generated Risks	6.46
Construction Industry specific Risks on Labour Supply and Seasonal Trends		Construction Industry Specified Risks	0.76
Construction Industry Specified Regulation Risks and Seasonal Trends		Construction Industry Specified Risks	0.38
Client and Consultant Generated Risk on Submitting Accurate Design and Estimate	Client and Consultant Generated Risks	Stakeholder Generated Risks	19.42
Construction Industry Specified Regulation risks		Construction Industry Specified Risks	2.28
Client Generated Risk on Communicating the Scope of the Work	Client Generated Risks	Stakeholder Generated Risks	2.28
Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Contractor Generated Risks	Stakeholder Generated Risks	4.18
Construction Industry Specified Sand Problem		Construction Industry Specified Risks	2.28
Consultant Generated Risk on Communicating the Scope of the Work	Consultant Generated Risks	Stakeholder Generated Risks	1.14
Consultant Generated Risk on Submitting Accurate Design and Estimates	Consultant Generated Risks	Stakeholder Generated Risks	0.76
Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Contractor Generated Risks and Construction Industry Specified Risk on Labour Supply and Seasonal Risks	Construction Industry Specified Risks and Stakeholder Generated Risks	0.38
Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Contractor Generated Risks and Construction Industry Specified Seasonal Trends	Construction Industry Specified Risks and Stakeholder Generated Risks	2.28

Risk Category 1	Risk Category 2	Risk Category 3	Responses %
Client and Consultant Generated Risk on Submitting Accurate Design and Estimate/Risk on supply of funding/Risk on Communicating the Scope of the Work and Contractor Generated Planning, Financial and Sub-contractor Risks	Materials Supply Related Availability Risks ,Contractor, Client and Consultant Generated Risks	Materials Supply Related Risks and Stakeholder Generated Risks	1.52
Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Materials Supply Related On-time Delivery Risks and Quality Risks and Contractor Generated Risks	Materials Supply Related Risks and Stakeholder Generated Risks	0.38
Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Materials Supply Related On-time Delivery Risks and Contractor Generated Risks	Materials Supply Related Risks and Stakeholder Generated Risks	1.90
Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Materials Supply Related Price Risks and Contractor, and Client and Consultant Generated Risks	Materials Supply Related Risks and Stakeholder Generated Risks	2.66
Client and Consultant Generated Risk on Submitting Accurate Design and Estimate and Contractor Generated Planning, Financial and Sub-contractor Risks	Materials Supply Related Quality Risks, Contractor, and Client and Consultant Generated Risks	Materials Supply Related Risks and Stakeholder Generated Risks	0.38
Client and Consultant Generated Risk on Communicating the Scope of the Work and Risk on supply of funding	Client and Consultant Generated Risks	Stakeholder Generated Risks	1.14
Client and Consultant Generated Risk on Communicating the Scope of the Work	Client and Consultant Generated Risks	Stakeholder Generated Risks	20.91
Consultant generated Risk on Communicating the Scope of the Work	Consultant Generated Risks	Stakeholder Generated Risks	0.38

Risk Category 1	Risk Category 2	Risk Category 3	Responses %
Consultant Generated Risk on Submitting Accurate Design and Estimate	Consultant Generated Risks	Stakeholder Generated Risks	0.76
Client and Consultant Generated Risk on Submitting Accurate Design and Estimate and Contractor Generated Planning, Financial and Sub-contractor Risks	Client, Consultant and Contractor Generated Risks	Stakeholder Generated Risks	19.77
Client and Consultant Generated Risk on Communicating the Scope of the Work	Client and Consultant Generated Risks, Construction Industry specific Risks on Labour Supply and Materials Supply related availability risks	Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks	1.14
Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Client, consultant and Contractor Generated Risks, Construction Industry specific Risks on Labour Supply and Materials Supply related availability risks	Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks	0.38
Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks	Client and Consultant Generated Risks, Construction Industry specific Risks on Labour Supply and Materials Supply related availability risks	Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks	0.76

(Source: Author)

Equation used in Section 5.2

$$\text{Response Rate as a percentage} = \frac{\text{Number of Responses to each case}}{\text{n}} \ \% \ldots (5.1)$$

Where, n = frequency of Risk Category

From the Table 5.2-1, similar risk trigger- risk owner- risk classification patterns are identified and presented as follows.

A. **Construction Industry Specified Risks**

1. Construction Industry specific Risks on Labour Supply → Construction Industry Specified Risks
2. Construction Industry specific Risks on Labour Supply and Seasonal Trends → Construction Industry Specified Risks
3. Construction Industry Specified Regulation Risks and Seasonal Trends → Construction Industry Specified Risks
4. Construction Industry Specified Regulation Risks → Construction Industry Specified Risks
5. Construction Industry Specified Seasonal Trends → Construction Industry Specified Risks

B. **Combination of Construction Industry Specified Risks and Stakeholder Generated Risks**

1. Contractor Generated Planning, Decision making, Communication, Financial and Sub-Contractor Risks → Contractor Generated Risks and Construction Industry Specified Risk on Labor Supply and Seasonal Risks → Construction Industry Specified Risks and Stakeholder Generated Risks
2. Contractor Generated Planning, Decision making, Communication, Financial and Sub-Contractor Risks → Contractor Generated Risks and Construction Industry Specified Seasonal Trends → Construction Industry Specified Risks and Stakeholder Generated Risks

C. **Combination of Materials Supply Related Risks and Stakeholder Generated Risks**

1. Client and Consultant Generated Risk on submitting accurate design and estimate and Contractor Generated Planning, Financial and Sub-Contractor Risks → Materials Supply Related Availability Risks and Contractor, Client and Consultant Generated Risks → Materials Supply Related Risks and Stakeholder Generated Risks
2. Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks → Materials Supply Related On-time Delivery

Risks and Quality Risks and Contractor Generated Risks → Materials Supply Related Risks and Stakeholder Generated Risks

3. Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks → Materials Supply Related On-time Delivery Risks and Contractor Generated Risks → Materials Supply Related Risks and Stakeholder Generated Risks
4. Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks → Materials Supply Related Price Risks and Contractor, and Client and Consultant Generated Risks → Materials Supply Related Risks and Stakeholder Generated Risks
5. Client and Consultant Generated Risk on submitting accurate design and estimate and Contractor generated planning, financial and sub-contractor Risks → Materials Supply Related Quality Risks, Contractor, and Client and Consultant Generated Risks → Materials Supply Related Risks and Stakeholder Generated Risks

D. Stakeholder Generated Risks

1. Client/Consultant Generated Risk on Communicating the Scope of the Work → Client and Consultant Generated Risks → Stakeholder Generated Risks
   i. Client Generated Risk on Communicating the Scope of the Work → Client and Consultant Generated Risks → Stakeholder Generated Risks
   ii. Consultant Generated Risk on Communicating the Scope of the Work → Consultant Generated Risks → Stakeholder Generated Risks

2. Client/Consultant generated Risk on Submitting Accurate Design and Estimate → Client and Consultant Generated Risks → Stakeholder Generated Risks

   i. Client Generated Risk on Submitting Accurate Design and Estimate → Client and Consultant Generated Risks → Stakeholder Generated Risks

ii. Consultant generated Risk on Submitting Accurate Design and Estimate → Consultant Generated Risks → Stakeholder Generated Risks

3. Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks → Contractor Generated Risks → Stakeholder Generated Risks

4. Client and Consultant Generated Risk on Communicating the Scope of the Work and Risk on supply of funding → Client and Consultant Generated Risks → Stakeholder Generated Risks

5. Client and Consultant Generated Risk on Submitting Accurate Design and Estimate and Contractor Generated Planning, Financial and Sub-Contractor Risks → Contractor and Consultant Generated Risks → Stakeholder Generated Risks
6. Stakeholder Generated Risks → Contractor and Consultant Generated Risks → Contractor and Consultant Generated Risk on Communicating the Scope of the Work

E. Combination of Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks

1. Client and Consultant Generated Risk on Communicating the Scope of the Work → Client and Consultant Generated Risks, Construction Industry Specific Risks on Labour Supply and Materials Supply Related Availability Risks → Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks.

2. Contractor Generated Planning, Decision making, Communication, Financial and Sub-contractor Risks → Client, Consultant and Contractor Generated Risks, Construction Industry specific Risks on Labour Supply and Materials Supply related Availability Risks → Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks.

3. Client and Consultant Generated Risk on Communicating the Scope of the Work and Contractor Generated Planning, Decision Making, Communication, Financial and Sub-Contractor Risks → Client, Consultant and Contractor Generated Risks, Construction Industry Specific Risks on Labour Supply and Materials Supply Related Availability Risks → Stakeholder Generated Risks, Construction Industry Specified Risks and Materials Supply Related Risks

5.2.1 Summerizing the Risk Trigger-Risk Owner-Risk Classification Patterns using a Tree Diagram.

Figure 5.1 depicts the construction supply chain risk - tree diagram derived from all the above tree diagrams explained in Section 4.4.

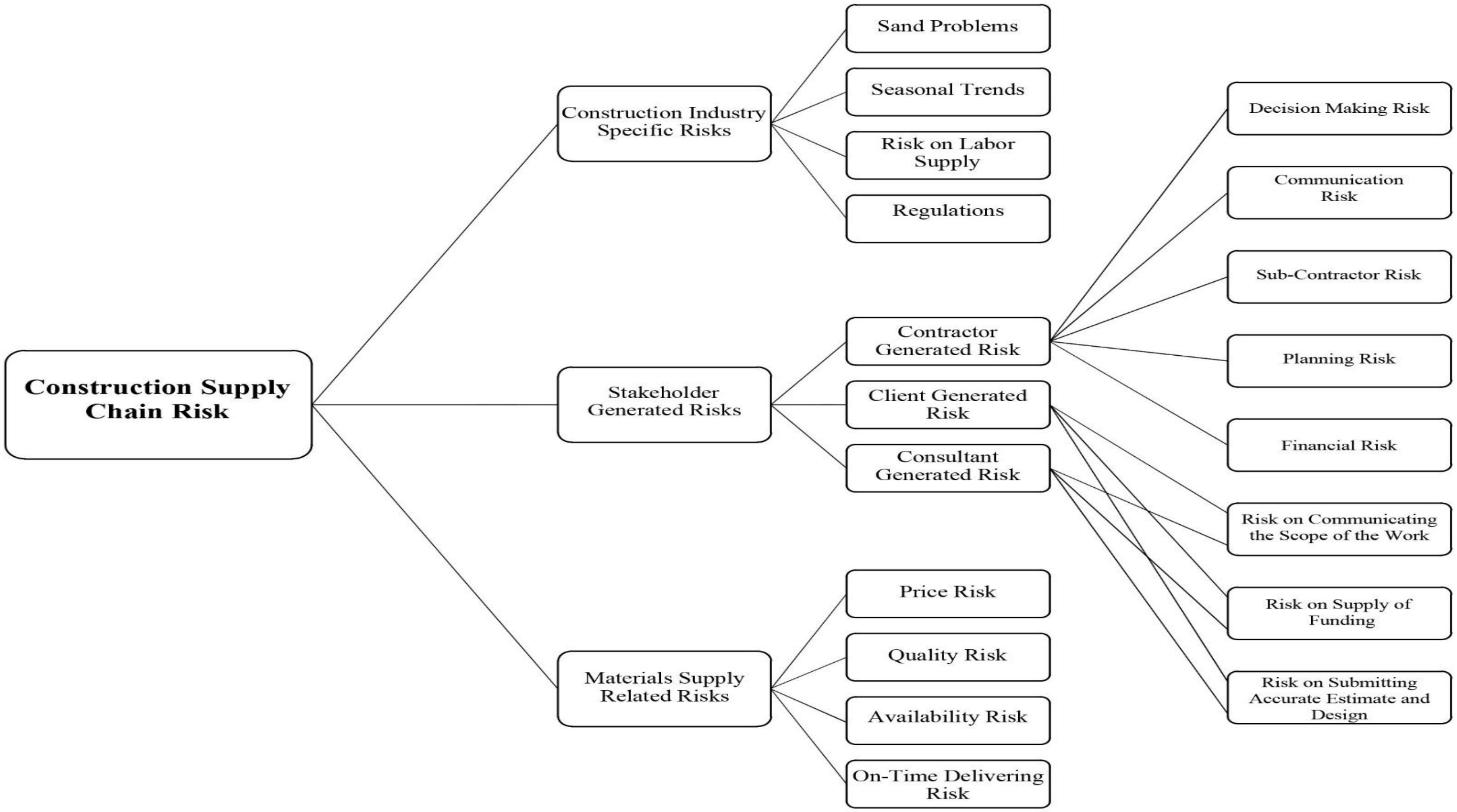


***Figure 5.1*: Construction Supply Chain Risk - Tree Diagram (Source: Author)**

Figure 5.1 explains all of the branches of the construction supply chain risks including the relationships. By mapping the above tree diagrams and the different combinations of risk triggers, risk owners, under three major topics of risk classification, the dark lines with arrows of the following Risk Relationship Diagram (RRD) was constructed.

As explained in Chapter 3, the same respondents were asked to analyze the various risk topics introduced by them. A sample analysis is depicted in the following table 5.2-2. The original risks revealed by the respondents presented under each risk topic. The conversion of the risk topic to the terminology introduced in Chapter 3 is presented under tier 1 risk triggers. The causes of the tier 1 risk triggers are presented under tier 2 risk triggers.

Table 05.2-2: Understanding Tier one and Tier Two Risk Triggers

Risk Topic	Tier 1 Risk Triggers	Tier 2 Risk Triggers
No proper construction plan for contractor	Contractor Generated Planning Risks	Consultant Generated Risk On Submitting Accurate Design and Estimate, Client's Risk on Communicating the Scope of the Work
Congested programme	Contractor Generated Planning, Decision Making Risks, Contractor Risks, Communication Risks, Financial Risks	Consultant and Client Generated Risks, Regulation Risks, Material supply risks, Other service supply risks (such as machines, equipment)
Delay in construction drawings submission	Client's Risk on Communicating the Scope of the Work	
Concrete cracks due to no proper thermal insulation	Contractor Generated Decision Making Risks	Consultant Generated Risk on submitting accurate design and estimate
Shortage of sand	Sand Problems	Contractor Generated Decision Making, Planning and Communication and Sub-Contractor Risks, Regulatory Risks
Shortage of cement	Materials Supply Related Availability Risks	Contractor Generated Decision Making, Planning and Communication and sub-contractor Risks,

Risk Topic	Tier 1 Risk Triggers	Tier 2 Risk Triggers
Cash flow issues	Contractor Generated Decision Making, Planning and Communication Risks	Client Generated Risks, Consultants Generated Risk
Quality problem	Contractor Generated Decision Making, Planning and Communication Risks	
Shortage of labour	Labour Problem	Contractor Generated Decision making, Planning, Communication and Sub-Contractor Risk
Political influences	Regulation Risks	
Government policy changes	Regulation Risks	

(Source: Author)

By using the above Table 5.2-2 the dotted lines with arrows of the following Risk Relationship Diagram (RRD) was constructed.

The placement of the arrows is easy to understand the link of each and every identified risk trigger. In the proactive and reactive risk identification, the arrows can help to find the risk easily. The Risk Relationship Diagram (RRD) explains the interction among various risk triggers. It can be either risk triggers coming under the same risk owner or different risks owners. For an example, decision making Risk is one of the risk triggers directly coming under the risk owner Contractor Generated Risks. That is why it is depicted in a dark line with an arrow towards Contractor Generated Risks. It can be a decision making risk trigger of the owner of the contruction company, project manager, engineer or the technical officer for example. That decision making can be affected by the risk of submitting accurate designs or estimates by the consultants or in some circumstances, the risk on supply of funding by the client. However, they are one of the reasons indirectly affecting decision making risks and that is why they are depicted in a light line with an arrow towards decision making. On the other hand, the contractors'decision making risks may influence the materials supplier plans and it can create material supply related risks for construction. This is indicated with a light line towards the materials supplier.

The sub categories of the risk triggers were identified in such a manner that they cover all of the risk triggers possible. As explained in Chapter 4, the popular risk topics in construction supply chains such as accident related risk, safety and security risk, health risk of workers, environment pollution risk are covered under contractor's planning risks in this model.

The RRD is useful in identifying risk involved in construction supply chains in general and to do a risk assessment prior to commence a project or whilst the project is ongoing. The RRD is helpful to understand all stakeholders as to how a simple mistake will effect whole construction supply chain. This model shows interrelationship between various risk triggers and it will enable engineers, managers to get a good idea about risk management in complicated construction supply chains. The RRD can be used to identify risk and problems faced by each part of the construction supply chain so that most of the problems can be addressed proactively. The RRD can be used as check list and monitoring can be done accordingly.

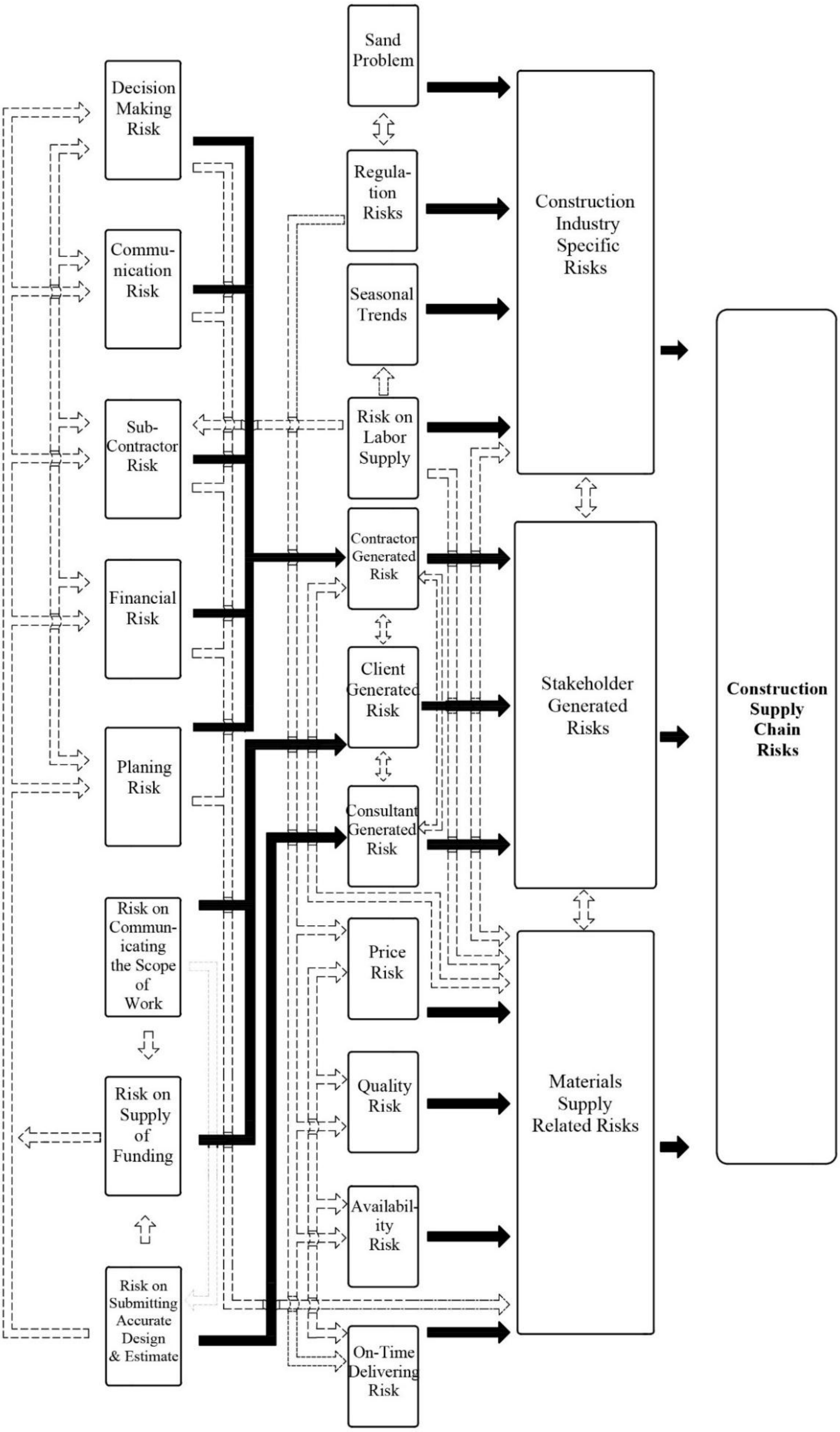


***Figure 5.2*: Risk Relationship Diagram (RRD) (Source: Author)**

5.3 Validation of the Risk Relationship Diagram (RRD) by Qualitative Triangulation

The following feedback are a sample (See Appendix X for full details) from 55 project managers/engineers/quantity surveyors/architects and 10 senior level supply managers from construction materials, who were asked to comment about the Risk Relationship Diagram (RRD) explained above.

Table 5.3-1: Sample Table on Selected Quotes about RRD by the Respondents

Designation of the Respondent	**Comment about Risk Relationship (RRD) Model**
Project Manager from a construction company	"We basically understand some construction risks through intuition and take necessary actions proactively. Sometimes we never assess the risks until it occurs and the approach is reactive and we may not be able to do the full at this point. However, this RRD can be effectively used as tool to underrate the interaction natures of construction risks and thereby to improve the intuitive judgments."
Consultant Structural Engineer	"As design engineers, we very less think about the impact of our performance to the final construction program and the client. We in our best try to introduce safe and economical structural designs. However, by looking at this RRD, I understand the importance of submitting accurate designs once and for all at the agreed timelines. It will help the contractor and other supply chain partners to complete the project in the planned way. Additionally, as engineers we used to change the structural drawings time to time and now I understand the impact of that to the entire construction supply chain"
Senior Engineer Representing the client organization	"As client's engineer we generally used to put the blame on contractors and sometimes the consultants, but this RRD clearly shows us the impact of our communication particularly the scope of the work on the entire construction work. Hence, as client's engineer this diagram is helpful for me to get the inputs of client accurately at the planning stage to achieve our construction objectives as a team rather than passing the ball to others specially the contractor"
Owner of a construction company	"The RRD taught me what I knew and what I had in mind. This is a useful tool to assess the risk together as a team and take risk management actions. From this diagram, I understand the importance of communication, right decision making, planning and sub-contractor management. This teaches us the importance of employing talented engineers and other staff to minimize many risks"

Designation of the Respondent	Comment about Risk Relationship (RRD) Model
Supply chain manager from a construction materials supply company	"The RRD model is useful to forecast accurately and take necessary actions to produce right quantities and supply them. When I saw this I felt how blind we were when it comes to assessing the supply risks to the dynamic construction industry. Additionally, the RRD helps us to proactively work with all the relevant stakeholders. This model is quite useful"
Consultant Architect	“Truly good model to assess the risk produce by architect to the entire construction project. We have to more listen to the client to understand the expectations accurately so that the things are easier in the construction duration"

(Source: Author)

All the 55 respondents agreed that RRD can be used effectively in assessing and managing various construction supply chain risks. According to all of them, RRD can be used as tool to make accurate judgments in the proactive risks management process. In the reactive risks management process, the RRD can be used as tool to diagnose the problem and take actions to manage a crisis.

5.4 Validation of the Risk Relationship Diagram (RRD) Quantitatively

As explained in the Section 3.6.3, Figure 5.2 (RRD) was given to each of the 55 project managers/engineers/quantity surveyors/architects to give a value for each of the major risk classifications out of 100. They were further asked to give values for each of the risk triggers coming under each risk owner out of 100 (Dark lines). Additionally, they were asked to give a value out of 100 for the relationships marked in dotted lines (See Appendix VI - Data set 3).

Table 5.4-1: Independent and Dependent Variables

Case	Dependent Variable/Variable 1	Independent Variables/Variable 2
Directly Related Cases		
01	Construction Industry Specified Risks Y_1	Sand Problem Y_4
		Regulation Risks Y_5
		Seasonal Trends Y_6
		Risk on Labour Supply Y_7
02	Stakeholder Generated Risks Y_2	Contractor Generated Risks Y_8
		Client Generated Risks Y_9
		Consultant Generated Risks Y_{10}
03	Materials Supply Related Risks Y_3	Price Risks Y_{11}
		Quality Risks Y_{12}
		Availability Risks Y_{13}
		On-time Delivery Risks Y_{14}
04	Contractor Generated Risks $Y_{8.1}$	Decision Making Risks Y_{15}
		Communication Risks Y_{16}
		Sub-contractor Risks Y_{17}
		Financial Risks Y_{18}
		Planning Risks Y_{19}
05	Client Generated Risks $Y_{9.1}$	Risk on Communicating the Scope of the Work Y_{20}
		Risk on supply of funding Y_{21}
Indirectly Related Cases		
06	Consultant Generated Risks $Y_{10.1}$	Risk on Submitting Accurate Design and Estimate Y_{22}
07	Risk on Submitting Accurate Design and Estimate $Y_{22.1}$	Risk on Communicating the Scope of the Work $Y_{20.1}$
08	Risk on supply of funding $Y_{21.1}$	Risk on Submitting Accurate Design and Estimate $Y_{22.2}$
09	Materials Supply Related Risks $Y_{3.1}$	Risk on Labour Supply $Y_{7.1}$
10	Price Risks $Y_{11.1}$	Regulation Risks $Y_{5.1}$
	Quality Risks $Y_{12.1}$	
	Availability Risks $Y_{13.1}$	
	On-time Delivery Risks $Y_{14.1}$	
11	Materials Supply Related Risks $Y_{3.2}$	Decision Making Risks $Y_{15.1}$
		Communication Risks $Y_{16.1}$
		Sub-contractor Risks $Y_{17.1}$
		Financial Risks $Y_{18.1}$
		Planning Risks $Y_{19.1}$
12	Sub-contractor Risks $Y_{17.2}$	Risk on Labour Supply $Y_{7.1}$
13	Risk on supply of funding $Y_{21.2}$	Risk on Communicating the Scope of the Work $Y_{20.2}$
14	Decision Making Risks $Y_{15.2}$	Risk on Submitting Accurate Design and Estimate $Y_{22.3}$
	Communication Risks $Y_{16.2}$	
	Sub-contractor Risks $Y_{17.2}$	
	Financial Risks $Y_{18.2}$	
	Planning Risks $Y_{19.2}$	

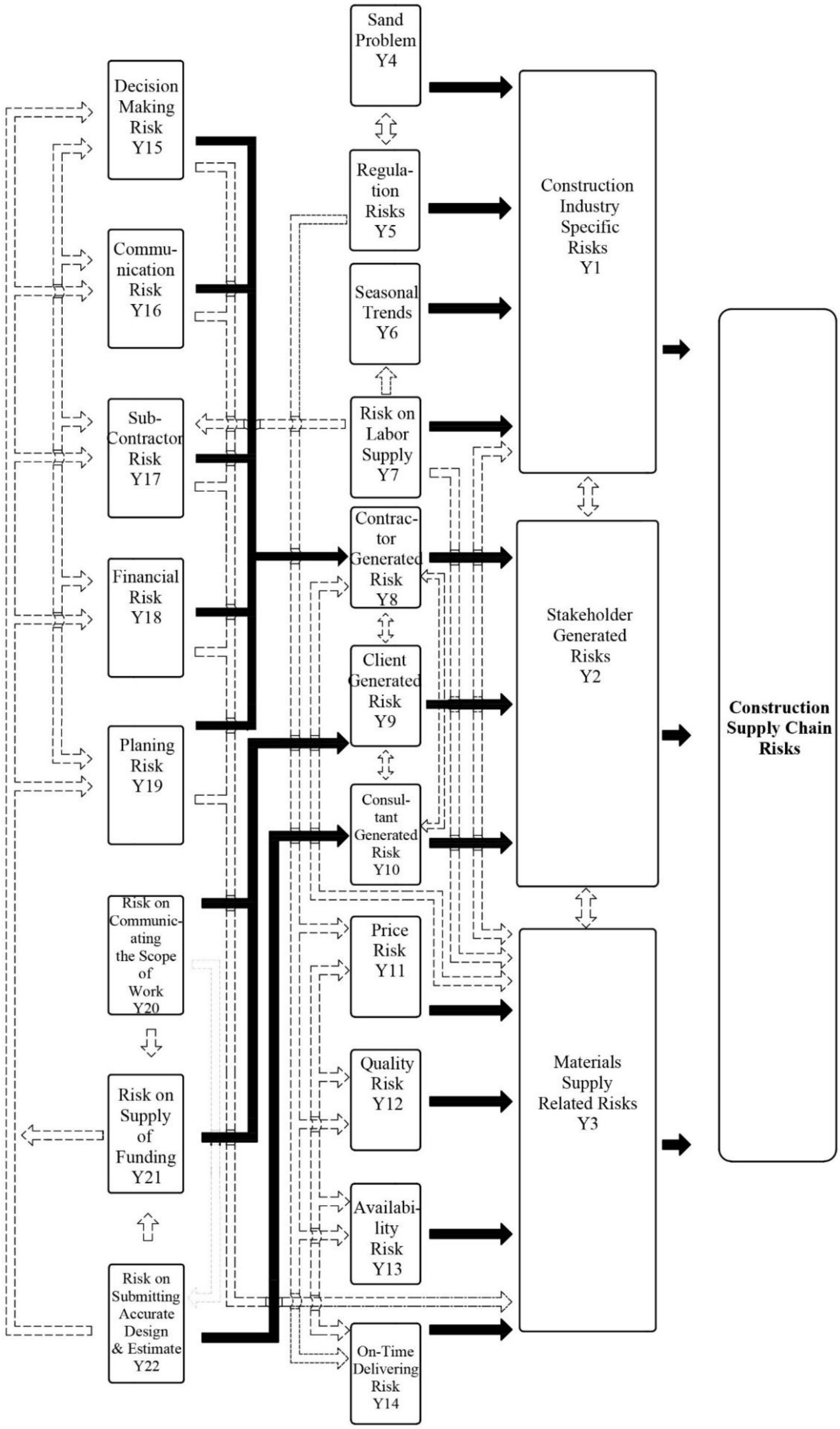


***Figure 5.3*: Risk Relationship Diagram with Y Coding (Source: Author)**

Based on the statistical calculations of data set 3, Figure 5.4 is derived (See Appendix VII). Based on the above values, further quantitative analysis was carried out. This diagrams depicts the perceived total risk for each risk category, risk owner and risk triggers which gives an indication of the contributing factors of the construction supply chain risks in the Sri Lankan context. This diagram came as an output of the quantitative feedback for the RRD which explained all the stakeholders of the construction supply chain. As such, it gives a more reliable understanding of the risks contribution of each risk trigger in the construction supply chains in the Sri Lankan context.

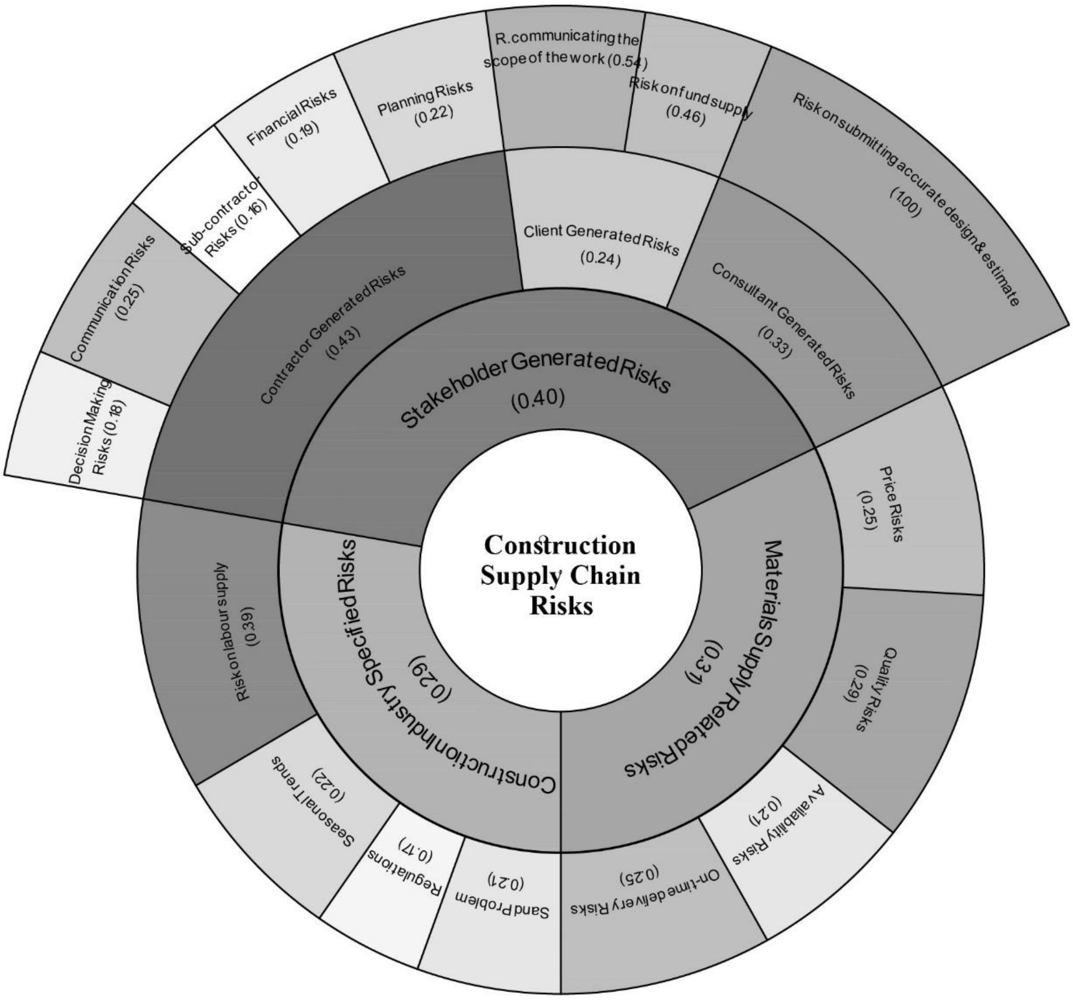


Figure 5.4: **Perceived Risk for Each Risk Trigger, Risk Owner and Risk Classification (Source: Author)**

5.5 Triangulation of Risk Relationship Diagram (RRD) Quantitatively

A Quantitative approach was used to validate the RRD Diagram, provided by the Qualitative approach. Correlation analysis were conducted to investigate the relationships among the variables and regression analysis or simple mathematical relationships were shown to thirteen different cases identified in RRD diagram. While triangulating the relationships in-between the different risk triggers, regression analysis was conducted to derive equations to describe the risk impact caused by different risk triggers.

Mathematical model is,

$$\text{Dependent Variable} = \text{f (Independent Variables)} \ \ldots\ldots\ldots(5.2)$$

5.5.1 Correlation Coefficients Matrix for Major Risk Classifications

Table 5.5-1 explains the correlation coefficient matrix for major construction industry specified risks, stakeholder risks and materials supply related risks (See Appendix XII for further details)

Table 5.5-1: Primary Risk – Correlation Coefficients

Primary Risk		Y_1	Y_2	Y_3
Construction Industry Specified Risks	Y_1	1		
Stakeholder Risks	Y_2	**-0.599** P Value=**0.000**	1	
Materials Supply Related Risks	Y_3	-0.533 P Value=0.000	-0.357 P Value=0.007	1

The Pearson Correlation coefficient lay in between -1 and + 1, where +1 indicates high positive linear relationship, while -1 indicates high negative linear relationship in-between the variables. If the coefficient is 0, it indicates that there is no linear relationship in-between the variables. If coefficient is greater than 0.7 correlation in between dependent and independent variables are high if it is 0.5 the correlation in between dependent and independent variables are moderate. When it is near to 0 the correlation in between dependent and independent variables are low.

With 95% confidence level, as the p value =0.000 ($p<0.05$) and Pearson Correlation coefficient = -0.599, which is close to -1, it can be concluded that the correlation in between Y_1-Y_2 is significant.

With 95% confidence level, as the p value = 0.000 ($p<0.05$) and Pearson Correlation coefficient = -0.533, which is close to -1, it can be concluded that the correlation in between Y_1-Y_3 is significant.

5.5.2 Case 01: RelationshipAmongY_1 and Y_4, Y_5, Y_6,Y_7

Construction Industry Specified Risks Y_1

Sand Problems Y_4

Regulation Risks Y_5

Seasonal Trends Y_6

Risk on Labour Supply Y_7

Correlations: Y_1, Y_4, Y_5, Y_6 and Y_7

Table 5.5-2 explains the correlation coefficient matrix for major construction industry specified risks, sand problem, regulations risks, seasonal trends and risk on labour supply (See Appendix XII for further details).

Table 5.5-2: Correlation Coefficients of Y_1, Y_4, Y_5, Y_6 and Y_7

	Y_1	Y_4	Y_5	Y_6
Y_4	0.883 0.000			
Y_5	0.730 0.000	0.865 0.000		
Y_6	0.856 0.000	0.770 0.000	0.756 0.000	
Y_7	0.662 0.000	0.326 0.015	0.020 0.883	0.322 0.016
Cell Contents: Pearson correlation P-Value				

H_0: Correlation between Y_1 and Y_i (i = 4 to 7) is not significantly different from zero.

H_1: Correlation between Y_1 and Y_i (i = 4 to 7) is significantly different from zero.

H_0: ρ = 0, H_1: ρ≠0

P (Y_1 and Y_i) value =0.000, which is less than 0.05 at 95% of confidence level

Therefore, correlations between Y_1- Y_4, Y_1-Y_5, Y_1-Y_6, and Y_1-Y_7 are significantly different from zero.

According to the data table, the relationship in-between the construction industry specified risks and four independent variables; sand problems, regulation risks, seasonal trends and risk on labour supply are high, because all four Pearson Correlation coefficients are close to 1.

The highest positive relationship is identified in-between the sand problem and the construction industry specified risks. Secondly, when seasonal trends increases construction industry specified risks also increases considerably.

When regulation risks and risk on labour supply increases construction industry specified risks also increases significantly.

Regression Analysis: Y_1 versus Y_4, Y_5, Y_6, Y_7

Regression Model

Regression model indicates that, Y_1 is a function of Y_4, Y_5, Y_6, and Y_7

$$Y1 = \beta 0 + \beta 1Y_4 + \beta 2Y_5 + \beta 3Y_6 + \beta 4Y_7 \pm \varepsilon \text{……………….(5.3)}$$

$$Y_1 = -0.00004 + 1.19\ Y_4 + 0.848\ Y_5 + 1.02\ Y_6 + 0.956\ Y_7 \text{...........(5.4)}$$

From the regression analysis,

$\beta 0$ is not significant.

Coefficient of Y_4 = 1.19

Coefficient of Y_5 = 0.848

Coefficient of Y_6 = 1.02

Coefficient of Y_7 = 0.956

Risk Equation

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

$$Y_1 = f(Y_4, Y_5, Y_6, Y_7) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.5)$$

Risk equation coefficients;

Coefficient of Y_4 = Mean value * 1.19 = 0.21*1.19 = 0.25

Coefficient of Y_5 = Mean value * 0.848 = 0.17*0.848 = 0.14

Coefficient of Y_6 = Mean value * 1.02 = 0.22*1.02 = 0.22

Coefficient of Y_7 = Mean value * 0.956 = 0.39*0.956 = 0.37

$$Y_1 = 0.25\, Y_4 + 0.14\, Y_5 + 0.22\, Y_6 + 0.37\, Y_7 \ldots\ldots\ldots\ldots\ldots (5.6)$$

$$\begin{aligned}\text{Construction Industry Specified Risks} \\ &= 0.25 \text{ Sand Problem} + 0.14 \text{ Regulation Risk} \\ &+ 0.22 \text{ Seasonal Trends} + 0.37 \text{ Risk on Labour Supply}\end{aligned}$$

The above equation shows the weight of contribution of the sand problem, regulation risks, seasonal trends (such as rain) and labour supply, respectively on construction industry specified risks. This proves the aspects of RRD quantitatively. Using the above equation, the construction industry specified risk in value of money or time for a historical project can be calculated by plugging in monetary values/time values related to the above variables. Risk created by one of the risk triggers (e.g. the sand problem) in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent - budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger (e.g. sand problem). Knowing the construction industry specified risk in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from these variables for a similar construction project.

Knowing the above risk impacts will motivate the contractor to proactively manage the risks so that the contractor can make cost and time related savings. Furthermore, using this equation the monetary and time impact of rain can be calculated which is useful for effective contract administration and project management. Furthermore, this equation can be used for national level policy decision making. It can be used to calculate the monetary impact of a decision made by a government affecting the entire construction industry (i.e. tax on cement, new regulation on sand mining, banning asbestos, etc.). It can be further used to calculate the shortage of labour or sand to the construction industry.

5.5.3 Case 02: RelationshipAmongY_2 and Y_8, Y_9, Y_{10}

Stakeholder Generated Risks Y_2

Contractor Generated Risks Y_8

Client Generated Risks Y_9

Consultant Generated Risks Y_{10}

Correlations: Y_2, Y_8, Y_9, Y_{10}

Table 5.5-3 explains the correlation coefficient matrix for stakeholder generated risks, contractor generated risks, client generated risks and consultant generated risks (See Appendix XII for further details).

Table 5.5-3: Correlation co-efficient Y_2 and Y_8, Y_9, Y_{10}

	Y_2	Y_8	Y_9
Y_8	0.602 0.000		
Y_9	0.705 0.000	0.155 0.257	
Y_{10}	0.579 0.000	-0.227 0.096	0.413 0.002
Cell Contents: Pearson correlation P-Value			

H_0: Correlation between Y_2 and Yi (i= 8, 9, 10) is not significantly different from zero.

H_1: Correlation between Y_2 and Yi (i= 8, 9, 10) is significantly different from zero.

With 95% confidence level that as the p value more than 0.05, correlations between Y_8-Y_9 and Y_8-Y_{10}, are significantly zero.

Regression Model

Regression model indicates that, Y_2 is a function of Y_8, Y_9, and Y_{10}

$$Y_2 = \beta 0 + \beta 1 Y_8 + \beta 2 Y_9 + \beta 3 Y_{10} \pm \varepsilon \text{ ....(5.7)}$$

$$Y_2 = 1.00\ Y_8 + 1.00\ Y_9 + 1.00\ Y_{10} \text{ ....(5.8)}$$

Risk Equation

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

$$Y_2 = f(Y_8, Y_9, Y_{10}) \text{ ....(5.9)}$$

Risk equation Coefficients;

Coefficient of Y_8 = Mean value * 1= 0.43*1 = 0.25

Coefficient of Y_9 = Mean value * 1 = 0.24*1 = 0.14

Coefficient of Y_{10} = Mean value * 1= 0.33*1= 0.22

$$Y_2 = 0.43\ Y_8 + 0.24\ Y_9 + 0.33\ Y_{10} \text{ ....(5.10)}$$

$$\begin{aligned}&\text{Stakeholder Generated Risks}\\ &\qquad = 0.43 \text{ Contractor Generated Risks} + 0.24 \text{ Client Generated Risks}\\ &\qquad + 0.33 \text{ Consultant generated Risks}\end{aligned}$$

The above equation shows the weight contribution of contractor generated risks consultant generated risks and client generated risks respectively on stakeholder generated risks. This proves these aspects of RRD quantitatively. Using the above equation, the stakeholder generated risk in value of money or time for a historical project can be calculated by plugging in monetary values/time values related to the above variables.

5.5.4 Case 03: Relationship Among Y_3 and Y_{11}, Y_{12}, Y_{13}, Y_{14}

Materials Supply Related Risks Y_3

Price Risks Y_{11}

Quality Risks Y_{12}

Availability Risks Y_{13}

On-time Delivery Risks Y_{14}

Correlations: Y_3, Y_{11}, Y_{12}, Y_{13}, Y_{14}

Table 5.5-4 explains the correlation coefficient matrix for materials supply related risks, price risks, quality risks, availability risks, and on-time delivery risks (See Appendix XII for further details)

Table 5.5-4: Correlation Coefficients Y_3, Y_{11}, Y_{12}, Y_{13}, Y_{14}

	Y_3	Y_{11}	Y_{12}	Y_{13}
Y_{11}	0.725 0.000			
	0.723 0.000	0.289 0.032		
Y_{13}	0.555 0.000	0.159 0.245	0.263 0.052	
Y_{14}	0.668 0.000	0.555 0.000	0.254 0.062	0.085 0.537
Cell Contents: Pearson correlation P-Value				

H_0: Correlation between Y_3 and Yi (i= 11 to 13) is not significantly different from zero.

H_1: Correlation between Y_3 and Yi (i= 11 to 13) is significantly different from zero.

Correlations between Y_3-Y_{11}, Y_3-Y_{12}, Y_3-Y_{13}, and Y_3-Y_{14} are significantly different from zero. According to the table, the relationship in-between material supply related risks and four independent variables; price, quality, availability and on-time delivery risks are high, because all four Pearson Correlation coefficients are close to 1.00.

Regression Model

Regression model indicates that, Y_3 is a function of Y_{11}, Y_{12}, Y_{13}, and Y_{14}

$$Y_3 = \beta 0 + \beta 1 Y_{11} + \beta 2 Y_{12} + \beta 3 Y_{13} + \beta 4 Y_{14} \pm \varepsilon \text{ ....(5.11)}$$

$$Y_3 = -0.00193 + 0.920\ Y_{11} + 1.12\ Y_{12} + 1.04\ Y_{13} + 0.911\ Y_{14} \text{.........(5.12)}$$

Therefore coefficients of the degree of risks derived from the regression analysis,

$\beta 0$ is not significant.

Coefficient of Y_{11} = 0.920

Coefficient of Y_{12} = 1.120

Coefficient of Y_{13} = 1.040

Coefficient of Y_{14} = 0.911

Risk Equation

To define the coefficients of risk equation, probability calculated from the RRD diagram was multiplied by the coefficient derived from the regression analysis.

$$Y_3 = f(Y_{11}, Y_{12}, Y_{13}, Y_{14}) \text{ ....(5.13)}$$

Risk equation coefficients;

Coefficient of Y_{11} = Mean value * 0.92 = 0.25*0.92 = 0.23

Coefficient of Y_{12} = Mean value * 1.12 = 0.29*1.12 = 0.33

Coefficient of Y_{13} = Mean value * 1.04 = 0.21*1.04 = 0.22

Coefficient of Y_{14} = Mean value * 0.911 = 0.25*0.911 = 0.23

$$Y_3 = 0.23\ Y_{11} + 0.33\ Y_{12} + 0.22\ Y_{13} + 0.23\ Y_{14} \text{ ....(5.14)}$$

$$\begin{aligned}\text{Materials Supply Related Risks} \\ &= 0.23 \text{ Price Risks} + 0.33 \text{ Quality Risks} + 0.22 \text{ Availability Risks} \\ &+ 0.23 \text{ On time delivery Risks}\end{aligned}$$

The above equation shows the weight contribution of price risks, quality risks, availability risks and respectively on material supply related risks. This proves these aspects of RRD quantitatively. Using the above equation, the materials supply related risk in value of time or money for a historical project can be calculated by plugging in monetary values/time values related to the above variables. Risk created by one of the risk triggers (e.g. price risk) in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent- budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger (e.g. price risk). Knowing the materials supply related risks in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from these variables for a similar construction project and by similar type of construction materials suppliers. Knowing these types of impacts will motivate the contractor to proactively manage the risks so that the contractor can make cost and time related savings. This is useful for the contractor in construction materials supplier selection decisions for future projects. Furthermore, knowing the impacts to the construction project is important to the construction materials supplier in managing proactively in sustaining the supply opportunities.

5.5.5 Case 04: Relationship Among $Y_{8.1}$ and Y_{15}, Y_{16}, Y_{17}, Y_{18}, Y_{19}

Contractor Generated Risks $Y_{8.1}$

Decision Making Risks Y_{15}

Communication Risks Y_{16}

Sub-contractor Risks Y_{17}

Financial Risks Y_{18}

Planning Risks Y_{19}

Correlations: $Y_{8.1}$, Y_{15}, Y_{16}, Y_{17}, Y_{18}, Y_{19}

Table 5.5-5 explains the correlation coefficient matrix for contractor generated risks, decision making risks, communication risks, sub-contractor risks, financial risks, and planning risks (See Appendix XII for further details).

Table 5.5-5: Correlation Coefficients Y8.1, Y15, Y16, Y17, Y18, Y19

	$Y_{8.1}$	Y_{15}	Y_{16}	Y_{17}	Y_{18}
Y_{15}	0.714 0.000				
Y_{16}	0.589 0.000	0.677 0.000			
Y_{17}	0.615 0.000	0.188 0.169	0.164 0.231		
Y_{18}	0.567 0.000	0.069 0.618	-0.047 0.735	0.459 0.000	
Y_{19}	0.674 0.000	0.312 0.020	0.215 0.114	0.303 0.025	0.349 0.009
Cell Contents: Pearson correlation P-Value					

H_0: Correlation between $Y_{8.1}$ and Yi (i=15 to 19) is not significantly different from zero.

H_1: Correlation between $Y_{8.1}$ and Yi (i=15 to 19) is significantly different from zero.

Therefore, correlations between $Y_{8.1}$-Y_{15}, $Y_{8.1}$-Y_{16}, $Y_{8.1}$-$Y1_{7}$, $Y_{8.1}$-Y_{18} and $Y_{8.1}$-$Y_{19}$are significantly different from zero.

According to the data table, the relationship in-between contractor generated risks and four independent variables; decision making risks, communication risks, sub-contractor risks, financial risks, and planning risks are high, given that all four Pearson Correlation coefficients are close to 1.

Regression Analysis: $Y_{8.1}$ versus Yi

Regression Model

Regression model indicates that, $Y_{8.1}$ is a function of Y_{15}, Y_{16}, Y_{17}, Y_{18} and Y_{19}

$$Y_{8.1} = \beta 0 + \beta 1 Y_{15} + \beta 2 Y_{16} + \beta 3 Y_{17} + \beta 4 Y_{18} + \beta 5 Y_{19} \pm \varepsilon \ldots\ldots (5.15)$$

$$Y_{8.1} = 0.0189 + 1.47\ Y_{15} + 0.637\ Y_{16} + 0.921\ Y_{17} + 0.891\ Y_{18} + 0.971\ Y_{19} \ldots (5.16)$$

Therefore coefficients of degree of risks derived from the regression analysis,

$\beta 0$is not significant.

Coefficient of Y_{15} = 1.47

Coefficient of Y_{16} = 0.637

Coefficient of Y_{17} = 0.921

Coefficient of Y_{18} = 0.891

Coefficient of Y_{19} = 0.971

Risk Equation

To define the coefficients of risk equation, probability calculated from the RRD diagram was multiplied by the coefficient derived from the regression analysis.

$$Y_{8.1} = f(Y_{15}, Y_{16}, Y_{17}, Y_{18}, Y_{19}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5.17)$$

Risk equation coefficients;

Coefficient of Y_{15} = Mean value * 1.47 = 0.18*1.47 = 0.26

Coefficient of Y_{16} = Mean value * 0.647 = 0.25*0.647 = 0.16

Coefficient of Y_{17} = Mean value * 0.921 = 0.16*0.921 = 0.15

Coefficient of Y_{18} = Mean value * 0.891 = 0.19*0.891 = 0.17

Coefficient of Y_{19} = Mean value * 0.971 = 0.22*0.971 = 0.21

$$Y_{8.1} = 0.26\, Y_{15} + 0.16\, Y_{16} + 0.15\, Y_{17} + 0.17\, Y_{18} + 0.21\, Y_{19} \ldots\ldots (5.18)$$

$$\begin{aligned} \text{Contractor Generated Risks} & \\ &= 0.26 \text{ Decision Making Risks} + 0.16 \text{ Communication Risks} \\ &+ 0.15 \text{ Subcontractor Risks} + 0.17 \text{ Financial Risks} \\ &+ 0.21 \text{Planning Risks} \end{aligned}$$

The above equation shows the weight contribution of decision making risks, communication risk, sub-contractor risks, financial risks and planning risks, on contractor generated risks. This proves these aspects of RRD quantitatively. Using the above equation, contractor generated risk in value of money or time for a historical project can be calculated by plugging in monetary values/time values related to the above variables. Risk created by one of the risk triggers (e.g. decision making risk) in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent - budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger (e.g. decision making risk). Knowing the contractor generated risks in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from these variables for a similar construction contractor and project. Knowing these impacts will motivate the contractor to proactively manage the internal risks so that the contractor can make cost and time related savings. Furthermore, this is important for the client and consultant in deciding on a contractor for a future project.

5.5.6 Case 05: Relationship Among $Y_{9.1}$ and Y_{20}, Y_{21}

Client Generated Risks $Y_{9.1}$

Risk on Communicating the Scope of the Work Y_{20}

Risk on Supply of Funding Y_{21}

Correlations: $Y_{9.1}$, Y_{20}, Y_{21}

Table 5.5-6 explains the correlation coefficient matrix for client generated risks, risk on communicating the scope of the work and risk on supply of funding (See Appendix XII for further details).

Table 5.5-6: Correlation Coefficients $Y_{9.1}$, Y_{20}, Y_{21}

	$Y_{9.1}$	Y_{20}
Y_{20}	0.732 0.000	
Y_{21}	0.536 0.000	-0.183 0.182
Cell Contents: Pearson correlation P-Value		

H_0: Correlation between $Y_{9.1}$ and Yi (i=20,21) is not significantly different from zero.

H_1: Correlation between $Y_{9.1}$ and Yi (i=20,21) is significantly different from zero.

Therefore, correlations between $Y_{9.1}$- Y_{20}, and $Y_{9.1}$-Y_{21} are significantly different from zero.

According to the table, the relationship in-between client generated risks and two independent variables; risk on communicating the scope of the work and Risk on supply of funding are high, because Pearson correlation coefficients are close to 1.

Mathematical Model

Mathematical model indicates that, $Y_{9.1}$ is a function of Y_{20}, and Y_{21}

$$Y_{9.1} = \beta 1 Y_{20} + \beta 2 Y_{21} \qquad (5.19)$$

Where,

$\beta 1$ -Coefficient of Y_{20} = 1

$\beta 2$ - Coefficient of Y_{21} = 1

$$Y_{9.1} = 1.00\ Y_{20} + 1.00\ Y_{21} \qquad (5.20)$$

Risk Equation

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

Risk equation coefficients;

Coefficient of Y_{15} = Mean value * 1.00 = 0.54*1.00 = 0.54

Coefficient of Y_{16} = Mean value * 1.00 = 0.46*1.00 = 0.46

$$Y_{9.1} = 0.54\ Y_{20} + 0.46\ Y_{21} \qquad (5.21)$$

$$\text{Client Generated Risks} = 0.54 \text{ Risk on Communicating the Scope of the Work} + 0.46 \text{ Risk on Supply of Funding}$$

The above equation shows the weight contribution of communicating the scope of work and risk of fund supply on client generated risks. This proves these aspects of the RRD quantitatively. Using the above equation, the client generated risk in value of money or time for a historical project can be calculated by plugging in monetary values/time values related to risk on communicating the scope of work and Risk on supply of funding with a particular client and particular type of project.

Risk created by one of the risk trigger (e.g. risk on communicating the scope of work) in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent- budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger (e.g. risk on communicating the scope of work). Knowing the client generated risks in monetary value/time value for a given client and given type of project can be used as a forecasting tool to find the risks that can be generated from these variables for a similar client and project. Knowing the above impacts will motivate the client to proactively manage the internal risks so that the client can make cost and time related savings. Furthermore, this is important for the contractor in deciding on an opportunity given by client for a future project.

5.5.7 Case 06: Relationship Among $Y_{10.1}$ and Y_{22}

Consultant Generated Risks $Y_{10.1}$

Risk on Submitting Accurate Design and Estimate Y_{22}

$$Y_{10.1} = Y_{22} \quad \text{...(5.22)}$$

Risk of Consultant Generated Risks equal to the risk on submitting accurate design and estimate.

Risk Equation

$$Y_{10.1} = f(Y_{22}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.23)$$

Risk equation coefficients;

Coefficient of Y_{22} = Mean value * 1.00 = 1.00*1.00 = 1.00

$$Y_{10.1} = Y_{22} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.24)$$

$$\text{Consultant Generated Risks} = \text{Risk on submitting accurate design and estimate}$$

This proves the above aspects of RRD quantitatively. Additionally, using the above equation, the consultant generated risk in value of money or time can be calculated for an historical project by plugging in monetary values/time values of a particular consultant. Risk created by the risk trigger in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent- budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger. Knowing the consultant generated risks in monetary value/time value for a given client and given type of project can be used as a forecasting tool to find the risks that can be generated from these variables for a similar consultant and a project. Knowing these impacts will motivate the consultant to proactively manage the internal risks so that the consultant can make cost and time related savings. Furthermore, this is important for the client and contractor in deciding on a consultant for a future project.

Case 07: Relationship Among $Y_{22.1}$ and $Y_{20.1}$

Risk on Submitting Accurate Design and Estimate $Y_{22.1}$

Risk on Communicating the Scope of the Work $Y_{20.1}$

$$Y_{22.1} = Y_{20.1} = 1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.25)$$

Degree of risk on submitting accurate design and estimate is not dependent on degree of risk on communicating the scope of the work, as it always remain 1. Probability of occurring risk on submitting accurate design and estimate is always 1.

Risk Equation

$$Y_{22.1} = f(Y_{20.1}) \qquad (5.26)$$

Risk equation coefficients;

Coefficient of $Y_{20.1}$ = Mean value * 1.00 = 0.54*1.00 = 0.54

$$Y_{22.1} = 0.54\, Y_{20.1} \qquad (5.27)$$

$$\text{Risk on Submitting Accurate Design } and \text{ Estimate} = 0.54 \text{ Risk on Communicating the Scope of the Work}$$

This proves these aspects of RRD quantitatively. Using the above equation, submitting accurate designs and estimates risk in value of money or time for an historical project can be calculated by putting monetary values/time values for communicating the scope of work of an historical project with a particular client and consultant. Knowing the above impacts will motivate the client and consultant to proactively manage the internal risks so that they can make cost and time related savings.

5.5.8 Case 08: Relationship Among$Y_{21.1}$ and $Y_{22.2}$

Risk on supply of funding $Y_{21.1}$

Risk on Submitting Accurate Design and Estimate $Y_{22.2}$

$$Y_{21.1} = Y_{22.2} \qquad (5.28)$$

Degree of risk on funding supply equals to degree of risk on submitting accurate design and estimate.

Risk Equation

$$Y_{21.1} = f(Y_{22.2}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.(5.29)$$

Risk equation coefficients;

Coefficient of $Y_{22.2}$ = Mean value * 1.00 = 1.00*1.00 = 1.00

$$Y_{21.1} = Y_{22.2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.30)$$

$$\text{Risk on Supply of Funding} = \text{Risk on submitting accurate design and estimate}$$

This proves these aspects of RRD quantitatively. This shows the impact of the consultants' ability to understand the need of the client and thereby producing the designs and estimates to align with the funding capacity of the client. Knowing these impacts will motivate the consultant and client to proactively manage the internal risks so that they can make cost and time related savings. Furthermore, this is important for the client in deciding on a consultant for a future project.

5.5.9 Case 09: Relationship Among$Y_{3.1}$ and $Y_{7.1}$

Materials Supply Related Risks $Y_{3.1}$

Risk on Labour Supply $Y_{7.1}$

Pearson correlation of $Y_{3.1}$ and $Y_{7.1}$= 0.702

P-Value = 0.000

H_0: Correlation between $Y_{3.1}$ and $Y_{7.1}$ is not significantly different from zero.

H_1: Correlation between $Y_{3.1}$ and $Y_{7.1}$ is significantly different from zero.

Therefore, correlation between materials supply related risks and Risk on labour supply are significantly different from zero.

Regression Analysis: $Y_{3.1}$ versus $Y_{7.1}$

Regression Model

Regression model indicates that, $Y_{3.1}$ is a function of $Y_{7.1}$

$$Y_{3.1} = \beta 0 + \beta 1 Y_{7.1} \pm \varepsilon \text{ ....(5.31)}$$

The regression equation is,

$$Y_{3.1} = 0.159 + 1.23\ Y_{7.1} \text{ ....(5.32)}$$

Risk Equation

$$Y_{3.1} = f(Y_{7.1}) \text{ ....(5.33)}$$

Degree of Risk of $Y_{3.1}$:

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

Risk equation coefficients;

Coefficient of $Y_{7.1}$ = 0.159+ Mean value * 0.39 = 0.159+ 1.29*0.39 = 0.66

$$Y_{3.1} = 0.66\ Y_{7.1} \text{ ....(5.34)}$$

$$\text{Materials Supply Related Risks} = 0.66 \text{ Risk on Labour Supply}$$

The above equation clearly shows the risk of labour supply is affected to the risk of materials supply. Additionally, this proves these aspects of RRD quantitatively. Knowing one of the variable can help in finding or cross checking the other variable in the construction supply chains.

5.5.10 Case 10: Relationship Among $Y_{11.1}$, $Y_{12.1}$, $Y_{13.1}$, $Y_{14.1}$ and $Y_{5.1}$

Price Risks $Y_{11.1}$

Quality Risks $Y_{12.1}$

Availability Risks $Y_{13.1}$

On-time Delivery Risks $Y_{14.1}$

Regulation Risks $Y_{5.1}$

Correlations $Y_{11.1}$, $Y_{12.1}$, $Y_{13.1}$, $Y_{14.1}$ and $Y_{5.1}$

Table 5.5-7 explains the correlation coefficient matrix for price risks, quality risks, availability risks, on-time delivery risks, and regulation risks (See Appendix XII for further details).

Table 5.5-7: Correlations Coefficients $Y_{11.1}$, $Y_{12.1}$, $Y_{13.1}$, $Y_{14.1}$ and $Y_{5.1}$

	$Y_{11.1}$	$Y_{12.1}$	$Y_{13.1}$	$Y_{14.1}$
Pearson correlation of Y_5 and Yi	0.559	0.632	0.741	0.391
P-Value	0.000	0.000	0.000	0.003

H_0: Correlation between Yi (i=11 to 14) and $Y_{5.1}$ is not significantly different from zero.

H_1: Correlation between Yi (i=11 to 14) and $Y_{5.1}$ is significantly different from zero.

Therefore, correlations between regulation risks and price, quality, and availability related risks and regulation risks related risks are significantly different from zero, except for on time delivery risks and regulation risks.

Risk Equation

$$f(Y_{11.1}, Y_{12.1}, Y_{13.1}, Y_{14.1}) = Y_{5.1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.35)$$

Risk equation coefficients;

Coefficient of $Y_{11.1}$ = 0.18

Coefficient of $Y_{12.1}$ = 0.25

Coefficient of $Y_{13.1}$ = 0.16

Coefficient of $Y_{14.1}$ = 0.19

$$0.18\,Y_{11.1} + 0.25\,Y_{12.1} + 0.16\,Y_{13.1} + 0.19\,Y_{14.1} = Y_{5.1} \ldots\ldots\ldots(5.36)$$

$$0.18 \text{ Price Risks } + 0.25 \text{ Quality Risks} + 0.16 \text{ Availability Risks} + 0.19 \text{ Ontime delivery Risks} = \text{Regulation Risks}$$

The above equation shows the change in regulatory risk affects price risks quality risks, availability risks and on time delivery risks, respectively. Additionally, this proves these aspects of RRD quantitatively. Using this equation, the materials suppliers and contractors can analyze the impacts of regulation risks on various variables on materials supply.

5.5.11 Case 11: Relationship Among $Y_{3.2}$, $Y_{15.1}$, $Y_{16.1}$, $Y_{17.1}$, $Y_{18.1}$ and $Y_{19.1}$

Materials Supply Related Risks $Y_{3.2}$

Decision Making Risks $Y_{15.1}$

Communication Risks $Y_{16.1}$

Sub-contractor Risks $Y_{17.1}$

Financial Risks $Y_{18.1}$

Planning Risks $Y_{19.1}$

Correlations: $Y_{3.2}$, $Y_{15.1}$, $Y_{16.1}$, $Y_{17.1}$, $Y_{18.1}$, $Y_{19.1}$

Table 5.5-8 explains the correlation coefficient matrix for materials supply related risks, decision making risks, communication risks, sub-contractor risks, financial risks, and planning risks (See Appendix XII for further details).

Table 5.5-8: Correlation Coefficients $Y_{3.2}$, $Y_{15.1}$, $Y_{16.1}$, $Y_{17.1}$, $Y_{18.1}$, and $Y_{19.1}$

	$Y_{3.2}$	$Y_{15.1}$	$Y_{16.1}$	$Y_{17.1}$	$Y_{18.1}$
$Y_{15.1}$	0.702 0.000				
$Y_{16.1}$	0.707 0.000	0.689 0.000			
$Y_{17.1}$	0.498 0.000	0.037 0.788	0.215 0.115		
$Y_{18.1}$	0.398 0.003	-0.041 0.769	-0.056 0.686	0.252 0.063	
$Y_{19.1}$	0.633 0.000	0.299 0.026	0.250 0.066	0.182 0.183	0.205 0.133
Cell Contents: Pearson correlation P-Value					

H_0: Correlation between $Y_{3.2}$ and yi (i=15 to 19) is not significantly different from zero.

H_1: Correlation between $Y_{3.2}$ and Yi (i=15 to 19) is significantly different from zero.

The correlation between material supply related risks and Yi significantly different from 0.

But,

Pearson Correlation Coefficients;

$Y_{3.2}$-Y_{15} = 0.702; close to 1

$Y_{3.2}$-Y_{16} = 0.625; close to 1

$Y_{3.2}$-Y_{17} = 0.463; not close to 1

$Y_{3.2}$-Y_{18} = 0.388; not close to 1

$Y_{3.2}$-Y_{19} = 0.548; close to 1

Therefore it can be concluded that there is high correlation between material supply related risks and decision making risk, communication risks and planning risks, but not with sub-contractor or financial risks.

Regression Analysis: $Y_{3.2}$ versus $Y_{15.1}$, $Y_{16.1}$, $Y_{19.1}$

Regression model indicates that, $Y_{3.2}$ is a function of $Y_{15.1}$, $Y_{16.1}$, and $Y_{19.1}$

Regression Model

$$Y_{3.2} = \beta 0 + \beta 1 Y_{15.1} + \beta 2 Y_{16.1} + \beta 3 x Y_{19.1} \pm \varepsilon \text{ ....(5.37)}$$

P value of $Y_{16.1}$ = 0.210, p>0.05

So β2 is equal to zero; H_0: $\beta_i \leq 0$

Therefore the regression can be modeled as;

$$Y_{3.2} = \beta 0 + \beta 1 Y_{15.1} + \beta 3 x Y_{19.1} \pm \varepsilon \text{ ....(5.38)}$$

Regression Analysis: $Y_{3.2}$ Versus $Y_{15.1}$, $Y_{19.1}$

The regression equation is

$$Y_{3.2} = 0.0821 + 2.15\ Y_{15.1} + 1.61\ Y_{19.1} \ldots\ldots\ldots\ldots\ldots\ldots..(5.39)$$

Coefficient of $Y_{15.1}$ = 2.15

Coefficient of $Y_{19.1}$ = 1.61

Risk Equation

$$Y_{3.2} = f(Y_{15.1}, Y_{19.1}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.40)$$

To define the coefficients of risk equation, probability calculated from the RRD diagram was multiplied by the coefficient derived from the regression analysis.

Risk equation coefficients;

Coefficient of $Y_{15.1}$ = Mean value * 2.15 = 0.18*1.19 = 0.21

Coefficient of $Y_{19.1}$ = Mean value * 1.61 = 0.25*1.61 = 0.40

$$Y_{3.2} = 0.21\ Y_{15.1} + 0.40\ Y_{19.1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.41)$$

$$\text{Materials Supply Related Risks} = 0.21\ \text{Decision Making Risks} + 0.40\ \text{Planning Risks}$$

This equation shows the impact of communication of the contractor followed by decision making of the contractor on material supply. Additionally, this proves these aspects of RRD quantitatively.

The above equation shows the weight contribution of decision making risks and communication risks of the contractor on materials supply related risks. Using the above equation, the materials supply risk in value of money or time for an historical project can be calculated by plugging in monetary values/time values related to risk on communication and decision making with a particular contractor and particular type of project which will be useful to predict such risks in future similar projects with similar contractor. This is useful for the materials supplier in managing the risks proactively.

5.5.12 Case 12: Relationship Among $Y_{17.2}$ and $Y_{7.1}$

Sub-contractor Risks $Y_{17.2}$

Risk on Labour Supply $Y_{7.1}$

Pearson correlation of $Y_{17.2}$ and $Y_{7.1}$ = 0.871

P-Value = 0.000

H_0: Correlation between $Y_{17.2}$ and $Y_{7.1}$ is not significantly different from zero.

H_1: Correlation between $Y_{17.2}$ and $Y_{.1}$ is significantly different from zero.

The correlation between sub-contractor risks and risk on labour supply is significantly different from 0.

According to the Pearson Correlation coefficient value, which is 0.871, close to 1, the correlation in-between subcontractor risks and risk on labour supply is significantly high.

Regression Analysis: $Y_{17.2}$ versus $Y_{7.2}$

Regression model indicates that, $Y_{17.2}$ is a function of $Y_{7.2}$

Regression Model

$$Y_{17.2} = \beta 0 + \beta 1 Y_{7.2} \pm \varepsilon \quad (5.42)$$

The regression equation is

$$Y_{17.2} = 0.0577 + 1.61\, Y_{7.2} \quad (5.43)$$

Coefficient of $Y_{7.2}$ = 1.61

Risk Equation

$$Y_{17.2} = f(Y_{7.2}) \qquad (5.44)$$

Risk equation coefficients;

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

Coefficient of $Y_{7.2}$ = 0.577+ Mean value * 1.61 = 0.577+ 0.39*1.61 = 1.20

$$Y_{17.2} = 1.2\, Y_{7} \qquad (5.45)$$

$$\text{Sub contractor Risks} = 1.2 \text{ Risk on labour supply}$$

This shows how the risks on labour supply affects the sub-contractor risks. Additionally, this proves these aspects of RRD quantitatively. Knowing one of the variable can help in finding or cross checking the other variable in the construction supply chains.

5.5.13 Case 13: Relationship Among $Y_{21.2}$ and $Y_{20.2}$

Risk on supply of funding $Y_{21.2}$

Risk on Communicating the Scope of the Work $Y_{20.2}$

Correlations: $Y_{21.2}$, $Y_{20.2}$

Pearson correlation of $Y_{21.2}$ and $Y_{20.2}$= 0.375

P-Value = 0.005

H_0: Correlation between $Y_{21.2}$and $Y_{20.2}$ is not significantly different from zero.

H_1: Correlation between $Y_{21.2}$ and $Y_{20.2}$ is significantly different from zero.

The correlation between Risk on supply of funding and risk on communicating the scope of the work significantly different from 0.

According to Pearson Correlation coefficient value, 0.375, which is not close to 1, describes that the correlation in-between Risk on supply of funding and risk on communicating the scope of the work is significantly low.

5.5.14 Case 14: Relationship Among $Y_{15.2}$, $Y_{16.2}$, $Y_{17.2}$, $Y_{17.2}$, $Y_{18.2}$, $Y_{19.2}$ and $Y_{22.3}$

Decision Making Risks $Y_{15.2}$

Communication Risks $Y_{16.2}$

Sub-contractor Risks $Y_{17.2}$

Financial Risks $Y_{18.2}$

Planning Risks $Y_{19.2}$

Risk on Submitting Accurate Design and Estimate $Y_{22.3}$

$$Y_{22.3} = 1 \quad \ldots\ldots\ldots(5.46)$$

$$Y_{15.2} + Y_{16.2} + Y_{17.2} + Y_{18.2} + Y_{19.2} = Y_{22.3} = 1 \quad \ldots\ldots\ldots(5.47)$$

Risk Equation

$$Y_{22.3} = f(Y_{15.2}, Y_{16.2}, Y_{17.2}, Y_{18.2}, Y_{19.2}) \quad \ldots\ldots\ldots(5.48)$$

Risk equation coefficients;

To define the coefficients of risk equation, probability calculated from RRD diagram was multiplied by the coefficient derived from the regression analysis.

Coefficient of $Y_{15.2}$ = 0.18

Coefficient of $Y_{16.2}$ = 0.25

Coefficient of $Y_{17.2}$ = 0.16

Coefficient of $Y_{18.2}$ = 0.19

Coefficient of $Y_{19.2}$ = 0.22

$$0.18\,Y_{15.2} + 0.25\,Y_{16.2} + 0.16\,Y_{17.2} + 0.19\,Y_{18.2} + 0.22\,Y_{19.2} = Y_{22.3} \ldots(5.49)$$

$$\begin{aligned} &0.18\ \text{Decision Making Risks} + 0.25\ \text{Communication Risks} + 0.16\ \text{Sub contractor Risks} \\ &+ 0.19\ \text{Financial Risks} + 0.22\ \text{Planning Risks} \\ &= \text{Risk on Submitting Accurate Design and Estimate} \end{aligned}$$

The above equation explains when a mistake has happened in submitting designs and estimates as to how it contributes to create risks in decision making, communication, sub-contractor management, financial planning and overall planning of the contractor. This proves these aspects of RRD quantitatively. Knowing the above impacts will motivate the consultant to proactively manage the internal risks so that the consultant can make cost and time related savings. Furthermore, this is important for the contractor in deciding on accepting a project with a particular consultant in the future.

Table 5.5-9 indicates the summery of regression analysis, which validates the equations derived.

In concluding the analysis, Table 5.5-9 explains the summary of the regression analysis which were mathematically validated, for Case 1, 3, 4, 9, 11 and 12 (See Appendix XII for further details), while the rest of the cases were validated by simple mathematical models. It describes the Standard Error, R Squared Value, F-Value, P-Values, Durbin-Watson Statistic and A-D test statistic under 95% Confidence level.

Table 5.5-9: Summary of Regression Analysis

Case	**SE**	**R-Sq**	**R-Sq(adj)**	**F - Value**	**P - Value**	**Durbin-Watson Statistic**	**A-D test statistic**	**P - Value**
1	0.0066	99.80%	99.80%	5968.88	0	1.77189	6.7	<0.005
3	0.0083	99.50%	99.50%	2711.69	0	2.23108	1.893	<0.005
4	0.0201	96.70%	96.40%	291.35	0	2.20431	2.37	<0.005
9	0.0532	49.30%	48.30%	51.45	0	1.76974	1.142	<0.005
11	0.0420	68.90%	67.70%	57.55	0	2.19376	0.984	0.012
12	0.0291	75.90%	75.50%	167.3	0	1.86958	0.797	0.037

(Source: Author)

5.5.15 Construction Supply Chain Risk

Construction Supply Chain Risk = Y

$$Y = f(Y_1, Y_2, Y_3) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.50)$$

$$Y = 0.29Y_1 + 0.40Y_2 + 0.31Y_3 \quad \ldots\ldots\ldots\ldots\ldots\ldots(5.51)$$

$$\text{Construction Supply Chain Risk} = 0.29\ \text{Construction Industry Specified Risks} + 0.40\ \text{Stakeholder Generated Risks} + 0.31\ \text{Materials Supply Related Risks}$$

As per the perceived values/judgments of the respondents, the highest risk contributor for the construction supply chain risk is stakeholder generated risks (which includes contactors, clients and consultants) followed by materials supply related risks and construction industry specified risks respectively. Additionally, this proves these aspects of RRD quantitatively.

A summary of the equations derived from average degree of risks to describe risk triggers are as follows.

1. $Y_1 = 0.25\ Y_4 + 0.14\ Y_5 + 0.22\ Y_6 + 0.37\ Y_7$
2. $Y_2 = 0.43\ Y_8 + 0.24\ Y_9 + 0.33\ Y_{10}$
3. $Y_3 = 0.23\ Y_{11} + 0.33\ Y_{12} + 0.22\ Y_{13} + 0.23\ Y_{14}$
4. $Y_{8.1} = 0.26\ Y_{15} + 0.16\ Y_{16} + 0.15\ Y_{17} + 0.17\ Y_{18} + 0.21\ Y_{19}$
5. $Y_{9.1} = 0.54\ Y_{20} + 0.46\ Y_{21}$
6. $Y_{10.1} = Y_{22}$
7. $Y_{22.1} = 0.54\ Y_{20.1}$
8. $Y_{21.1} = Y_{22.2}$
9. $Y_{3.1} = 0.66\ Y_{7.1}$
10. $0.18\ Y_{11.1} + 0.25\ Y_{12.1} + 0.16\ Y_{13.1} + 0.19\ Y_{14.1} = Y5_{.1}$
11. $Y_{3.2} = 0.21\ Y_{15.1} + 0.40\ Y_{19.1}$
12. $Y_{17.2} = 1.2\ Y_{7.2}$
13. $0.18\ Y_{15.2} + 0.25\ Y_{16.2} + 0.16\ Y_{17.2} + 0.19\ Y_{18.2} + 0.22\ Y_{19.2} = Y22.3$

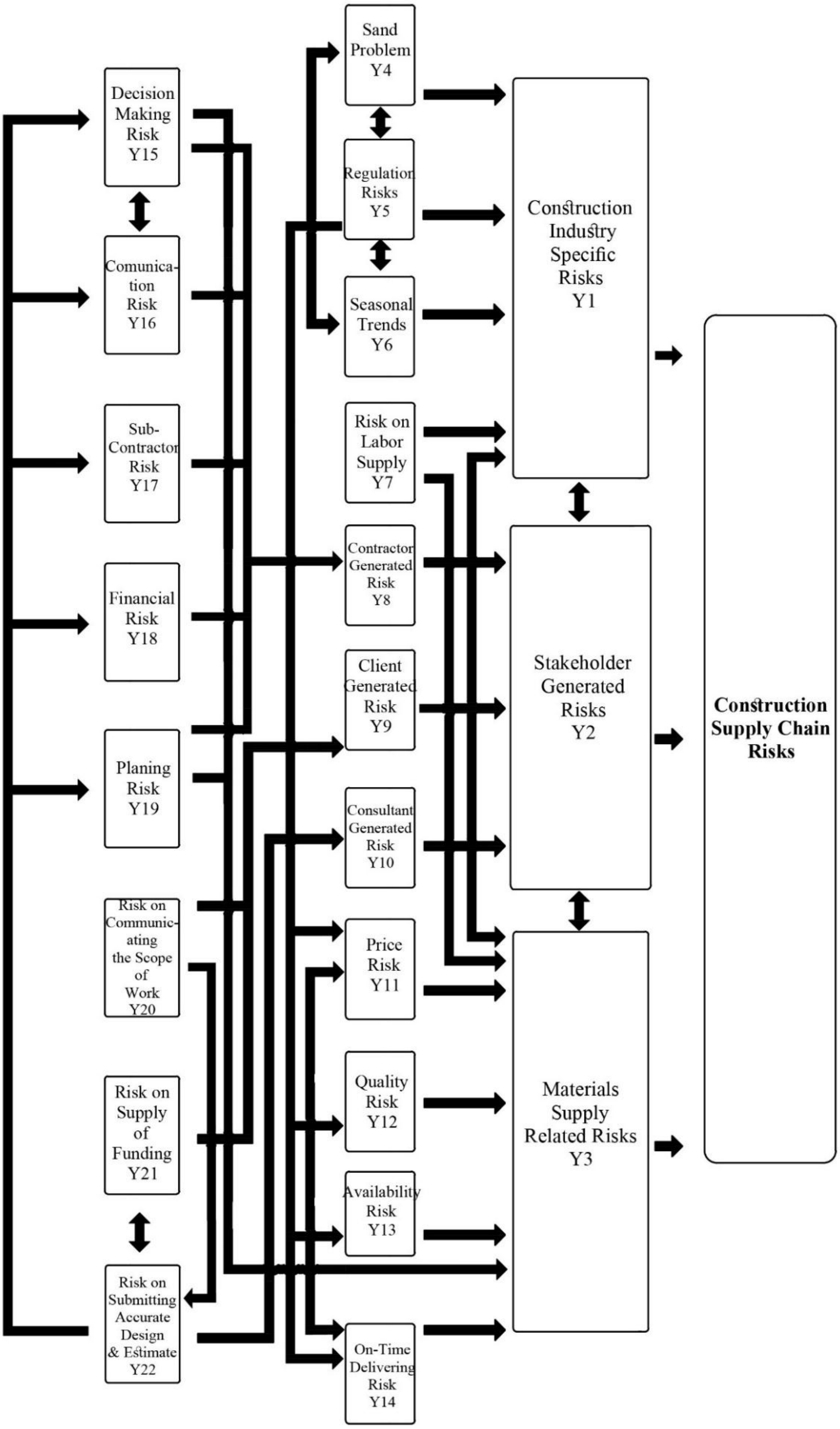


***Figure 5.5*: Quantitatively Proven Risk Relationship Diagram (RRD) (Source: Author)**

5.6 Mapping of the Risk Cycle for the Construction Supply Chains

Based on Table 5.2-1, the Risk Cycle below is derived (Figure 5.5).

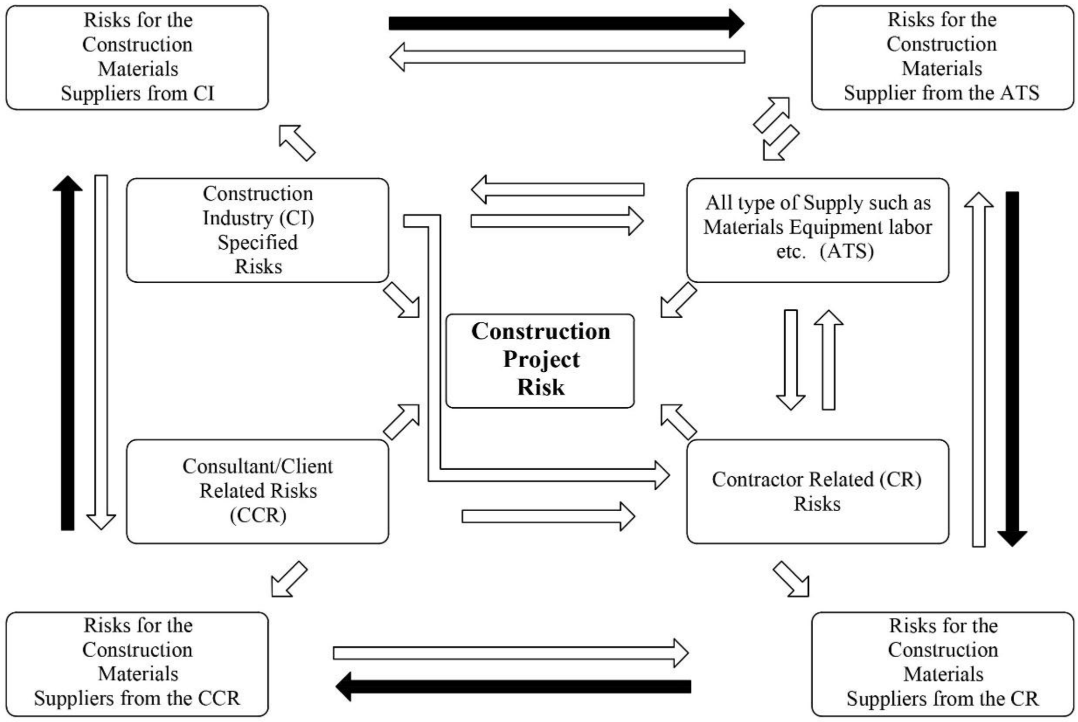


***Figure 5.6*: Mapping of the Risk Cycle for the Construction Supply Chains (Source: Author)**

Figure 5.6 illustrates the risk owners such as the contractor, consultant/client, construction industry and the types of supply including materials, equipment, labour, and funds etc. which affect the construction project risk. It also illustrates the cyclic nature of construction supply chain risks. With different arrows, it illustrates the propagation of the risk created at one point to the entire cycle. This diagram further demonstrates the complex nature of the construction supply chains and particularly assessing the risks of the construction supply chains.

5.7 Investigating the Deep Rooted Primary Risks

This section presents the analysis and findings of objective 5 of the research. Using further analysis of Table 5.7-1, 3 primary risk triggers are identified as human generated risks, resource limitation/infrastructure related risks and unavoidable risks. In other words, when any risk trigger is further analysed, each risk trigger is originated as human generated risk or resource limitation/infrastruture risk or unavoidable risks or combinination of 2-3 of them. Human generated risks can occur due to gaps in skills, knowledge, motivation, attitudes as well as negligence of human resources. Examples for resource limitation/infrastructure risks are shortage of materials, people, machines and equipment, money, time, vehicles etc. Examples of unavoidable risks are all type of natural disasters, political, regulatory and economical changes both local and global etc.

For an example, 'No proper contruction plan for contrcator is due to contractor generated planning risks'. It can be due to various reasons and root cause analysis is as follows.

- Technical error in planning: mistake of the project manager: human generated risk
- Lack of machinery/machine break down: resource limitation/unavoidable riks
- Lack of qualified technical offisers or supervisors: resource limitation

Table 5.7-1: Sample Table of the Root Cause Analysis of the Selected Risk Topics (Source: Author)

Risk Topic	Tier 1	Tier 2	Tier 3
No proper construction plan for contractor	Contractor generated Planning Risks	Consultant Generated Risk on Submitting Accurate Design and Estimate, Client's Risk on Communicating the Scope of the Work	Human Generated Risks, Resource Limitation/Infrastr ucture Risks, Unavoidable Risks
Congested programme	Contractor generated Planning, Decision Making Risks, Contractor Risks, Communication Risks, Financial Risks	Consultant and Client Generated Risks, Regulation Risks, Material Supply Risks, Other Service Supply risks (such as machines, equipment)	Human Generated Risks, Resource Limitation/Infrastr ucture Risks, Unavoidable Risks
Delay in construction drawings submission	Client's Risk on Communicating the Scope of the Work	Human Generated Risks, Resource Limitation/Infrastructure Risks, Unavoidable Risks	

Risk Topic	Tier 1	Tier 2	Tier 3
Concrete cracks due to no proper thermal insulation	Contractor Generated Decision Making Risks	Consultant Generated Risk on Submitting Accurate Design and Estimate	Human Generated Risks, Resource Limitation/Infrastructure Risks, Unavoidable Risks
Shortage of sand	Sand Problems	Contractor Generated Decision Making, Planning and Communication and Sub-Contractor Risks, Regulatory Risks	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks
Shortage of cement	Materials Supply Related Availability Risks	Contractor Generated Decision Making, Planning and Communication and Sub-Contractor Risks,	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks
Cash flow issues	Contractor generated Decision Making, Planning and Communication Risks	Client Generated Risks, Consultants Generated Risk	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks
Quality problem	Contractor generated Decision Making, Planning and Communication Risks	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks	
Shortage of labour	Labour problem	Contractor Generated Decision making, Planning, Communication and sub-contractor risk	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks
Political influences	Regulation Risks Risk	Unavoidable Risks, Human Generated Risks	
Government policy changes	Regulation Risks Risk	Unavoidable Risks, Human Generated Risks	

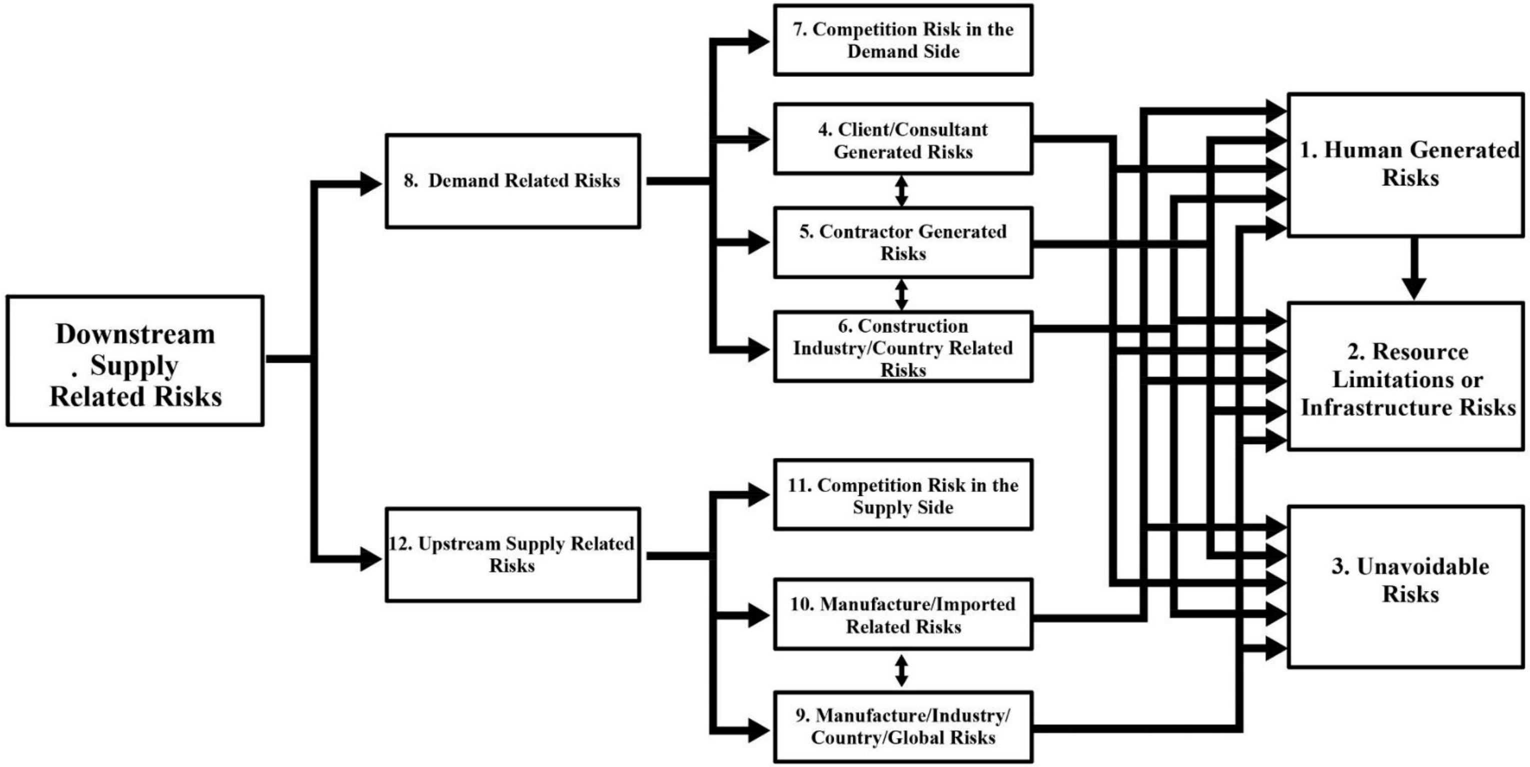


Figure 5.7: **Mapping of Demand Risks of Construction Materials and Upstream Supply Related Risks** (Source: Author)

Based on Table 5.7-1 and Appendix XIII, Figure 5.6 is derived which depicts mapping of demand risks of construction materials and upstream supply related Risks.

Figure 5.7 illustrates two major risk types, demand Related Risks which affect the downstream supply of construction materials (Box Numbered 8) and Upstream Supply Related Risks (Box Numbered 12) which affect the downstream supply of construction materials.

The triggers of the Demand Risks (Box Numbered 8) are categorized as Client/Consultant Generated Risks (Box Numbered 4), Contractor Generated Risks (Box Numbered 5), Construction Industry/Country Related Risks (Box Numbered 6), Competition in the Demand Side (Box Numbered 7), Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3)

Construction Industry/Country Related risks (Box Numbered 6) are categorized as regulatory risks, risks generated from scarcity of natural materials such as sand, risks due to labour shortages, risks due to seasonal trends and any other risks which cause them. The deep rooted primary risk triggers of the Construction Industry Related Risks are categorized as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

Contractor Generated Risks (Box Numbered 5) are categorized as decision making risks, communication risks, sub-contractor risks, financial risks and planning risks. The deep rooted primary risk triggers of such risks are categorized as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

The deep rooted primary risk triggers of Client/Consultant Generated Risks (Box Numbered 4) can be categorized as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

All the Demand Related Risks triggers which affect the downstream supply are originated as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

The triggers of the Upstream Supply Related Risks (Box Numbered 12) which affect the downstream supply of construction materials are categorized as Manufacturer/Importer Related Risks (Box Numbered 10), Manufacturing Industry/Manufacturing Country Specific Risks (Box Numbered 9) and Risks in the Competition in the Supply (Box Numbered 11).

The deep rooted primary risk triggers of Manufacturer/Importer Related Risks (Box Numbered 10) are categorized as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2), Unavoidable Risks such as natural disasters/global issues (Box Numbered 3) and Manufacturing Industry/Manufacturing Country Specific Risks (Box Numbered 9).

The deep rooted primary risk triggers of the Manufacturing Industry/Manufacturing Country Specific Risks (Box Numbered 9) are categorized as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2), Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

All the Demand Related Risks triggers which affect the downstream supply are originated as Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

In summary, all the risks triggers of supply risks in the downstream supply of materials into the construction Industry boil down to Human Generated Risks (Box Numbered 1), Resource Limitations or Infrastructure Issues (Box Numbered 2) and Unavoidable Risks such as natural disasters/global issues (Box Numbered 3).

Understanding the relationships among the different risks and understanding the deep rooted risks triggers are important in risk assessment and risks management process of the down-stream supply of construction materials. With suitable modifications, the results can be used in risk assessment and risk management process of downstream supply of any other materials.

5.8 Further Discussion

Using qualitative and quantitative methodology together with a double triangulation approach, the research presents an interaction model introduced as Risk Relationship Diagram (RRD) explaining the risk triggers and their impacts in the construction supply chains considering all the supply chain partners, was a gap in the construction supply chain literature. There is no available literature for comparison to the RRD. The Risk Relationship Diagram (RRD) and the Risk Cycle (RC) can be used as a basic tool to assess the impact of triggers created by each stakeholder on others or how the triggers created by other stakeholders will affect each stakeholder. The model is useful in academic and practitioner perspective to investigate risk triggers at various points of the construction supply chain and to assess the risks and mitigation methods. The RRD can be used as tool to make analytical as well as intuitive judgments accurately in the proactive risks management process. The RRD helps to each construction supply chain partners to figure out the impact of their work for the entire supply chain. The RRD covers most of the aspects in risk identification at a glance. In the reactive risks management process, the RRD can be used as a tool to diagnose the problem and take actions to manage crisis at hand. The RRD will help to identify the actual reasons for each and every risk and can be used to find mitigation actions. This will help to continue a project with minimum delays, within the budget and expected quality standards. Many of the common possible reasons which can cause the delay/cost overrun/quality drops can be clearly identified through the RRD. In the same way, RRD can be used to explain the frequent disruptions such as delaying the delivery of materials to the site. The RRD can be used to identify risk and disruptions faced by each part of the construction supply chain so that most of the problems can be addressed proactively. The RRD can be used as check list and monitoring can be done accordingly.

Using the equations explained in this chapter, any risk (e.g. construction industry specified risk) in value of money or time for a historical project can be calculated by plugging in monetary values/time values related to the variables related to that risk (e.g. sand problem, regulation risks, seasonal trends, labour supply risks). Risk created by one of the risk trigger (e.g. sand problem) in value of time or money for a past project can be calculated by accumulating the different risk in value of money or time amounts from the variances (actual amount of time or money spent- budgeted amount of time or money) in the breakdown items (such as foundation work, superstructure, etc.) in an engineering estimate caused by that particular risk trigger (e.g. sand problem). Knowing the risk in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from these variables for a similar construction project or similar contractor or similar consultant or similar client.

For example, assume that for a past project of LKR 20 million with a breakdown of sand problem LKR million, regulation LKR 2 million, seasonal trends LKR 1.5 million and labour supply LKR 3 million. As per the above equation 5.7, the construction industry specified risk is LKR 1.97 million (E.g. 1*0.25 +2*0.14+ 1.5*0.22+3*0.37= 1.97). Assume that we have to forecast for similar type of project with a budget of LKR 60 million.

Sand risk forecasted= 1/1.97/20*60= LKR 1.52 million

Regulation risk forecasted= 2/1.97/20*60= LKR 3.04 million

Seasonal trends risks (such as rain etc.) forecasted=1.5/1,97/20*60 = LKR 2.284 million
Labour supply risks forecasted= 3/1.97/20 * 60= LKR 4.57 million

Knowing the construction industry specified risk in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from regulation risks, labour supply risk and risks from sand problem and seasonal trends such as rain for a similar construction project. Knowing the above risk impacts will motivate the contractor to proactively manage the risks so that the contractor can make cost and time related savings. Using this equation the monetary and time impact of rain can be calculated which is useful for effective contract administration and project management. This equation can be used for national level policy decision making. It can be used to calculate the monetary impact of a decision made by a government affecting the entire construction industry (i.e. tax on cement, new regulation on sand mining, banning asbestos). It can be further used to calculate the shortage of labour or sand to the entire construction industry.

Knowing the materials supply risk in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from price, quality, availability and on time delivery risks for similar construction materials suppliers and similar construction project. Knowing the above impacts from the materials suppliers will motivate the contractor to proactively manage the risks so that the contractor can make cost and time related savings. This is useful for the contractor in construction materials supplier selection decision for future projects. Furthermore, knowing the above impacts to the construction project is important to the construction materials supplier in managing proactively in sustaining the supply opportunities.

Knowing the contractor generated risks in monetary value/time value for a given project with a given budget and duration can be used as a forecasting tool to find the risks that can be generated from decision making, communication, sub-contractor, financial and planning risks for a similar construction contractor and construction project. Knowing the above impacts will motivate the contractor to proactively manage the internal risks so that the contractor can make cost and time related savings. This teaches the contractor the importance of employing talented engineers and other staff to minimize many risks as well as the importance of developing them on knowledge, skills, attitudes and motivation to minimize internal risks. This is important for the client and consultant in deciding on a contractor for a future project.

Mainly client or client's engineer generally put the blame mainly on contractors and sometimes the consultants, but this RRD clearly shows the impact of client's communication particularly the scope of the work on the entire construction work. Knowing the client generated risks in monetary value/time value for a given client and given type of project can be used as a forecasting tool to find the risks that can be generated from fund supply risks and risk on communicating the scope of work. For a similar client and similar type of project. Knowing the above impacts will motivate the client to proactively manage the internal risks so that the client can make cost and time related savings. This is important for the contractor in deciding on an opportunity given by client for a future project.

Knowing the consultant generated risks in monetary value/time value for a given client and given type of project can be used as a forecasting tool to find the risks that can be generated from risk of submitting accurate designs and estimates for a similar consultant and similar type of project. Knowing the above impacts will motivate the consultant to proactively manage the internal risks so that the consultant can make cost and time related savings. This is important for the client and contractor in deciding on a consultant for a future project.

When a mistake happens in submitting designs and estimates, it contributes to create risks in decision making, communication, sub-contractor management, financial planning and overall planning of the contractor. Knowing these impacts will motivate the consultant to proactively manage the internal risks so that the consultant can make cost and time related savings. This is important for the contractor in deciding on accepting a project with a particular consultant in the future.

Materials supply related risks are mainly influenced by the decision making and planning risks of the contractor. Knowing the impact of this is useful for the materials supplier to improve the forecasting accuracy. Change in regulatory risk affects price risks quality risks, availability risks and on time delivery risks, respectively. The materials suppliers and contractors can analyze the impacts of regulation risks on these variables on materials supply.

The RRD can be simply used as it is by the stakeholders in the construction supply chains or else it can be used as basic model to develop Cased Based Reasoning (CBR) Approach to move to an Artificial Intelligence Risk identification and management methodology in construction supply chains. The Risk Cycle introduced by this research can be used by materials suppliers to assess the demand side risk and disruptions accurately.

The RRD can be further customized for specific projects such as buildings, roads etc. as well as contract type as well as for specific contractor. The RRD can be customized for government, semi government and privet organizations as well.

This research reveals that any of the construction supply chain risk can be rooted at 3 primary risks: Human Generated Risks, Resource/Infrastructure Limitation and Unavoaidable Risks. This is the first time in the literature that quantifies the deeply rooted primary risks. Human generated risks can occur due to gaps in skills, knowledge, motivation, attitudes as well as negligence of human resources. This contributes to the emerging research area of behavioral issues in Supply Chain Management. This model is not perpetual, therefore continuous research is recommended to evolve the model to meet the changes in the environment. According to the findings, one of the primary methods of risk management is managing the risks created by people. When it comes to people development, emphasis should be given to the gaps discussed above. Resource limitation or infrastructure related risks contributes to give a foundation knowledge in risks related research more specifically to proactive side of risk management. Further research can be carried out to explore this area. In practice, another primary way of risk management is managing the risks created by resource limitation or infrastructure issues. This finding is useful when it comes to supply chain design, risk management, resilient supply chain management, sustainable supply chain, and business continuity planning.

The next chapter provides the conclusion for this work, contribution to the knowledge and recommendations further for work.

Chapter 06

6.0 CONCLUSION, CONTRIBUTION TO THE KNOWLEDGE AND RECOMMENDATIONS

6.1 Introduction

Chapter 4 and 5 discussed the findings of the research work on risk topics, risk triggers, risk classifications and interaction among risk triggers and risk owners. This chapter provides the conclusion of the work, contribution to the knowledge and recommendations for further work.

6.2 Conclusion and Contribution to the Knowledge

The primary research problem was to identify and study the nature of triggers of construction supply chain risks in the Sri Lankan construction industry. All of the important supply chain risk owners of the construction supply chains such as construction contractors, materials suppliers, consultants, client and construction industry as a whole as well as risk triggers created by them were considered in the research. The focus and level of research has not been conducted before in this context. The construction supply chain risk triggers are identified and categorized under construction industry specified risks, stakeholder generated risks and materials supply related risks.

$$\text{Construction Supply Chain Risk} = 0.29\ \text{Construction Industry Specified Risks} + 0.40\ \text{Stakeholder Generated Risks} + 0.31\ \text{Materials Supply Related Risks}$$

The equation stakeholder risks are further categorized as client generated risks, consultant generated risks and contractor generated risks. This is the first time that a holistic categorization for construction supply chain risks has been established. The relationship is explained mathematically as follows.

$$\text{Stakeholder Generated Risks} = 0.43\ \text{Contractor Generated Risks} + 0.24\ \text{Client Generated Risks} + 0.33\ \text{Consultant generated Risks}$$

The stakeholder generated risk in value of money or time for an historical project can be calculated using the above risk equation. By using that answer the perceived risk for each of the above variables for a future similar type of project can be forecasted.

The construction industry specified risk triggers are all type of risks from the construction industry/country/global context which are broken into sand problems, regulations, seasonal trends and labour problem. However, this is the first time that, the risk triggers are identified in the given topics.

Various types of causes of the risks related to earth materials (sand, soil, aggregates, etc.) availability, quality and excavation approval are defined as sand problem risk triggers. Various types of climatic/natural risks such as rain, drought, flood, tsunami, wind, land-slides, etc. are defined as seasonal trends risk triggers. All types of causes of the risks coming from rigidities/flexibilities in the regulations and policies (e.g. legal risks, approval delays, labour laws, environmental concerns, inflation, exchange rate fluctuations, rights of the general public, etc.) as well as weakness in the regulations and policies(e.g. political influences, unethical behaviors, public protests etc.) are defined as regulation risk triggers. Skilled and unskilled labour supply risk are defined as labour problem. Skilled labour includes professionals such as engineers, project managers, quantity surveyors, architects, land surveyors as well as others such as technical officers, technicians, electricians, masons, bar benders, plumbers, machine operators etc. There are few instances in the literature these risk topics are discussed, but not within the context of Sri Lanka or indeed as a holistic and integrated approach. The relationship is explained mathematically as follows.

$$\text{Construction Industry Specified Risks} = 0.25\,\text{Sand Problem} + 0.14\,\text{Regulation Risk} + 0.22\,\text{Seasonal Trends} + 0.37\,\text{Risk on Labour Supply}$$

The construction industry specified risk in value of money or time for a historical project can be calculated using the above risk equation, by using that answer the perceived risk for each of the above variables for a future similar type of project and similar type of construction industry can be forecasted.

Causes of the risks generated by the owner/directors/advisers/consultants/top level managers/project-managers/engineers/quantity-surveyors/accountants and other professionals, technical officers/electricians and all the other skilled/unskilled labour/sub-contractors working for contractor are defined as contractor generated risk triggers. Contractor generated risks triggers are planning risk, decision making risk, financial risk, communication risk and sub-contractor risk. This is the first time that, the risk triggers are identified in the given topics. The reason for the given risk trigger topic is that, the practitioner can clearly identify the causes of risks and take proactive and reactive approaches to manage the risks. Causes of the planning risks of contractor/contractor's employees or contractor's consultants are defined as contractor generated planning risk triggers. This includes all the planning made by, for an example, a top level manager, engineer, or a site worker to sub-contractor employed by the contractor. Causes of the decision making risks of contractor/contractor's employees or contractor's consultants are defined as contractor generated decision making risk triggers. This includes all the decisions made by, for an example, a top level manager/engineer to site worker employed by the contractor. Causes of the contractor's cash flow issues and profitability issues are defined as contractor generated financial risk triggers. Causes of the communication risks of contractor/contractor's employees or contractor's consultants are defined as contractor generated communication risk triggers. This includes communication planning written, verbal communication, submission of calculations, etc.. Causes of the risks of selecting and managing all type of sub-contractors (including supply of equipment and machinery) by contractor/contractor's employees or contractor's consultants are defined as contractor generated sub-contractor risk triggers.

The relationship is explained mathematically as follows.

$$\text{Contractor Generated Risks} = 0.26\ \text{Decision Making Risks} + 0.16\ \text{Communication Risks} + 0.15\ \text{Subcontractor Risks} + 0.17\ \text{Financial Risks} + 0.21\text{Planning Risks}$$

The contractor generated risk in value of money or time for a historical project can be calculated using the above risk equation. By using that answer the perceived risk for each of the above variables for a future similar type of project and similar type of contractor can be forecasted.

Causes of the risks that can be generated from client or his engineer/architect/quantity surveyor/project manager/adviser are defined as client generated risk triggers. These can be summarized as risk on communicating the scope of work plus risk of fund supply. Client generated risk triggers are risk on communicating the scope of work and Risk on supply of funding. There are few instances in the literature where the same risk trigger topics were reported.

The relationship is explained mathematically as follows.

$$\text{Client Generated Risks} = 0.54\ \text{Risk on Communicating the Scope of the Work} + 0.46\ \text{Risk on supply of funding}$$

The client generated risk in value of money or time for an historical project can be calculated using the above risk equation. By using that answer the perceived risk for each of the above variables for a future similar type of project and similar type of client can be forecasted.

Risks generated by consultant designated as all type of engineers/architects/quantity surveyors or consultants' third party employees are defined as consultant generated risks. The consultant generated risks triggers are risk on submitting accurate designs and estimates. There are few instances in the literature where the same risk trigger topic have been reported. Causes of the consultant generated risks on submitting accurate designs and estimates as well as site supervising, advising and approving are defined as risk on submitting accurate designs and estimates.

All type of material supply related risks including price risks, quality risks, availability risks and on time delivery risks are defined as material supply risks. The materials supply related risk triggers are materials supply related quality risks, materials supply related availability risks, materials supply related on time delivery risks, materials supply related price risks. There are few instances in the literature where some of these risk topics are reported. However, this is the first time that the risk triggers are identified as given topics explained above. Causes of the risks of increasing the price due to various reasons are defined as price risk triggers. Causes of the risks of not achieving expected quality levels due to various reasons are defined as quality risk triggers. Causes of the risks on non-availability of materials due to various reasons are defined as non-availability risk trigger. Causes of the risks of not delivering on time are defined as material supply related on time delivery risk triggers.

The relationship is explained mathematically as follows.

$$\begin{aligned}\text{Materials Supply Related Risks} \\ &= 0.23 \text{ Price Risks} + 0.33 \text{ Quality Risks} + 0.22 \text{ Availability Risks} \\ &+ 0.23 \text{ On time delivery Risks}\end{aligned}$$

The material supply generated risk in value of money or time for a historical project can be calculated using the above risk equation. By using the outcome of the calculation answer the perceived risk for each of the above variables for a future similar projects and similar types of materials suppliers can be forecast.

This identified that the human generated risks, infrastructure/resource limitation risks and unavoidable risks are deep rooted primary risk triggers of any of the construction supply chain. This is the first time that these deeply rooted primary risks have been identified. Human generated risks are created due to gaps in skills, knowledge, motivation, attitudes as well as negligence by human resources. One of the primary ways of risk management is managing the risks created by people. Human generated risks provide an insight into the recruitment of suitable people as well as the importance of training and development of people to reduce risk generated by them. Resource limitation (e.g. scarcity or unavailability of finance, people, equipment, etc.) or Infrastructure issues (e.g. restrictions, scarcity or unavailability of roads, buildings etc.) should be managed proactively. This finding is useful when it comes to supply chain design, risk management, resilient supply chain management, sustainable supply chain, and business continuity planning. Unavoidable risks (e.g. natural disasters, global crisis) can be managed only reactively.

Each risk owner's (e.g. contractor, consultant, client, materials supplier) perspective about their risks are mostly external. They mostly attributed their risk to the immediate upstream and downstream partners and they fail to recognize the internal risks created by themselves, as well as risk coming from extended supply chain both upstream and downstream. All of the above findings quantify the risks of each of the risk trigger as well as risk owners.

Using qualitative and quantitative methodology together with a Double Triangulation approach, the research presents an interaction model introduced as Risk Relationship Diagram (RRD) explaining the risk triggers and their impacts in the construction supply chain considering all the supply chain partners, which was a gap in the construction supply chain literature. There is no available literature to compare the RRD. The Risk Cycle (RC) introduced in this work, presents how each of the risk owners/stakeholders in the construction supply chain impact on each other as well as the respective construction project. The Risk Relationship Diagram and the Risk Cycle can be used as a basic tool to assess the impact of triggers created by each stakeholder on others or how the triggers created by other stakeholders will affect each stakeholder.

The RRD is useful in identifying risk involved in construction supply chain in general and to do a risk assessment prior to commence a project or whilst the project is going on. This model shows interrelationship between various risk triggers and it will enable engineers and managers to get a good idea about risk management in complicated construction supply chains. The RRD can be used to identify risk and problems faced by each part of the construction supply chain so that most of the problems can be addressed proactively. The RRD can be used as check list and monitoring can be done accordingly.

The model is useful in academic and practitioner perspective to investigate risk triggers at various points of the construction supply chain and to assess the risks and mitigation methods. The RRD can be used as tool to make analytical as well as intuitive judgments accurately in the proactive risks management process. In the reactive risks management process, the RRD can be used as a tool to diagnose the problem and take action to manage a given situation. The RRD will help to identify the actual reasons for each risk and can be used to find mitigation actions. This will help to continue a project with minimum delays, within the budget and expected quality standards. All the possible reasons which can cause the delay/cost overrun/quality drops can be clearly identified through the RRD. In the same way, the RRD can be used to explain the frequent disruptions such as delaying the delivery of materials to the site. The RRD can be used to identify risk and disruptions faced by each and every part of the construction supply chain so that most of the problems can be addressed proactively, and it can be used as a quality checking tool and for monitoring purposes.

The RRD gives insights to the policy makers of the country, because it shows the impact of policy changes on construction supply chains and in turn to the economy of a country. The model can be used as it is by the stakeholders in the construction supply chains or else it can be used as basic model to develop Cased Based Reasoning (CBR) Approach to move to an Artificial Intelligence Risk identification and management methodology in construction supply chains. The Risk Cycle introduced by this research can be used by materials suppliers to assess the demand side risk and disruptions accurately.

This study further reveals the risk profile (which depicts the risk probability and risk impacts of each of the risk triggers) of the Sri Lankan construction industry which could be adopted in any other construction industry with appropriate assumptions. Further, the most accepted 25 risk topics were identified for the Sri Lankan construction supply chains which is common to many construction industries.

This research revealed 12 methods of risk identification as a holistic approach of construction supply chain risk identification. According to the literature, expert interview, personal brainstorming and literature review were most commonly accepted and used methods. Action research method/Ishikawa diagram, disruption/crisis/disaster analysis were discussed in the literature as occasionally used risk identification methods. The following seven approaches are originally suggested as risk identification methods. They are:

i. Customer/stakeholder complaints and their root cause analysis,
ii. Understanding and analyzing what each of the risk owner continuously monitoring,
iii. Understanding and analyzing what each of the risk owner in sourcing,
iv. Understanding and analyzing what each of the risk owner outsourcing,
v. Understanding and analyzing existing risks management methods,
vi. Understanding and analyzing risk management methods in business continuity planning/sustainable supply chains,
vii. Understanding what is insured by each of the risk owner,

The methods can be used with suitable modifications to identify risks in any other supply chain.

The Double Triangulation Methodology introduced in this research can be applied in other research as a viable research methodology. In the Double Triangulation Methodology, it is suggested that it is compulsory to validate the results using a minimum two other different data sets/two other approaches (ex: qualitative and quantitative both). This will help the researcher to conclude the findings accurately. The whole concept is validating the results twice to have more accurate conclusions.

6.3 Limitations of the Research

The research was conducted in the Sri Lankan context and the risk profiles and triggers and fitness of these risk profiles to any other country, needs to be found out through empirical work. However, the findings can be useful to derive the risk profiles and explore the link between the risk triggers of various construction supply chain stakeholders. When the findings are applied for different socio economic context, the methodology explained can be used to a good extent but the models should be verified with the new context and new equations should be derived accordingly.

The findings are based on construction supply chains of construction project managed by a large construction contractors, involvement of consultants and sub-contractors. Construction supply chains involving small/medium projects conducted by small/medium contractors were excluded in this research. Only the main part of risk owners such as main construction contractors, clients or their engineers, direct material suppliers (business to business) were interviewed. Risk owners such as sub-contractors of the main contractor, upstream suppliers of the material suppliers, fund suppliers of the client or external stakeholders such as regulatory authorities, politicians, general public etc., were not interviewed directly. In this research, impact of the risks were assessed on the impacts of construction cost and construction duration because they are the only parameters that can be compared with estimates and actuals.

6.4 Future Research

Future research is suggested below:

1. Research on whether the twelve risk identification methods can be used to identify risks in any other supply chains and how it can be modified or expand further.
2. Research on how the Double Triangulation Methodology can be modified to different types of supply chains as well as the context of minimum data/method/approach availability.
3. Research on how construction supply chain risk triggers can be modified to different construction industries or specific segment such as roads, buildings, etc.
4. Research on how the risk equations are going to be changed with different country, context, specific project context (e.g. Road) etc.
5. Research on how the Risk Relationship Diagram will appear in any other supply chains (e.g. manufacturing supply chains, services supply chains) and how the risk cycle can be used in any other supply chain management. Further research is needed to understand how this model can be used to develop a case based reasoning approach to move to Artificial Intelligence risk identification and management methodology in construction supply chains.
6. Research on the deriving of the possible Risk Cycle for any other supply chains (e.g. manufacturing supply chains, services supply chains) and the ways that the risk cycle can be used in supply chain risk management.
7. Research on how the risk profile of the Sri Lankan construction industry can be used to derive the risk profile of any other construction industry. This includes how far the concept of deep rooted primary risk triggers can be used in proactive and reactive approaches of construction supply chain risk management. Further research can be carried out to check whether these deep rooted risk triggers are applicable for any other supply chains such as manufacturing.
8. Research on human generated risk exploring further the area of behavioral supply chains.
9. Research on unavoidable risks exploring further the area of crisis management.

The future research is suggested to address the above 9 areas explained.

Reference List

A Case Study and Research Propositions. (n.d.). *Journal of Supply Chain Management*, *41*(4), 44-57.

Abbasi, B. (2009). A neural network applied to estimate process capability of non-normal processes. *Expert Systems with Applications*, *36*(2), 3093-3100.

Abd El-Razek, M. E., Bassioni, H. A., & Mobarak, A. M. (2008). Causes of delays in building construction projects in Egypt. *Journal of Construction Engineering and Management, 134*(11), 831-841.

Abd.Majid, M. Z., & McCaffer, R. (1998). Factors of non-excusable delays that influence contractors' performance. *Journal of Management in Engineering, 14*(3), 42-48.

Adhitya, A., Srinivasan, R., & Karimi, I. A. (2007a). A model-based rescheduling framework for managing abnormal supply chain events. *Computers & Chemical Engineering, 31*(5-6), 496-518.

Adhitya, A., Srinivasan, R., & Karimi, I. A. (2009). Supply chain risk identification using a HAZOP-based approach. *AIChE Journal, 55*(6), 1447-1463.

Agapiou, A., Clausen, L. E., Flanagan, R., Norman, G., & Notman, D. (1998). The role of logistics in the materials flow control process. *Construction Management and Economics, 16*, 131-137.

Agapiou, A., Price, A. D., & McCaffer, R. (1995). Planning future construction skill requirements. *understanding labour resource issues. Construction Management and Economics, 13*(2), 149 -161.

Ahmed, S. M., & Azhar, S. (2004). Risk Management in the Florida Construction Industry. *2nd Latin American and Caribbean Conference for Engineering and Technology*. Miami, Florida.

Ahmed, S. M., & Kangari, R. (1995). Analysis of client-satisfaction factors in construction industry. *Journal of Management in Engineering, 11*(2), 36-44.

Ahmet, Ö., & Önder, Ö. (2003). Risk analysis in fixed-price design–build construction projects. *Building and Environment, 39*, 229-237.

Aibinu, A. A., & Odeyinka, H. A. (2006). Construction delays and their causative factors in Nigeria. *J Constr Eng Manage, 132*(7), 667–677.

Ailawadi, S., & Singh, R. (2005). *Logistics Management.* (E. E. Edition, Ed.) Prentice Hall of India Private Ltd.

Akintoye, A., McIntosh, G., & Fitzgerald, E. (2000, December). A survey of supply chain collaboration and management in the UK construction industry. *European Journal of Purchasing & Supply Management, 6*(3–4), 159 - 168.

Al Kuwaiti, E., Ajmal, M. M., & Hussain, M. (2017). Determining success factors in Abu Dhabi health care construction projects: customer and contractor perspectives. *International Journal of Construction Management*. doi:10.1080/15623599.2017.1333401

Alaghbari, W., Kadir, M. R., Salim, A., & Ernawati. (2007). The significant factors causing delay of building construction projects in Malaysia. *Engineering, Construction and Architectural Management, 14*(2), 192-206.

Al-Bahar, J. F. (1990). Systematic Risk Management Approach for Construction Projects. *Construction Engineering and Management*, 49-55.

Al-Bahar, J. F., & Crandall, K. C. (1990). Systematic risk management approach for construction projects. *Journal of Construction Engineering and Management, 116*.

Ale, B. J., Baksteen, H., Bellamy, L. J., Bloemhof, A., Goossens, L., Hale, A., & Whiston, J. Y. (2008). Quantifying occupational risk, The development of an occupational risk model. *Safety Science*, *46*(2), 176-185.

Alfonso, G. H., & & Suzanne, S. (2008). Crisis communications management on the web, how internet-based technologies are changing the way public relations professionals handle business crises. *Journal of Contingencies and Crisis Management, 16*(3), 143-153.

Al-Momani, A. H. (2000). Construction delay: A quantitative analysis. *International Journal of Project Management, 17*, 51-59.

Alvarenga, C. A., & Malmierca, P. (2010). The case for outsourcing SCM. *Accenture Supply Chain Services.*

Ameh, O. J., & Osegbo, E. E. (2011). Study of relationship between time overrun and productivity on construction sites. *International Journal of Construction Supply Chain Management, 1*(1), 56-67.

Anderson, D. L., Britt, F. F., & Favre, D. J. (2007, April). The Seven Principles of Supply Chain Management. *Supply Chain Management Review*, 41–46.

Anderson, J. C., & Narus, J. A. (1990). A Model of Distributor Firm and Manufacturer Firm Working Partnerships. *Journal of Marketing, 54*(1), 42-58.

Annual Report of the Central Bank of Sri Lanka . (2016).

Anthony, J., Rebecca, K. F., Nancy, L. L., & Kathleen, M. C. (2011). A mixed research study of pedagogical approaches and student learning in doctoral-level mixed research courses. *International Journal of Multiple Research Approaches*, *5*(2), 169–199.

Anthony, R. (2002). A multi-dimensional empirical exploration of technology investment, coordination and firm performance. *International Journal of Physical Distribution & Logistics Management*, *32*(7), 591-609. Retrieved from https://doi.org/10.1108/09600030210442603

Arashpour, M. (2012). A collaborative perspective in green construction risk management. *Proceedings of the 37th Annual conference of the Australaasian Universities Buidling Education Association (AUBEA)*, (pp. 1-11). Sydney, Australia.

Arashpour, M., & Farzanehfar, P. (2011). *Project management and control*. Tehran.

Arzu Akyuz, G., & Erman Erkan, T. (2010). Supply chain performance measurement: a literature review. *International Journal of Production Research*, *48*(17), 5137-5155.

Asif, S. M. (2007). *Application of resource- based theory of competitive advantage for supply chain management.* (R. M. Management, Ed.) Bangkok, Thailand: Assumption University press.

Asoke, D., Paul, L., & Mahesh, S. (2011). Building sustainability in logistics operations: a research agenda. *Management Research Review, 34*(11), 1237-1259. Retrieved from https://doi.org/10.1108/01409171111178774

Assaf, S. A., & Al-Hejji, A. (2006). Causes of delay in large construction projects. *International Journal of Construction Management, 24*(4), 349-357.

Awad, D. (2010). Supply chain integration: definition and challenges. *Management and Technology, 1*(1).

Awad, H. A., & & Nassar, M. O. (2010). A broader view of the supply chain integration challenges. *International Journal of Innovation, Management and Technology, 1*(1), 51.

Ayers, J. B. (2009). *Supply Chain Project Management, a structured collaborative and measurable approach* (2 ed.). (B. Raton, Ed.) St. Lucie Press.

Azhar, S. M., & Ginder, W. C. (2016). An Assessment of Risk Management Practices in the Alabama Building Construction Industry.

Bagchi, P. K., H. B., Skjoett-Larsen, T., & Soerensen, L. B. (2005). Supply chain integration: a European survey. *The International Journal of Logistics Management, 16*(2), 275-294.

Balachandra, H. K. (2014). Construction, ICRA Lanka. *The 20th Asia Construct Conference.* Hong Kong.

Ball, J. (2002). Can ISO 14000 and eco-labelling turn the construction industry green? *Building and Environment, 37*(4), 421-428.

Ballou, A. (1992). *Business Logistics Management.* New Jecrcy: Prentice-Hall, Inc.

Ballou, R. H. (2007). *Business logistics/supply chain management: planning, organizing, and controlling the supply chain.* Pearson Education India.

Bank, W. (2007). *The World Bank Strategy for HNP Results* .

Bankvall, L., Bygballe, L. E., Dubois, A., & Jahre, M. (2010). Interdependence in supply chains and projects in construction. *Supply Chain Management: An International Journal, 15*(5), 385 - 393.

Barnes, P., & Oloruntoba, R. (2005). Assurance of security in maritime supply chains: conceptual issues of vulnerability and crisis management. *Journal of International Management*, 19–40.

Beamon, B. M. (1998). Supply chain design and analysis, Models and methods. *International journal of production economics, 55*(3), 281-294.

Bechtel, Christian, & Jayaram, J. (1997). Supply Chain Management: A Strategic Perspective. *International Journal of Logistics Management*, *8*(1), 15-34.

Behdani, B., Adhitya, A., Lukszo, Z., & Srinivasan, R. (2012). How to Handle Disruptions in Supply Chains – An Integrated Framework and a Review of Literature Social Science Research Network. Retrieved from www.ssrn.com/en

Bell, L. C., & Stukhart, G. (1987). Cost and benefits of materials management systems. *Journal of Construction Engineering and Management*, *113*(2), 222-234.

Bilelecki, M. (2012). Logistic efficiency of the product in logistics strategies of small.

Black, K., Asafu Adjaye, J., Khan, N., Perera, N., Edwards, P., & Harris, M. (2007). *Business Statistics.* Australia: Wiley.

Blackhurst, J., & & Wu, T. (2009). Managing supply chain risk and vulnerability: Tools and methods for supply chain decision makers.

Blackhurst, J., Craighead, C. W., Elkins, D., & Handfield, R. B. (2005). An empirically derived agenda of critical research issues for managing supply-chain disruptions. *International Journal of Production Research*, *43*(19), 4067-4081.

Blos, M. F., Quaddus, M., Wee, H. M., & Watanabe, K. (2009). Supply chain risk management (SCRM): a case study on the automotive and electronic industries in Brazil. *Supply Chain Management: An International Journal, 14*(4), 247-252.

Boin, A., Stern, E., & Sundelius, B. (2016). *The politics of crisis management, Public leadership under pressure.* Cambridge University Press.

Bondinuba, F. K., Edwards, D. J., Nimako, S. G., Owusu-Manu, D., & Conway, C. (2016). Antecedents of supplier relation quality in the Ghanaian construction supply chain. *International journal of construction supply chain management, 6*(1).

Booth, S. A. (2015). *Crisis management strategy: Competition and change in modern enterprises.* Routledge.

Bowersox, D. J., & Philip L. Carter, a. R. (1985). Material Logistics Management. *Internal Journal of Physical Distribution and Logistical Management, 15*(5), 27-35.

Bowersox, D. J., Closs, D. J., & Stank, T. P. (1999). *21st Century Logistics, Making Supply Chain Integration a Reality.* (C. o. Management., Ed.) Oak Brook,IL.

Bowersox, Donald, J., & Closs, D. C. (1996). Logistical Management, The Integrated Supply Chain Process. *McGraw-Hill Series in Marketing*.

Boyd, C. (2001). *Combining qualitative and quantitative approaches:In Munhall PL (Ed) Nursing Research: A Qualitative Perspective* (3 ed.). Sudbtiry MA.

Brent C. James, M. (1989). *Quality Management for Health Care Delivery.* Chicago: The Hospital Research and Educational Trust.

Brindley, C. (2004). *Supply Chain Risk.* (V. Tech, Ed.) Burlington: Ashgate Publishing Company.

Briscoe, B., & Dainty, A. (2005). Construction supply chain Integration: an elusive goal. *International Journal of Supply Chain Management, 10*(4), 319-326.

Briscoe, G., Dainty, A. R., & Millett, S. (2001). Construction supply chain partnerships: skills knowledge and attitudinal requirements. *European Journal of Purchasing and Supply Management, 7*, 243-255.

Briscoe, G., Dainty, A., Millett, S. J., & Neale, R. H. (2004). Client-led strategies for construction supply chain improvement. *Construction Management and Economics, 22*(2), 193-201.

Broadie, M., & Du, Y. (2015). Risk Estimation via Regression.

Brown, S., & Cousins, P. D. (2004). Supply and operations: Parallel paths and integrated strategies. *British Journal of Management, 15*, 303 - 320.

Canbolat, Y. B., Gupta, G., Matera, S., & Chelst, K. (2008). Analysing risk in sourcing design and manufacture of components and sub-systems to emerging markets. *International Journal of Production Research, 46*(18), 5145-5164.

Caniels, M. C., & Gelderman, C. J. (2010). The safeguarding effect of governance mechanisms in inter-firm exchange: the decisive role of mutual opportunism. *British Journal of Management, 21*(1), 239-254.

Cao, M., Vonderembse, M. A., Zhang, Q., & Ragu-Nathan, T. S. (2010). Supply chain collaboration: conceptualisation and instrument development. *48*(22), 6613–6635.

Caprar, D. V., Devinney, T. M., Kirkman, B. L., & Caligiuri, P. (2015). Conceptualizing and measuring culture in international business and management: From challenges to potential solutions. *Journal of International Business Studies, 46*(9), 1011-1027.

Carter, C. R., & Rogers, D. S. (2008). A framework of sustainable supply chain management, moving toward new theory. *International Journal of Physical Distribution & Logistics Management, Emerald Insight, 38* (5), 360-387.

Casey, D., & Murphy, K. (2009). Issues in Using Methodological Triangulation in Research. *Nurse Researcher, 16*, 40-55. Retrieved from http://dx.doi.org/10.7748/nr2009.07.16.4.40.c7160

Cavinato, & Joseph, L. (2002, May/June). What is Your Supply Chain Type? *Supply Chain Management Review*.

Cavinato, J. (2004). Supply chain logistics risks: from the back room to the board room. *International Journal of Physical Distribution & Logistics Management, 34*(5), 383-387.

Ceryno, P. S., L. F. Scavarda, and K. Klingebiel. (2015) “Supply Chain Risk: Empirical Research in the Automotive Industry.” Journal of Risk Research 18 (9): 1145–1164. doi:10.1080/13669877.2014.913662.

Challenges faced by the construction industry in Sri Lanka: perspective of clients and contractors . (n.d.).

Chan, A. P., Chan, D. W., & Ho, K. S. (2003). Partnering in construction: critical study of problems for implementation. *J Manage Eng, 19*, 126–135.

Chandra, C., & & Kumar, S. (2000). Supply chain management in theory and practice: a passing fad or a fundamental change? *Industrial Management & Data Systems, 100*(3), 100-114.

Chao, G. H., Iravani, S. M., & Savaskan, R. C. (2009). Quality Improvement Incentives and Product Recall Cost Sharing Contracts. *Management Science, 55*(7), 1122-1138.

Chapman, P., Christopher, M., Jüttner, U., Peck, H., & Wilding, R. (2002). Identifying and managing supply-chain vulnerability. *Logistics & Transport Focus, 4*(4), 59–64.

Cheng. (2008). Responsive supply chain, a competitive strategy in a networked economy Omega. *36* (4), 549-564.

Cheng, e. a. (2011). Managing carbon footprints in inventory management. *International Journal of Production Economics, 132*(2), 178-185.

Chevin, D. (2011). Morrell points the way to 20% cuts. Construction Manager. *Building Magazine*, pp. 4 - 5.

Choi, T. Y., & and Krause, D. R. (2006). The supply base and its complexity: Implications for transaction costs, risks, responsiveness, and innovation. *Journal of Operations Management, 24*(5), 637–652.

Chopra, S., & Sodhi, M. S. (2004). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review*. doi:10.1007/s10479-014-1544-3

Christopher & Martin, L. (1992). *Logistics and Supply Chain Management.* London: Pitman Publishing.

Christopher, M., & Lee, H. (2004). Mitigating supply chain risk through improved confidence. *International Journal of Physical Distribution & Logistics Management, 34*(5), 388-396.

Christopher, M., & Peck, H. (2002). *Building the Resilient Supply Chain, Cranfield School of Management; Report.*

Christopher, S. T. (2006, October). Perspectives in supply chain risk management. *International Journal of Production Economics, 103*(2), 451–488.

Christian A. Rudolf, Stefan Spinler (2018), Supply Chain Management: An International Journal Key risks in the supply chain of large scale engineering and construction projects

Chu, L. K., Li, H. Z., Sculli, D., & Wu, F. (2012). Supplier selection for outsourcing from the perspective of protecting crucial product knowledge. *International Journal of Production Research*.

Cohen, J., Krishnamoorthy, G., & & Wright, A. (2017). Enterprise risk management and the financial reporting process: The experiences of audit committee members, CFOs, and external auditors. *Contemporary Accounting Research, 34*(2), 1178-1209.

Colesca, S., & Dobrica, R. (2009). Information management in healthcare. *The Ninth International Conference, "Investments and Economic Recovery", 12.*

Colicchia, C., & Strozzi, F. (2012). Supply chain risk management: a new methodology for a systematic literature review. *Supply Chain Management: An International Journal, 17*(4), 403- 418.

Colicchia, C., Dallari, F., & Melacini, M. (2010). Increasing supply chain resilience in a global sourcing context. *Production Planning and Control, 21*(7), 680-694.

Company, M. &. (2009). *Building India-Accelerating Infrastructure Projects.* Retrieved from http://www.kpmg.com/in

(2014). *Construction industry development act, no. 33 Parliament of the democratic socialist republic of Sri Lanka.* Supplement to part ii of the gazette of the Democratic Socialist Republic of Sri Lanka. Department of government printing, Sri Lanka.

Cooke, J. A. (2002). Brave New World. *Logistics Management Distribution Report, 41*(1), 31-34.

Cooke, T. J., Davies, & Arzymanow, A. (2003). The maturity of project management in different industries: An investigation into variations between project management models. *International Journal of Project Management, 21*, 471–478.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: More than a new name for logistics. *The International Journal of Logistics Management, 8*(1), 1–14.

Corbin, J., & and Strauss, A. (2008). *Basics of Qualitative Research.* (T. Oaks, Ed.) CA, CA: Sage Publications.

Cox, A., & Thompson, I. (1997). Fit for purpose' contractual relations: determining a theoretical framework for construction projects. *European Journal of Purchasing & Supply Management, 3*(3), 127 - 135.

Craighead, C. W., Blackhurst, J., Rungtusanatham, M. J., & Handfield, R. B. (2007, February). The severity of the supply chain distruptions- Design characteristics and Mitigation Capabilities, Decision Sciences. *The journal of the decision science institute, 38*(1), 131-156.

Cremonini, M., & Samarati, P. (2012). Business continuity planning. *Handbook of Computer Networks: Distributed Networks, Network Planning, Control, Management, and New Trends and Applications, 3*, 671-688.

Creswell, J. (2009). *Research design. Qualitative, quantitative, and mixed methods approaches* (2 ed.). Los Angeles: Sage Publications.

Creswell, J., Klassen, A., Plano clerk, V., & Smith, K. (n.d.). *Best Practices for Mixed Methods Research in the Health Sciences.* Office of Behavioral and Social Sciences Research.

Croxton, K. L., Garcia-Dastugue, S. J., Lambert, D. M., & Rogers, D. (2001). The supply chain management processes. *The International Journal of Logistics Management, 12*(2), 13-36.

Cruz, J. M., & Liu. (2011). Modeling and analysis of the multiperiod effects of social relationship on supply chain networks. *European Journal of Operational Research, 214*(1), 39-52.

Daekwan, K., & Erin, C. (2009). The impact of supply chain integration on brand equity. *Journal of Business & Industrial Marketing*, *24*(7), 496-505. Retrieved from https://doi.org/10.1108/08858620910986730

Dainty, A. R., Millett, S. J., & Briscoe, G. H. (2001). New Perspectives On Construction Supply Chain Integration. *Supply Chain Management: An international Journal, 6*, 163-173.

Dani, S., & Deep, A. (2010). Fragile food supply chains- Reacting to risks. *International Journal of Logistics Research and Applications, 12*(5), 395-410.

Daniel, P., Baofeng, H., & Zhaojun, H. (2012). The effects of different aspects of ISO 9000 implementation on key supply chain management practices and operational performance",Supply Chain Management:. *An International Journal, 17*(3), 306.

Dapic, A., Novakovic, Z., & Mlenkov, P. (2015). Hospital Logistics. *Second Logistics International Conference*, (pp. 309-314). Belgrade, Serbia.

Das, T. K. (2006). Strategic alliance temporalities and partner opportunism. *British Journal of Management, 17*, 1 - 21.

Das, T. K., & Teng, B. S. (1996). Risk types and inter-firm alliance structures. *Journal of Management Studies, 33*, 827–843.

Das, T. K., & Teng, B. S. (2001). Trust, control, and risk in strategic alliances: An integrated framework. *Organisational Studies, 22*(2), 251-283.

Datta, P. P., Christopher, M., & Allen, P. (2007). Agent-based modelling of complex production/distribution systems to improve resilience. *International Journal of Logistics Research and Applications, 10*(3), 187-203.

David, L., Anderson, Frank, F., Britt, & Donavon, J. F. (2007, April). The Seven Principles of Supply Chain Management. *Supply Chain Management Review*.

Davis, S. D., & Prichard, R. (2000). Risk Management, Insurance and Bonding for the Construction Industry, Associated General Contractors of America.

De Silva, N., Rajakaruna, R. W., & Bandara, K. A. (n.d.). Challenges faced by the construction industry in Sri Lanka: perspective of clients and contractors.

Deane, J., Craighead, C. W., & Ragsdale, C. T. (2009). Mitigating environmental and density risk in global sourcing. *International Journal of Physical Distribution and Logistics Management, 39*(10), 861-883.

Denzin, N. K. (1978). *A Theoretical Introduction to Sociological Methods* (2 ed.). New York: McGraw-Hill.

Denzin, N. K. (1989). *The Research Act: A Theoretical Introduction To Sociological Method* (3 ed.). New York: Prentice Hall.

Dey, P. K., & Ogunlana, S. O. (2004). Selection and application of risk management tools and techniques for build-operate-transfer projects. *Industrial Management & Data Systems*, 334-346.

Dlakwa, M. M., & Culpin, M. F. (1990). Reason for overrun in public sector construction projects in Nigeria. *International Journal of Project Management, 8*(4), 237-241.

Doherty, N. A. (2000). *Innovation in corporate risk management: the case of catastrophe risk. In Handbook of Insurance.* Springer Netherlands.

Dowst, & Somerby. (1988, January 28). Quality Suppliers: The Search Goes On. *Purchasing*, 94A4-12.

Dowty, R. A., & Wallace, W. A. (2010). Implications of organizational culture for supply chain disruption and restoration. *International Journal of Production Economics, 126*(1), 57-65.

Drozdowski, & Ted, E. (1986, March 13). At BOC They Start With the Product. *Purchasing*, 62B5-11.

Druker, J., White, G., & Hegewisch, A. (1996). Between hard and soft HRM, human resource management in the construction industry. *Construction Management and Economics, 14*(5), 405-416.

Dumas, M., La Rosa, M., Mendling, J., & Reijers, H. A. (2013). *Fundamentals of Business Process Management.* Heidelberg, New York: Springer. doi:10.1007/978-3-642-33143-5

Ekambaram, P., Mohan, K., & Thomas, N. G. (2003). Targeting optimum value in public sector projects through “best value”-focused contractor selection". *Engineering, Construction and Architectural Management, 10*(6), 418-431.

Elhag, T. M., Boussabaine, A. H., & Ballal, T. M. (2005). Critical determinants of construction tendering costs: Quantity surveyors' standpoint. *International Journal of Project Management*, *23*(7), 538-545.

Elinwa, A. U., & Joshua, M. (2001). Time-overrun factors in Nigerian construction industry. *Journal of Construction Engineering and Management*, *127*(5), 419-426.

Ellram, & Lisa, M. (1990). The Supplier Selection Decision in Strategic Partnerships. *Journal of Purchasing and Materials Management*, *26*(4), 8-14.

El-Sayegh, S. M. (2008, May). Risk assessment and allocation in the UAE construction industry. *International Journal of Project Management, 26*(4), 431–438.

Enshassi, A., Mohammed, S., Mustafa, Z. A., & Mayer, P. E. (2007). Factors affecting labour productivity in building projects in the Gaza Strip. *Journal of Civil Engineering & Management, 13*(4), 245-254.

Eriksson, P., & Laan, A. (2007). Procurement effects on trust and control in client-contractor relationship. *Engineering, Construction and Architectural Management, 14*(4), 387-399.

Ernst, & Young. (2012). *Managing bribery and corruption risks in the construction and infrastructure industry. 12th Global Fraud Survey.* Retrieved from http://www.ey.com

Escobar, V., Bourque, S., & Gallego, N. (2015). Hospital kanban system implementation: Evaluating satisfaction of nursing personnel. *TQM Journal, 27*, 101–110.

Eskandarpour, M., Dejax, P., Miemczyk, J., & Péton, O. (2015). Sustainable supply chain network design: an optimization-oriented review. *Omega*, *54*, 11-32.

Esmaeilikia, M., Fahimnia, B., Sarkis, J., Govindan, K., Kumar, A., & Mo, J. (2014). Tactical supply chain planning models with inherent flexibility: Definition and review. doi:10.1007/s10479-014-1544-3.

Exchanges, R. S. (n.d.). *Council of Supply Chain Management Professionals (CSCMP).*

Fahimnia, B., Tang, C. S., Davarzani, H., & Sarkis, J. (2015). Quantitative models for managing supply chain risks, A review. *European Journal of Operational Research, 247*(1), 1-15.

Faisal, M. N., Banwet, D. K., & Shankar, R. (2007). Quantification of risk mitigation environment of supply chains using graph theory and matrix methods. *European Journal of Industrial Engineering, 1*(1), 22-39.

Fawcett, S. E., & Magnan, G. M. (2002). The rhetoric and reality of supply chain integration. *International Journal of Physical Distribution & Logistics Management*, *32*(5), 339 - 361.

Fearne, A., & Fowler, N. (2006). Efficiency versus Effectiveness in Construction Supply Chains, The Dangers of "Lean" Thinking in Isolation. *Supply Chain Management, An International Journal, 11*(4), 283-287.

Fernie, S., & Thorpe, A. (2007). Exploring Change in Construction, Supply Chain Management. *Engineering, Construction and Architectural Management, 14*(4), 319-333.

Finch, P. (2004). Supply chain risk management, Supply Chain Management. *An International Journal, 9*(2), 183-196.

Flynn, B., Huo, B., & Zhao, X. (2010). The impact of supply chain integration on performance. *A contingency and configuration approach Journal of operations management, 28*(1), 58-71.

Formoso, C. T., Soibelman, L., De Cesare, C., & Isatto, E. L. (2002). Material waste in building industry: Main causes and prevention. *Journal of Construction Engineering and Management, 128*(4), 316-325.

Foss, C., & EUefsen, B. (2002). The value of combining qualitative and quantitative approaches in nursing research by means of method triangtilation. *Journal of Advanced Nursing, 40*(2), 242-248.

Freire, J., & Alarcón, L. (2002). Achieving a lean design process. *Journal of Construction Engineering and Management*, 248-256.

Frimpong, Y., Oluwoye, J., & Crawford, L. (2003). Causes of delays and cost overruns in construction of groundwater projects in developing countries: Ghana as a Case Study. *International Journal of Project Management, 21*, 321-326.

Fugar, F. D., & Agyakwah-Baah, A. B. (2010). Delays in building construction projects in Ghana. *Australasian Journal of Construction Economics and Building, 10*(1/2), 103-116.

Galway, L. (2004). *Quantitative Risk Analysis for Project Management.* RAND Corporation.

Gang, L., Yi, L., Shouyang, W., & Hong, Y. (2006). Enhancing agility by timely sharing of supply information. *Supply Chain Management: An International Journal, 11*(5), 425-435. Retrieved from https://doi.org/10.1108/13598540610682444

Gaonkar, R. S., & Viswanadham, N. (2007). Analytical framework for the management of risk in supply chains. *IEEE Transactions on Automation Science and Engineering, 4*(2), 265-273.

Giunipero, Lawrence, C., & Richard, R. B. (1996). Purchasing's Role in Supply Chain Management," The Internationa (1996), "Purchasing's Role in Supply Chain Management. *The International Journal of Logistics Management, 7*(1), 29-37.

Glaser, B. G. (1998). *Doing Grounded Theory: Issues and Discussions.* (M. Valley, Ed.) CA: Sociology Press.

Gleissner, H., & Femerling, J. (2013). The Principles of Logistics. *Logistics*.

Govan, P., & Damnjanovic, I. (2016, September). The Resource-Based View on Project Risk Management. *Journal of Construction Engineering & Management, 142*(9).

Gray, C. F., & Larson, E. W. (2008). *Project Management: The Managerial Process* (4 ed.). McGraw Hill.

Green, S., & May, S. C. (2005). Lean construction: arenas of enactment, models of diffusion and the meaning of 'leanness. *Building Research & Information, 33*(6), 498 - 511.

Greene, & Alice, H. (1991). Supply Chain of Customer Satisfaction. *Production and Inventory Management Review and APICS News, 11*(4), 24-25.

Greene, J. C. (2006). Toward a methodology of mixed methods social inquiry. *Research in the Schools, 13*(1), 93–98.

Greene, J. C. (2008). Is mixed methods social inquiry a distinctive methodology? *Journal of Mixed Methods Research, 2*, 7–22.

Greenwood, D. J. (2001). Subcontract procurement: Are relationships changing? *Construction Management and Economics, 19*, 5-7.

Greer, B. M., & Ford, M. W. (2009). Managing change in supply chains: a process comparison. *Journal of Business Logistics, 30*(2), 47-63.

Gunasekaran, A., Lavastre, O., & Spalanzani, A. (2012). Supply chain risk management in French companies. *Decision Support Systems, SciVerse ScienceDirec, 52*, 828–838.

Gunawardena, N. D., Wickremarachchi, M. M., & Nismy, R. M. (2004). Costs of Quality in Construction: Can these be reduced through implementation of ISO 9000? *Built-Environment-Sri Lanka, 5*(1).

Halcomb, E., & Andrew, S. (2005). Triangulation as a method for contemporar. *Nurse Researcher, 13*(2), 71-82.

Hale, J. E., Hale, D. P., & Dulek, R. E. (2006). Decision Processes During Crisis Response: An Exploratory Investigation. *Journal of Magerial Issues, 18*(3), 301-320.

Hallikas, J., Karvonen, I., Pulkkinen, U., Virolainen, V. M., & Tuominen, M. (2004). Risk management processes in supplier networks. *International Journal of Production Economics, 90*(1), 47-58.

Harland, C. M., Brenchley, R., & Walker, H. (2003). Risk in supply networks. *Journal of Purchasing and Supply Management, 9*(2), 51-62.

Hatmoko, J., & Scott, S. (2010). Construction Management and Economics. *Simulating the impact of supply chain management practice on the performance of medium-sized building projects, 28*(15), 35-49.

Hatush, Z., & Skitmore, M. (n.d.). Assessment and evaluation of contractor data against client goals using PERT approach. *Construction Management & Economics, 15*(4), 327- 340.

Heckmann, I., Comes, T., & Nickel, S. (2015). A critical review on supply chain risk–Definition, measure and modeling. *Omega, 52*, 119-132.

Heide, J. B., & George, J. (1990). Alliances in Industrial Purchasing, The Determinants of Joint Action in Buyer - Supplier Relationships. *Journal of Marketing Research, 27*, 24-36.

Hennig-Thurau, T., Gwinner, K. P., & Gremler, D. D. (2002). Understanding relationship marketing outcomes and integration of relational benefits and relationship quality. *Journal of Service Research, 4*(3), 230-247.

Herath, R. (2016). *The Strategic Importance of supply Chain Management in SMEs.*

Herriot-Watt, F. K., Edwards, D. J., & Nimako, S. G. (n.d.). Antecedents of supplier relation quality in the Ghanaian construction supply chain, Bondinuba.

Hetland, P. W. (1999 (A)). Project uncertainties and complexities. A framework for complex projects and complex strategies. . *European Programme for Project Executives, Stavanger*.

Hewitt, F. (1994). Supply chain redesign. *International Journal of Logistics Management, 5*(2), 1-9.

Hillson, D. (2002). Extending the Risk Process to Manage the Opportunities. *Project Management*, 235-240.

Hillson, D. (2003). Using a risk breakdown structure in project management. *2*(1), 85–97.

Hokey Min, G. Z. (2002, July). Supply chain modeling: past, present and future. *Computers & Industrial Engineering, 43*(1–2; 1), 231–249.

Hong, K., & Jinyan, X. (2015). *Research and control of the Risk of EPC Contractor Based on the Supply Chain.* Tianjin 300384, China: School of management, Tianjin University of Technology.

Houlihan, & John, B. (1988). International Supply Chains, A New Approach. *Management Decision, 26*(3), 13-19.

Huang, H. Y., Chou, Y. C., & Chang, S. (2009). A dynamic system model for proactive control of dynamic events in full-load states of manufacturing chains. *International Journal of Production Research, 47*(9), 2485-2506.

Hughes, W. (2009). Construction Supply Chain Management Handbook. London.

Iannone R., L. A. (2013). Modelling Hospital Materials Management Processes. *International Journal of Engineering Business Management*.

International Journal of Civil Engineering and Technology (IJCIET). (2017, Apeil). *8*(4), pp. 884-894. Retrieved from http://www.iaeme.com/IJCIET/issues.asp?JType=IJCIET&VType=8&IType=4

Iyer, K. C., & Jha, K. N. (2006). Critical factors affecting schedule performance: Evidence from Indian Construction Industry. *Journal of Construction Engineering Management, 132*(8), 871-881.

Jabbarzadeh, A., Fahimnia, B., & Seuring, S. (2014). Dynamic supply chain network design for the supply of blood in disasters: A robust model with real world ap-aplication. *Transportation Research Part E: Logistics and Transportation Review*, *70*, 225–244.

Jagtap, M., & Kamble, S. (2015). Evaluating the modus operandi of construction supply chains using organization control theory. *International Journal of Construction Supply Chain Management , 5*(1), 16-33. doi:10.14424/ijcscm501015-16-33

Jarzemskis, A. (2006). Determination and evaluation of the factors of outsourcing logistics. (T. &. Francis, Ed.) *Transport*, 44-47.

Jayawardena, H. K., Senevirathne, K., & Jayasena, H. S. (n.d.). Skilled Workforce in Sri Lankan Construction Industry: Production Vs. Acceptance.

Jha, K., & Iyer, K. (2007). Commitment, coordination, competence and the iron triangle. *International Journal of Project Management*, *25*(5), 527-540.

Jiang, L., Yu, M., Zhou, M., Liu, X., & Zhao, T. (2011a). Target-dependent Twitter Sentiment Classification. *Proceedings of the 49th Annual Meeting of the Association for Computational Linguistics: Human Language Technologies*, *1*, pp. 151-160.

Jiho Yoon, Srinivas Talluri, Hakan Yildiz & William Ho (2017) Models for supplier selection and risk mitigation: a holistic approach, International Journal of Production Research, ISSN: 0020-7543 (Print) 1366-588X (Online) Journal homepage: http://www.tandfonline.com/loi/tprs20, 2017

Jitesh, T., & Arun Kanda, S. G. (2008). Supply chain management in SMEs: development of constructs and propositions. *Asia Pacific Journal of Marketing and Logistics*, *20*(1), 97-131. Retrieved from https://doi.org/10.1108/13555850810844896

Johnson, M. E. (2001). Learning from toys: lessons in managing supply chain risk from the toy industry. *California Management Review*, *43*(3), 106-124.

Johnson, R. B., & Gray, R. (2010). A history of philosophical and theoretical issues for mixed methods research. *In A. Tashakkori & C. Teddlie . (Eds.), Sage handbook of mixed methods in social and behavioral research*, 69–94.

Johnson, R. B., & Onwuegbuzie, A. J. (2004). Mixed methods research: A research paradigm whose time has come. . *Educational Researcher, 33*(7), 14–26.

Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112–133.

Jüttner, U., & Maklan, S. (2011). Supply chain resilience in the global financial crisis: an empirical study. *Supply Chain Management, 16*(4), 246–59.

Jüttner, U., Peck, H., & Christopher, M. (2003). Supply chain risk management: Out- lining an agenda for future research. *International Journal of Logistics Research and Applications, 6,* 197–210.

Kaare, K., & Koppel, O. (2012). Improving the road construction supply chain by developing a national level performance measurement system: The case of Estonia. *International Journal of Social and Human Sciences, 6*, 225-231.

Kafetzidakis, I., & Mihiotis, A. (2012). Logistics in the Health Care System: The Case of Greek Hospitals . *International Journal of Business Administration , 3*(5), 23-32.

Kale, S., & Arditi, D. (2001). Construction Management and Economics.

Kara, S., Kayis, B., & Gomez, E. (2008). Managing supply chain risks in multi-site, multi-partner engineering projects. 100-112.

Kavcic, K., & Tavcar, M. I. (2008). Planning successful partnership in the process of outsourcing. *37*(2), 241–249.

Keah, C. T., Steven, B. L., & Joel, D. W. (2002). Supply chain management: a strategic perspective. *International Journal of Operations & Production Management, 22*(6), 614-631. Retrieved from https://doi.org/10.1108/01443570210427659

Khalfan, M. M., McDermott, P., & Swan, W. (2007). Building trust in construction projects. *Journal of Supply Chain Management, 12*(6), 385-391.

Kim, G., & Schniederjans, M. (1993). Empirical comparison of just-in-time and stockless material management. *Hospital Material Management Quarterly, 4*(14), 65-75.

Kimchi, J., Polivka, B., & Stevenson, J. S. (1991). Triangulation: operational definitions. *Nursing Research, 40*(6), 364-366.

King, A. P., & Pitt, M. C. (2009). Construction Supply Chain Management Concepts and Case Studies.

Kini, D. U. (1999). Materials management: The key to successful project management. *Journal of Management Engineering, 15*(1), 30-34.

Kleindorfer, P. R., & Saad, G. H. (2005). Managing disruption risks in supply chains. *Production & Operations Management, 14*(1), 53-68.

Knemeyer, A. M., Zinn, W., & Eroglu, C. (2009). Proactive planning for catastrophic events in supply chains. *Journal of Operations Management, 27*(2), 141-153.

Knight, F. H. (1921). Risk, uncertainty and profit, Hart, Schaffner, and Marx Prize Essays. (31), 19.

Korczynski, M. (1996). The low-trust route to economic development: Inter-firm relations in the UK engineering construction industry in the 1980s and 1990. *Journal of Management Studies, 33*(6), 787 - 808.

Kovács, G., & Spens, K. M. (2007). Logistics Theory Building. *The Icfai Journal of Supply Chain Management*, 7-27.

Kremic, Rom, Tukel, & Latham, M. (n.d.). *Constructing the Team.* London: London.

Kriegel, J., & Dieck, M. (2013). Advanced services in hospital logistics in the German health. *Logist. Res.*

Kull, T., & Closs, D. (2008). The risk of second-tier supplier failures in serial supply chains: Implications for order policies and distributor autonomy. *European Journal of Operational Research, 186*(3), 1158-1174.

Kumar, V., & Viswanadham, N. (2007). A CBR-based Decision Support System Framework for Construction Supply Chain Risk Management. *3rd Annual IEEE Conference on Automation Science and Engineering Scottsdale*, (pp. 22-25). AZ, USA.

Lambert, D. M., & Cooper, M. C. (1997). Issues in supply chain management Industrial marketing management. *29*(1), 65-83.

Landry, P. (2002). 4U2C, or How Logistics Can ServiceHealthcare.

Langevin, A., & Riopel, D. (2005). *Logistics Systems Design and Optimization.* New York: Springer.

Lariviere, M. A. (n.d.). OM Forum—Supply Chain Contracting: Doughnuts to Bubbles.

Laryea, S., & Hughes, W. (2008). How contractors price risk in bids: theory and practice. *Construction Management & Economics, 26*(9), 911-924.

Laryea, S., & Hughes, W. (2011). Risk and Price in the Bidding Process of Contractors. *Journal of Construction Engineering & Management, 137* (4), 248-258.

Lee, H. L. (2004). The triple-A supply chain. , 102–112. *Harvard Business Review*, pp. 102-112.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. Management Science. *43*, 546–558.

Ling, F. Y. (2005). Global Factors Affecting Margin Size of Construction Projects. *Journal of Construction Research, 6*(1), 91-106.

Ling, F. Y., & Liu, M. (2005). Factors considered by successful and profitable contractors in mark-up size decision in Singapore. *Building and Environment, 40*(11), 1557-1565.

Lockamy, A. I., & Mc Cormack, K. (2004b). Linking SCOR planning practices to supply chain performance, an exploratory study. *International Journal of Operations & Production Management, 24*(12), 192-218.

Lockamy, A. I., & McCormack, K. (2004a). The development of a supply chain management process maturity model using the concepts of business process orientation. *Supply Chain Management, An International Journal, 9* (4), 272-8.

Lockamy, A., & McCormackb, K. (2010). Analyzing risks in supply networks to facilitate outsourcing decisions. *International Journal of Production Research, 48*(2), 593–611.

Lodree Jr, E. J., & Taskin, S. (2008). An insurance risk management framework for disaster relief and supply chain disruption inventory planning. *Journal of the Operational Research Society, 59*(5), 674-684.

Long, N. D., Ogunlana, S., Quang, T., & Lam, K. C. (2004). Large construction projects in developing countries: a case study from Vietnam. *International Journal of Project Management, 22*, 553-561.

Lonngren, H. M., Rosenkranz, C., & Kolbe, H. (2010). Aggregated construction supply chains: Success factors in implementation of strategic partnerships. Supply Chain Management. *An International Journal, 15*(5), 404 - 411.

Lorterapong, P. (1996). Project-network analysis using fuzzy sets theory. *Journal of Construction Engineering and Management, 122*, 308.

Lu, S., & Hao, G. (2013). he influence of owner power in fostering contractor cooperation: Evidence from China. *International Journal of Project Management, 31*(4), 522-531.

Lummus, R. R., & Vokurka, R. J. (1999). Defining Supply Chain Management, A Historical Perspective and Practical Guidelines. *Industrial Management and Data Systems, 99*(1), 11-17.

Lummus, R. R., Vokurka, R. J., & Alber, K. L. (1998). Strategic Supply Chain Planning. *Production and Inventory Management Journal, 39*(3), 49-58.

Machalaba, D., & Kim, Q. (2002, September 30). West Coast Docks are shut down after series of work disruptions. *Wall Street Journal*.

Magal, S. R., & Word, J. (2012). *Integrated Business Process withERP Systems.* JOHN WILEY & SON S, I N C.

Makulsawatudom, A., Emsley, M. W., & Sinthawanarong, K. (2004). Critical factors affecting construction productivity in Thailand. *The Journal of KMITN, 14*(3), 1-6.

Male, S. P., & Mitrovic, D. (2005). The project value chain: Models for procuring supply chain in construction. *Research Week Conference.*

Mansfield, N. R., Ugwu, O. O., & Doran, T. (1994). Causes of delay and cost overrun in Nigeria construction projects. *International Journal of Project Management, 12*(4), 254-60.

Manuj, I., & Mentzer, J. T. (2008). Global supply chain risk management strategies. *International Journal of Physical Distribution and Logistics Management, 38*(3), 192-223.

Marien, E. J. (2000, March/April). The Four Supply Chain Enablers. *Supply Chain Management Review*.

Markmann, C., Darkow, I. L., & von der Gracht, H. (2013). A Delphi-based risk analysis—Identifying and assessing future challenges for supply chain security in a multi-stakeholder environment. *Technological Forecasting and Social Change, 80*(9), 1815-1833.

Marucheck, A., Greis, N., Mena, C., & Cai, L. (2011). Product safety and security in the global supply chain: Issues, challenges and research opportunities. *Journal of Operations Management, 29*(7), 707-720.

Matook, S., Lasch, R., & Tamaschke, R. (2009). Supplier development with benchmarking as part of a comprehensive supplier risk management framework. *International Journal of Operations and Production Management, 29*(3), 241-67.

Matsuo, H. (2015). Implications of the Tohoku earthquake for Toyota′ s coordination mechanism: Supply chain disruption of automotive semiconductors. *International Journal of Production Economics, 161*, 217-227.

Mazlan, R., & Ali, K. N. (2006). Relationship between supply chain management and outsourcing.

Mbachu, J. (2011). Sources of contractor's payment risks and cash flow problems in the New Zealand construction industry: project team's perceptions of the risks and mitigation measures. *Construction Management & Economics, 29*(10), 1027-1041.

Mbachu, J., & Frei, M. (2010). Diagnosing the strategic health of an organisation from SWOT analysis results: Case study of the Australasian cost management profession. *Construction Management & Economics*, *29*(3), 287-303 .

Mbachu, J., & Taylor, S. (2014). Contractual risks in the New Zealand construction industry: Analysis and mitigation measures. *International Journal of Construction Supply Chain Management, 4*(2), 22-33. doi:10.14424/ijcscm402014-22-33

McCormack, K. (2001). Supply chain maturity assessment: a road-map for building the extended supply chain. *Supply Chain Practice, 3*(4), 4-21.

McCormack, K., & Johnson, W. (2003). *Supply Chain Networks and Business Process Orientation* (Vol. CRC Press). (B. Raton, Ed.) Supply Chain Networks and Business Process Orientation, FL.

McKinnon, A. (2006). Life without trucks: the impact of a temporary disruption of road freight transport on a national economy. *Journal of Business Logistics, 27*(2), 227-250.

Melnyk, S. A., Zsidisin, G. A., & Ragatz, G. L. (2005, November/December). The Plan Before the Storm. *APICS Magazine*, 32-35.

Melo, T. (2012). *A note on challenges and opportunities for Operations Research in hospital Logistics.* Technical reports on Logistics, Saarland Business School.

Meng, X., Sun, M., & Martyn, J. (2011). Maturity model for supply chain relationships in construction. *Journal of Management in Engineering*, 97 - 105.

Mentzer, J. T., DeWitt, W. J., Keebler, J. S., Min, S., Nix, N. W., & Smith, C. D. (2001). Defining supply chain management. *Journal of Business Logistics, 22*(2), 1–26.

Micheli, G., E, C., & Zorzini, M. (2008). Supply risk management vs. supplier selection to manage the supply risk in EPC supply chain. *Management Research New, 36*(11), 846-866.

Miles, R. E. (1986). Organizations: New concepts for new forms. *California Management Review, 38*(3), 62 - 73.

Min, H., & Zhou, G. (2002). Supply chain modeling: past, present and future. *Computers & Industrial Engineering, 43*, 231-249.

Min, S., Mentzer, J. T., & Ladd, R. T. (2007). *Acad. Mark. Sci. , 35*(507). Retrieved from https://doi.org/10.1007/s11747-007-0020-x

Mitroff, I. I., & Alpasian, M. C. (2003). Preparing for evil. *Harvard Business Review, 81*(4), 109-115.

Mochtar, K., & Arditi, D. (2001). Pricing strategy in the US construction industry. *Construction Management & Economics*, 405. .

Mohd, N. F., Banwet, D. K., & Ravi, S. (2006). Mapping supply chains on risk and customer sensitivity dimensions. *Industrial Management & Data Systems, 106*(6), 878-895. Retrieved from https://doi.org/10.1108/02635570610671533

Monczka, R. M., Handfield, R. B., Giunipero, L. C., & Patterson, J. L. (2015). *Purchasing and supply chain management.* Cengage Learning.

Morse, J. M., & Field, P. A. (1995). Qualitative research methods for health professionals.

Mosly, I., & Zhang, G. (2010). Study on risk management for the implementation of energy efficient and renewable technologies in green office buildings. *4th International Conference on Sustainability Engineering and Science.*

Muehlhausen, F. B. (1991). Construction Site Utilisation: Impact of Material Movement and Storage on Productivity and Cost. *AACE Transactions*, L.2.1 – L.2.9.

Mulholland, B., & Christian, J. (1999). Risk assessment in construction schedules. *Journal of Construction Engineering and Management, 125*, 8-15.

Narayandas, D. &. (2004). Building and sustaining buyer-seller relationships in mature industrial markets. *Journal of Marketing, 68*(3), 63-77.

Natarajaratthinam, M., Caper, I., & Arunachalam, N. (2009). Managing supplychains at times of crisis. *International journal of physical distribution and logistics management, 39*(7).

Navon, R., & Berkovich, O. (2006). An automated model for materials management and control. *Construction Management and Economics, 24*(6), 635-646.

Nembhard, H. B., Shi, L., & Aktan, M. (2005). IIE transactions.

Nembhart, H., Shi, L., & Aktan, M. (2005). A real-options-based analysis for supply chain decisions. *IIE Transactions, 37*, 945-956.

Ngai, E. W., & Ngai, A. G. (2004). Implementation of EDI in Hong Kong: an empirical analysis. *Industrial Management & Data Systems, 104*(1), 88-100. Retrieved from https://doi.org/10.1108/02635570410514124

Nguyen, P. T., Crase, L., & Durden, G. R. (2008). Organizational Logistics Processes: A Literature Review and an Exploratory Investigation of International Multimodal Transport in Vietnam. *Asia Pacific Management Review, 13*(1), 403-418.

Niechwiadowicz, K., & Khan, Z. (n.d.). *Robot Based Logistics System for hospitals- Survey.*

Nieto-Morote, A., & Ruz-Vila, F. (2011). A fuzzy approach to construction project risk assessment. *International Journal of Project Management, 29*(2), 220-231. doi:10.1016/j.ijproman.2010.02.002

Norrman, A., & Jansson, U. (2004). Ericsson's proactive supply chain risk management approach after a serious sub-supplier accident. *International Journal of Physical Distribution and Logistics Management, 34*(5), 434-456.

O'Brien, W. J. (2000). *Construction supply-chain management: A vision for advanced coordination, costing, and control.* University of Florida.

O'Brien, W. J., Formoso, C. T., London, K. A., & Vrijhoef, R. (2009). *Construction supply chain management handbook.* London: Taylor & Francis Group. OGC.

Ødega, A., & Økly, S. (2012). A mixed method approach to clarify the construct validity of interprofessional collaboration: An empirical research illustration. *Journal of Interprofessional Care, 26,* 283–288. doi:10.3109/13561820.2011.652784

Oehmen, J., Ziegenbein, Alard, A., & Schonsleben, R. (2009). System-oriented supply chain risk management. *Production Planning and Control, 20*(4), 343-361.

Ogden, T., Forgatch, M. S., Askeland, E., Patterson, G. R., & Bullock, B. M. (2005). Implementation of parent management training at the national level: The case of Norway. *Journal of Social Work Practice, 19*(3), 317-329.

Ojala, L., Solakivi, T., & Töyli, J. (2012). Logistics outsourcing, its motives and the level of logistics costs in manufacturing and trading companies operating in Finland. *Production Planning & Control: The Management of Operations.*

Oke, A., & Gopalakrishnan, M. (2009). Managing disruptions in supply chains: A case study of a retail supply chain. *International Journal of Production Economics, 118*(1), 168-174.

Okpala, D. C., & Aniekwu, A. N. (1988). Cause of high cost of construction in Nigeria. *Journal of Construction Engineering and Management, 114*(2), 223-34.

Olhager, J. (2012). The Role of Decoupling Points in Value Chain Management. In: Jodlbauer H., Olhager J., Schonberger R. (eds) Modelling Value. *Contributions to Management Science. Physica-Verlag HD.*

Olson, D. L., & Wu, D. D. (2010). A review of enterprise risk management in supply chain. *39*(5), 694-706.

Omachonu, V. K., & Einspruch, N. G. (2010). Innovation in Healthcare Delivery Systems: A Conceptual Framework. *The Innovation Journal: The Public Sector Innovation Journal, 15 (1)*(2).

(n.d.). *Organization, World Health.* http://www.who.int/topics/health_systems/en/.

Oyewobi, L. O., Ibrahim, A. D., & Ganiyu, B. O. (2012). Evaluating the Impact of Risk on Contractor's Tender Figure in Public Buildings Projects in Northern Nigeria. Journal of Engineering. *Project & Production Management, 2*(1), 2-13.

Pagell, M. (2004). Understanding the factors that enable and inhibit the integration of operations, purchasing and logistics. *Journal of Operations Management, 22*, 459-487.

Pai, R. R., Kallepalli, V. R., Caudill, R. J., & MengChu, Z. (2003). Methods toward supply chain risk analysis. *IEEE International Conference.*

Pan, Z., & Pokharel, S. (2007). Logistics in hospitals: a case study of some singapore hospitals. *Leadership in health services*, *20*(3), 195-207.

Panthi, K., Ahmed, S. M., & Azhar, S. (2007). Risk Matrix as a Guide to Develop Risk Response Strategies. *43rd ASC National Annual Conference.* Flagstaff, Arizona.

Pathitrage, A. (2008). 14th ASIA CONSTUCT Conference Country Report – Sri Lanka . Institute For Construction Training And Development.

Patrick, X. W., Guomin, Z., & Jiayuan, W. (2007, August). Understanding the key risks in construction projects in China. *International Journal of Project Management*, *25*(6), 601–614.

Paulsson, U. L. (2007). *On managing disruption risks in the supply chain – the DRISC model.* Sweden: Department of Industrial Management and Logistics Engineering Logistics Lund University.

Pearson, C. M., & Clair, J. A. (1998). Reframing crisis management. *Academy of management review, 23*(1), 59-76.

Peck, H. (2005). Drivers of supply chain vulnerability, An integrated framework. *International Journal of Physical Distribution and Logistics Management, 35*(4), 210-232.

Peck, H. (2006). Reconciling supply chain vulnerability, risk and supply chain management. *International Journal of Logistics Research and Applications, 9*(2), 127-142.

Penfield, P. (2014). 8 transformative steps for supply chain sustainability. *Supply Chain Management Review, 18 i*(2).

Perera, B. A., Rathnayake, R. M., & Rameezdeen. (2008). Use of insurance in managing construction risks: Evaluation of Contractors' All Risks (CAR) insurance policy. *Built-Environment - Sri Lanka*, *8*(2).

Perera, S., Karunasena, G., & Kaushalya, S. (2003). Application of Value Management in Construction . *Built-Environment-Sri Lanka , 4*(1).

Perttula, P., Merjama, J., Kiurula, M., & Laitinen, H. (2003). Accidents in materials handling at construction sites. *Journal of Construction Management and Economics, 7*(4), 729-736.

Peter, W. G. (1994). *The management of projects.* (T. Telford, Ed.) London.

Peto, M. (n.d.). The Decision Maling systems Model for Logistics.

Pettit, T. J., Fiksel, J., & Croxton, K. L. (2010). Ensuring supply chain resilience: development of a conceptual framework. *Journal of Business Logistics, 31*(1), 1–21.

Pinna, R., Carrus, P., & Marras, F. (2015). The drug logistics process: an innovative experience. *TQM Journal, 27*, 214-230.

Porter, & Michael, E. (1985). *Competitive Strategy, Techniques for Analyzing Industries and Competitors.* New York: The Free Press.

Prajogo, D., Chowdhury, M., Yeung, A. C., & Cheng, T. C. (2012). The relationship between supplier management and firm's operational performance: A multi-dimensional perspective. *International Journal of Production Economics, 136*(1), 123-130.

Prakash, A. A., Manikanta, D. K., & Prabhu, S. M. (n.d.). Risk assessment of residential buildings in Indian construction industry by application of fuzzy.

Praveen, R., Niththiyananthan, T., Kanarajan, S., & Dissanayake, P. B. (2011). Understanding and Mitigating the Effects of Shortage of Skilled Labour in the Construction Industry of Sri Lanka. *Construction.*

Proverbs, D. G., Holt, G. D., & Olomolaiye, P. O. (1999). A method of estimating labour requirements and cost for international construction project at inception. *Building and Environment, 34*, 43-45.

Pyke, D., & Tang, C. S. (2010). How to mitigate product safety risks proactively- Process, challenges and opportunities. *International Journal of Logistics Research and Applications, 13*(4), 243-256.

Ratlif, H., & Nulty, W. (1996). Logistics Composite Modeling. In H. Ratlif, & W. Nulty, *Introduction to Logistics Modeling.*

Ravindran, A. R., Bilsel, R. U., Wadhwa, V., & Yang, T. (2010). Risk adjusted multicriteria supplier selection models with applications. *International Journal of Production Research, 48*(2), 405-424.

Redfem, S. J., & Norman, U. (1994). Validity through triangulation. *Nurse Researcher, 2*(2), 41-56.

Rice, J. B., & Hoppe, R. M. (2001). Supply Chain vs. Supply Chain, the hype and the reality. *Supply Chain Management Review, 5*(5).

Rice, J., & Caniato, F. (2003). Building a secure and resilient supply network. *Supply Chain Management Review, 7*(5), 22-30.

Risjord, M. W., Dunbar, S. B., & Motoney, M. F. (2002). A new foundation for methodological triangulation. *Journal of Nursing Scholarship, 23,* 269–272.

Risjord, M., Moloney, M., & Dunbar, S. (2001). Methodological triangulation in nursing research. *Philosophy of the Social Sciences, 30*(1), 40-59.

Risk Management/Analysis and calculation. (n.d.). *Risk Analysis*.

Ritchie, B., & Brindley, C. (2007). Supply chain risk management and performance: A guiding framework for future development. *International Journal of Operations and Production Management, 27*(3), 303-322.

Ritchie, J., & Spencer, L. (1993). *Qualitative data analysis for applied policy research' in Analysing Qualitative Data.* (A. Bryman, & R. Burgess, Eds.) London: Routledge.

Robbins, S., bergnman, R., Stagg, I., & Coulter, M. (2006). *Foundation of Management* (2nd ed.). NSW: Pearson.

Robert, A. N., Langley, C. J., & Rinehart, L. M. (1995). Creating Logistics Value. *Oak Brook, IL: Council of Logistics Management*. Retrieved from www.pmgbenchmarking.com

Ross, & David, F. (1998). *Competing Through Supply Chain Management.* New York: Chapman & Hall.

Roth, A. V., Tsay, A. A., Pullman, M. E., & Gray, J. V. (2008). Unraveling the food supply chain: Strategic insights from China and the 2007 recalls. *Journal of Supply Chain Management, 44*(1), 22-39.

Rowe, W. D. (1977). *An Anatomy of Risk: R.E. Krieger Publishing Company*.

Ruben, V., & Lauri, K. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management, 6*(3–4), 169–178.

Russell, D. M., & Saldanha, J. P. (2003). Five tenets of security-aware logistics and supply chain operation. *Transportation Journal*, 44-54.

Sangam, V. (2012, April 24). Supply Chain – In-sourcing vs. Outsourcing. *Supply Chain World,* 1-7.

Sarathy, R. (2006). Security and the global supply chain. *Transportation journal*, 28-51.

Sathyendrakajan, N., Karunasena, G., & Wedikkara, C. (2012). Exploring Capacity of Construction Industry Post Disaster Housing Reconstruction. *Built - Environment - Sri Lanka*, *11*(1), 2-6.

Saunders, M. (1994). *Strategic Purchasing and Supply Chain Management.* London: Pitman Publishing.

Sawik, T. (2013). Selection of resilient supply portfolio under disruption risks. *Omega, 41*(2), 259-269.

Sawik, T. (2014). Joint supplier selection and scheduling of customer orders under disruption risks, Single vs. dual sourcing. *Omega, 43*, 83-95.

Schlichter, J. (2001). PMI's organizational project management maturity model: emerging standards. *PMI '01 Annual Symposium.* Nashville.

Schmitt, A. j., & Singh, M. (2012). A quantitative analysis of disruption risk in a multi echelon supply chain. *Integrated journal of Production Economics, 139* (1), 22-32.

Schoenherr, T., & Tummala, R. (2011). Assessing and managing risks using the Supply Chain Risk Management Process (SCRMP). *Supply Chain Management: an International Journal, 16*(06), 474 – 483.

Schoenherr, T., Rao Tummala, V. M., & Harrison, T. (2008). Assessing supply chain risks with the analytic hierarchy process, Providing decision support for the offshoring decision by a US manufacturing company. *Journal of Purchasing and Supply Manageme, 14*(2), 100-111.

SCOR Model 12.0, Supply chain Operations Reference Model Version 12.0. (2017). APICS.

Serrou, D., Abouabdellah, A., & Mharzi, H. (2015). Proposed an Approach for Measuring the Performance of Hospital Logistics. *International Journal of Scientific Engineering and Technology, 4*(1), 24-27.

Seuring, S., & Müller, M. (2008). Core issues in sustainable supply chain management–a Delphi study. *Business strategy and the environment, 17*(8), 455-466.

Seuring, S., & Müller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of cleaner production, 16*(15), 1699-1710.

Shadish, W., Cook, T., & Cambell, D. (2002). *Experimental and Quasiexperimental Designs.* Boston: MA: Haoghton Mifflin Company.

Sharif, F., & Armitage, P. (2004). The effect of psychological and educational counselling in reducing anxiety' in nursing student. *Journal of Psychiatric and Mental Health Nursing, 11*(4), 386-392.

Sharifi, S., & Saberi, K. (2014). Capacity Planning in Hospital Management: An Overview. *Indian Journal of Fundamental and Applied Life Sciences, 4 (2)*, 515-521.

Sheffi, Y. (2005). Preparing for the big one. *Manufacturing Engineer, 84*(5), 12-15.

Sheffi, Y., & Rice, J. B. (2005). A supply chain view of the resilient enterprise. *MIT sloan management review*.

Shou, Q. W., Mohammed, F. D., & Muhammad, Y. A. (2004). Risk management framework for construction projects in developing countries. *Construction Management and Economics, 22*(3), 237-252.

Silvio, P. R., & A, C. H. (2001). Measuring Supply Chain Performance. *Proceedings of the 12th Annual Conference of the Production and Operations Management Society, POM-2001.* Orlando, Florida.

Simchi-Levi, D., Schmidt, W., & Wei, Y. (2014, January-February). David Simchi-Levi; William Schmidt; Yehua Wei;. *Harvard Business Review*.

Sinha, P. R., Whitman, L. E., & Malzahn, D. (2004). Methodology to mitigate supplier risk in an aerospace supply chain, Supply Chain Management. *An International Journal, 9*(2), 154-168.

Sisco, C., Chorn, B., & Michael, P. (2010). Supply Chain Sustainability: A practical Guide for Continuous improvement. UN Global Compact Office and Business for Social Responsibility.

Sitkin, S. B., & Pablo, A. L. (1992). Reconceptualizing the determinants of risk behaviour. *Academy of Management Review, 17*(1), 9-38.

Skipper, J. B., & Hanna, J. B. (2009). Minimizing supply chain disruption risk through enhanced flexibility. *International Journal of Physical Distribution & Logistics Management, 39*(5), 4004-4427.

Skitmore, M., & Smyth, H. (n.d.). Construction supply chain management concepts and case studies. *Marketing and pricing strategy*.

Slone, R., Dittmann, J. P., & Mentzer, J. T. (2010). *The New Supply Chain Agenda.* Boston, MA: Harvard Business Press.

Smith, D. (2005). Business (not) as usual: crisis management, service recovery and the vulnerability of organizations. *The Journal of Services Marketing, 19*(5), 309-320.

Smith, G. R., & Bohn, C. M. (1999). Small to medium contractor contingency and assumption of risk. *Journal of Construction Engineering & Management, 125*(2).

Sodhi, M. S., & Lee, S. (2007). An analysis of sources of risk in the consumer electronics industry. *Journal of the Operational Research Society, 58*(11), 1430-1439.

Sodhi, M. S., & Tang, C. S. (2010). Supply chain risk management. *Wiley encyclopedia of operations research and management science*.

Sodhi, M. S., & Tang, C. S. (2012). Managing supply chain risk.

Sohrabinejad, A., & Rahimi, M. (2015). Risk Determination, Prioritization, and Classifying in Construction Project Case Study: Gharb Tehran Commercial-Administrative Complex.

Song, J., Haas, C. T., & Caldas, C. H. (2006). Tracking the location of materials on construction job sites. *Journal of Construction Engineering and Management, 132*(9), 911-918.

Soonhong, M., Anthony, S. R., Patricia, J. D., Stefan, E. G., Haozhe, C., Aaron, D. A., & Glenn, R. R. (2005). Supply chain collaboration: what's happening? *The International Journal of Logistics Management, 16*(2), 237-256.

Soyiri, I., & Reidpath, D. (2013). An overview of health forecasting. *Environ Health Prev Med*, 1-9.

Spencer-Oatey, H. (2008). *Culturally Speaking: Culture, Communication and Politeness Theory* (2 ed.). Bloomsbury, London.

Spillane, J. P., Oyedele, L. O., Von Meding, J., Konanahalli, A., Jaiyeoba, B. E., & Tijani, I. K. (2011). Challenges of UK/Irish contractors regarding material management and logistics in confined site construction. *International Journal of Construction Supply Chain Management*, *1*(1), 25-42.

Spinler, S., & Huchzermeier, A., (2002). *An Options Approach to Enhance Economic Efficiency in a Dyadic Supply Chain.*

Stadtler, H. (2015). *Supply chain management: An overview. In Supply chain management and advanced planning.* Springer Berlin Heidelberg.

Stank, T. P., Dittmann, J. P., & Chad, W. A. (2011). The new supply chain agenda: a synopsis and directions for future research. *International Journal of Physical Distribution & Logistics Management*, *41*(10), 940-955.

Stanley, E., Fawcett, & Gregory, M. M. (2002). The rhetoric and reality of supply chain integration. *International Journal of Physical Distribution & Logistics Management, 32*(5), 339-361. Retrieved from https://doi.org/10.1108/09600030210436222

Stecke, K. E., & Kumar, S. (2009). Sources of supply chain disruptions, factors that breed vulnerability, and mitigating strategies. *SourcJournal of Marketing Channels, 16*(3), 193-226.

Stephan, V., & Robert, D. K. (2006). Extending green practices across the supply chain: The impact of upstream and downstream integration. *International Journal of Operations & Production Management*, *26*(7), 795-821. Retrieved from https://doi.org/10

Stephens, S. (2001). Supply chain operations reference model (ed. 5.0): a new tool to improve supply chain efficiency and achieve best practice. *Information Systems Frontiers, 2*(4), 471-476.

Stevens, & Graham, C. (1989). Integrating the Supply Chains. *International Journal of Physical Distribution and Materials Management*, *8*(8), 3-8.

Stewart, J., Lohoar, S., & Higgins, D. (2011). Effective practices for service delivery coordination in Indigenous communities.

Stock, J. R., & Boyer, S. L. (2009). Developing a consensus definition of supply chain management. *International Journal of Physical Distribution & Logistics Management, 39*(4), 690-711.

Stukhart, G. (1995). Construction Materials Management, Marcel Dekker.

Styger, L. E. (2011). A contextual position on current research into and application of the concept of supply. *Sydney Business School Review*, 13-22.

Sunil, C., & Sodhi, M. S. (2014). Reducing the risk of supply chain disruptions, MIT Sloan Management Review. *Magazine Spring*.

Survey on Bribery and Corruption-Impact on Economy and Business Environment. (2011). Retrieved from KPMG: http://www.kpmg.com/in

Svensson, G. (2000). A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution & Logistics Management, 30*(9), 731-750.

Sweis, G., Sweis, R., Abu Hammad, A., & Shboul, A. (2008). Delays in construction projects: The case of Jordan. *International Journal of Project Management, 26*(6), 665-674.

Tah, J. H., & Carr, V. (2000). A proposal for construction project risk assessment using fuzzy logic. 491-500.

Tah, J. H., & Carr, V. (2001). Towards a framework for project risk knowledge management in the construction supply chain. *Advances in Engineering Software, 32*(10-11), 835-846.

Tan, D. (2002). *Quantitative Risk Analysis Step-By-Step.* SANS Institute Reading Room.

Tan, W. J., & Enderwick, P. (2006). Managing threats in the Global Era: The impact and response to SARS. *Thunderbird International Business Review, 48*(4), 515-536.

Tang, C. (2006a). Robust strategies for mitigating supply chain disruptions. *International Journal of Logistics, Research and Applications, 9*(1), 33-45.

Tang, C. (2006b). Perspectives in supply chain risk management. *International Journal of Production Economics, 132*(2), 451–488.

Tang, C. S., & Tomlin, B. (2008). The power of flexibility for mitigating supply chain risks. *International Journal of Production Economics*, 12-27.

Taylor, & Bjornsson, H. (1999). Construction supply chain improvements through internet pooled procurement. *Proceedings of IGLC-7,* (pp. 207-217). Berkeley, CA.

Teddlie, C., & Johnson, R. B. (2009). Methodological thought since the 20th century. In *Foundations of mixed methods research: Integrating quantitative and qualitative techniques in the social and behavioral sciences.* Thousand Oaks, CA: Sage.

Teddlie, C., & Tashakkori, A. (2003). *Major Issues and Controversies in the Use of Mixed Methods in Social and Behavioral Science, Handbook of Mixed Methods in Social and Behavioral Science, Thousand Oaks.* Sage Publications.

Tennant, S., & Fernie, S. (2012). An emergent form of client-led supply chain governance in UK construction: Clans. . *International Journal of Construction Supply Chain Management*, 1-16.

Thompson, P., & Perry, J. (1992). *Engineering Construction Risks: A Guide to Project Risk Analysis and Risk Management.* Thomas Telford, London.

Thun, J., & Hoenig, D. (2009). An Empirical Analysis of Supply Chain Risk Management in the German Automotive Industry. *International Journal of Production Economics, 131*(1), 242-249.

Thunberg, M., & Persson, F. (2013). A logistics framework for improving construction supply chain performance In: Smith, S.D and Ahiaga-Dagbui, D.D (Eds). *Procs 29th Annual ARCOM Conference.* Reading, UK, Association of Researchers in Con.

Thurmond, V. A. (2001). The point of triangulation. *Journal of Nursing Scholarship, 33*(3), 253-258.

Tomlin, B. (2006). On the Value of Mitigation and Contingency Strategies for Managing Supply Chain Disruption Risks. *Management Science, 52*(5), 639-657.

Tommelein, I. D., & Li, A. E. (1999). *Just-in-time concrete delivery: locating buffers in structural steel supply and construction process.*

Towill, D. R. (1996). Time compression and supply chain management - a guided tour. *Supply Chain Management, 1*(1), 15 – 27.

Towner, M., & Baccarini, D. (2008). Risk Pricing in Construction Tenders - How, Who, What. *Australasian Journal of Construction Economics and Building, 8*(1), 1-11.

Tran, V., & Tookey, J. E. (2012). Directions for future construction supply chain management research in New Zealand: A real options perspective. *International Journal of Construction Supply Chain Management, 2*(1), 34-45.

Treleven, & Mark. (1987). Single Sourcing, A Management Tool for the Quality Supplier. *Journal of Purchasing and Materials Management, 23*, 19-24.

Tsai, M. C., Liao, C. H., & Han, C. S. (2008). Risk perception on logistics outsourcing of retail chains: model development and empirical verification in Taiwan. *Supply Chain Management, An International Journal, 13*(6), 415-424.

Tuncel, G., & Alpan, G. (2010). Risk assessment and management for supply chain networks- A case study. *Computers in Industry, 61*(3), 250-259.

Turner, J. R. (1993). *The handbook of project based management.* McGraw-Hill, London.

Tyndall, Gene, Christopher, G., Wolfgang, P., & John, K. (1998). *Supercharging Supply Chains, New Ways to Increase Value Through Global Operational Excellence.* NewYork: John Wiley & Sons.

Uta, J. (2005). Supply chain risk management, Understanding the business requirements from a practitioner perspective. *The International Journal of Logistics Management, 16*(1), 120 – 141.

Uta, J., Helen, P., & Martin, C. (2003). Supply chain risk management: outlining an agenda for future research pages 197-210. *International Journal of Logistics Research and Applications, A Leading Journal of Supply Chain Management, 6*(4).

Vactor, J. (2011). A case study of collaborative communications withinhealthcare logistics. *Leadership in health services*, *24*, 51–63.

VanderBok, R., Sauter, J. A., Bryan, C., & Horan, J. (2007). Manage your supply chain risk. *Manufacturing Engineering, 138*(3), 153-161.

Vecchi, A., & Vallisi, V. (2015). *Supply Chain Resilience, Handbook of Research on Global Supply Chain Management.*

Velleman, P. F., & Wilkinson, L. (1993). Nominal, Ordinal, Interval, and Ratio Typologies are Misleading. *Leland Wilkinson, SYSTAT, Inc*.

Vidalakis, C., Tookey, J. E., & Sommerville, J. (2011). The logistics of construction supply chains: The builders' merchant perspective. Engineering, Construction and Architectural Management. *18*(1), 66-81.

Vose, D. (2000). *Risk Analysis, A Quantitative Guide.* West Sussex, England: John Wiley and Sons Pvt Ltd.

Vrijhoef, R., & Koskela, L. (1999). 133-146.

Vrijhoef, R., & Koskela, L. (2000). The four roles of supply chain management in construction. *European Journal of Purchasing & Supply Management, 6*.

Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of Business Logistics, 29*(1), 307-325.

Wagner, S. M., & Neshat, N. (2009). Assessing the vulnerability of supply chains using graph theory. *International Journal Production Economics, 126*(1), 121-129.

Wai, S. H., Yusof, A. M., Ismail, S., & Ng, C. H. (2012). International Journal of Construction Project Success. *Reviewing the notion of construction project success, 7*(1), 90-101.

Wakolbinger, T., & Cruz, J. M. (2011). Supply chain disruption risk management through strategic information acquisition and sharing and risk-sharing contracts. *International Journal of Production Research, 49*(13), 4063–84.

Walker, D. H. (2000). Client/customer or stakeholder focus? ISO 14000 EMS as a construction industry case study. *The TQM Magazine, 12*(1).

Walters, D. (2002). *Operations Strategy.* Palgrave: McMillan.

Wang, B. T. (1992). Development of the Malaysian construction industry: Its concept, approach and strategy. *ASEAN International Symposium on Construction Development.*

Ward, S. C., & Chapman, C. B. (1997). *Project Risk Management: Processes, Techniques and Insights.* John Wiley and Sons.

Waters, D. (2007). *Supply chain risk management.* Kogan Page Limited.

Waters, D. (2011). *Supply chain risk management: vulnerability and resilience in logistics.* Kogan Page Publishers.

Wickramatillake, C., Koh, L., Gunasekaran, A., & Subramanium, A. (2007). Measuring performance within the supply chain of a large scale project. *International Journal of Supply Chain Management*, *12*(1), 52-59.

Wiendahl, H. P., Selaouti, A., & Nickel, R. (2008). Proactive supply chain management in the forging industry. *Production Engineering, 2*(4), 425-430.

Wijewardana, R. L., & Rupasinghe, T. (2013). Applicability of Lean healthcare in Sri Lankan Healthcare Supply Chains. *International Journal of Supply Chain Management, 2*(4), 42-49.

Wolstenholme, A. (2009). Never waste a good crisis: A review of progress since Rethinking Construction and thoughts for our future. *International journal of construction supply chain management*, *2*. doi:0.14424/ijcscm201012-01-16

Wong, A., & Fung, P. (1999). Total quality management in the construction industry in Hong Kong: A supply chain management perspective. *Total Quality Management*, *10*, 199-208.

Wong, J. T., & Hui, E. C. (2006). Construction project risks: further considerations for constructors' pricing in Hong Kong. *Construction Management & Economics, 24*(4), 425-438.

Wong, W. P., & Wong, K. Y. (2011). Supply chain management, knowledge management capability, and their linkages towards firm performance. *Business Process Management Journal, 17*(6), 940-964. Retrieved from https://doi.org/10.1108/14637151111182701

Woodward, D. G. (1995). Use of sensitivity analysis in build-own-operate-transfer project evaluation. *International Journal of Project Management, 13*(4), 239-246.

Wu, I.-L., & Chen, J.-L. (2014). Knowledge management driven firm performance: the roles of business process capabilities and organizational learning. *Journal of Knowledge Management, 18*(6), 1141-1164. Retrieved from https://doi.org/10.1108/JKM-05-20

Wu, T., & Blackhurst, J. (2005). A modeling methodology for supply chain synthesis and disruption analysis. *International Journal of Knowlege-based and Intelligent Engineering Systems 9*, 93-105.

Wu, T., Blackhurst, J., & Chidambaram, V. (2006). A model for inbound supply risk analysis. *Computers in Industry, 57*(4), 350-365.

Wynn, D., & Williams, C. K. (2012). Principles for Conducting Critical Realist Case Study Research in Information Systems. *MIS Quarterly*, *36*(3), 787-810.

Xiao, H., & Proverbs, D. (2003). Factors influencing contractor performance: an international investigation. *Engineering, Construction and Architectural Management, 10*(5), 322-332.

Xiao, H., & Proverbs, D. (n.d.). The performance of contractors in Japan, the UK and the USA: A comparative evaluation of construction cost., (pp. 425-435).

Xiao, T., & Yu, G. (2006). Supply Chain Disruption Management and Evolutionarily Stable Strategies of Retailers in the Quantity-setting Duopoly Situation with Homogeneous Goods. *European Journal of Operational Research, 173*(2), 648-668.

Xue, X., Wang, Y., Shen, Q., & Yu, X. (2007). *International Journal of Project Management, 25*(2).

Yang, B., & Yang, Y. (2010). Postponement in supply chain risk management: A complexity perspective. *International Journal of Production Research, 48*(7), 1901-1912.

Yang, C., & Su, Y.-f. (2009). The relationship between benefits of ERP systems implementation and its impacts on firm performance of SCM. *Journal of Enterprise Information Management, 22*(6), 722-752. Retrieved from https://doi.org/10.1108/174103909109996

Yang, R. J., Zou, P. X., & Jin, X. H. (2011). A Social Network Analysis Model for Analysing Stakeholder-associated Safety Risks in Infrastructure Projects.

Yang, Y. C. (2011). Risk management of Taiwan's maritime supply chain security. *Safety science, 49*(3), 382-393.

Yao, L. J., Kam, T. H., & Chan, S. H. (2007). Knowledge sharing in Asian public administration sector: the case of Hong Kong. *Journal of Enterprise Information Management, 20*(1), 51-69. Retrieved from https://doi.org/10.1108/17410390710717138

Yim, H. L., Lee, S. H., Yoo, S. K., & Kim, J. J. (2011). Zero-cost collar option applied to materials procurement contracts to reduce price fluctuation risks in construction. *World Academy of Science, Engineering and Technology*, 41-46.

Yin, R. K. (2003). *Case Study Research: Design and Methods, Thousand Oaks.* Sage Publications.

Yu, H., Zeng, A. Z., & Zhao, L. (2009). Single or dual sourcing: decision-making in the presence of supply chain disruption risks. *Omega, 37*(4), 788–800.

Zegordi, S. H., & Davarzani, H. (2012). Developing a supply chain disruption analysis model: Application of colored Petri-nets. *Expert Systems with Applications, 39*(2), 2102-2111.

Zhi, H. (1995). Risk management for overseas. *Project Management, 13*(4), 231-237.

Zinn, J. O. (2008). Heading into the unknown: Everyday strategies for managing risk and uncertainty. *Health, risk & society, 10*(5), 439-450.

Zokaei, K., & Hines, P. (2007). Achieving consumer focus in supply chains. *International Journal of Physical Distribution & Logistics Management, 37*(3), 223-247.

Zokaei, K., & Simons, D. W. (2006a). Value chain analysis in improvement of customer focus: a case study of UK red meat industry. *International Journal of Logistics Management, 17*(2).

Zou, P. X., & Couani, P. (2012). Architectural Engineering and Design Management. *Managing risks in green building supply chain*, *8*(2), 143-158.

Zou, P. X., Zhang, G., & Wang, J. (2007). Understanding the key risking costruction projectsin China. *25*(6), 601–614.

Zoysa, S. D., Wand, Y., & Russel, A. D. (2005). Use of IT in managing environmental risks in construction projects. *ASCE conference*.

Zsidisin, G. A., & Ritchie, R. (2010). *Supply chain risk: A handbook of assessment, management, and performance*. New York Springer Publishing.

Zsidisin, G. A., Ellram, L. M., Carter, J. R., & Cavinato, J. L. (2004). An analysis of supply risk assessment techniques. *International Journal of Physical Distribution and Logistics Management, 34*(5), 397- 413.

Zsidisin, G. A., Melnyk, S. A., & Ragatz, G. L. (2005). An institutional theory perspective of business continuity planning for purchasing and supply management. *International Journal of Production Research, 43*(16), 3401-3420.

APPENDICES

Appendix I – Extract from Data Set: Background Study

Summary of the data collected from the interviews: Answers in line with the questions put in the methodology.

Table 1: Extract from Data Set: Background Study

Stakeholder	Immediate risks indicated	Reasons after probing- Supply chain thinking
Client's Engineer	Risk of quality shortfall	Materials problems, poor supervision, poor construction planning, resource limitation, machinery and equipment limitations
	Risk of cost overruns	Price escalation of materials, unexpected site conditions, quality issues, poor planning, scope changes of the client, government regulations
	Risk of achieving the objectives of the construction	Contractor's problems, client's problems, regulatory issues, environmental issues, legal issues
	Risk of client's scope changes	Poor communication skills of the client, client is interested on new ideas, client's financial issues, government regulations, legal issues
	Risk of clients financial issues and cash flow problems	Investor problems, borrowing issues, personal problems
	Risk of losing the client for future projects	Problems of the client's engineer, misunderstandings
	Risk for the personal brand image	Poor performance of the client's engineer, client's issues, contractors' problems, materials suppliers' problems, misunderstandings
	Risk of not being paid	Client's bankruptcy, cash flow issues of the client, client's attitudes, poor performance of the client's engineer

Stakeholder	**Immediate risks indicated**	**Reasons after probing- Supply chain thinking**
	Risk of appointing a wrong contractor and consultant	Decision making mistake of client or consultant, not having sufficient information
Consultants	Risk of quality shortfall	Materials problems, poor supervision, poor construction planning, resource limitation, machinery and equipment limitations, rain, unskilled sub-contractors
	Risk of cost overruns	Price escalation of materials, unexpected site conditions, quality issues, poor planning, scope changes of the client, government regulations, poor planning of contractor, wastage, inefficient procurement
	Time overruns	Contractor's poor planning, contractor's resource limitations , approval delays, unexpected site conditions, quality issues, poor planning, scope changes of the client, government regulations, poor planning of contractor, wastage, inefficient procurement, rain and bad weather conditions, delays of payments from client, delays from consultants
	Risk of client's scope changes	Client change the mind, funding issues, poor communication of the client and client's engineer and consultants, government regulations, legal requirements
	Risk of losing the client for future projects	Client's misunderstandings, poor performance of the contractor, poor performance of the consultants
	Risk for the personal brand image	
	Risk of not being paid	Client's bankruptcy, cash flow issues of the client, client's attitudes, poor performance of the client's engineer
	Risk of appointing a wrong contractor	Client's decision making problem

Stakeholder	Immediate risks indicated	Reasons after probing- Supply chain thinking
Contractors	Cost overruns	Price escalation of materials, unexpected site conditions, quality issues, poor planning, scope changes of the client, government regulations, poor planning of contractor, wastage, inefficient procurement, consultants mistakes and delays
	Time overruns	Consultant's mistakes and delays, approval delays, unexpected site conditions, quality issues, poor planning, scope changes of the client, government regulations, poor planning of contractor, wastage, inefficient procurement, rain and bad weather conditions, delays of payments from client
	Rain	Poor planning, poor forecasting
	Drought	Poor planning, poor forecasting
	Late submission of designs	Consultant's inefficiencies, consultant's resource limitations, consultant's poor planning, consultant's poor attitudes, poor communication from client, frequent scope changes from client
	Design and estimate accuracy problems	Consultant's inefficiencies, consultant's resource limitations, consultant's poor planning, consultant's poor attitudes, poor communication from client, frequent scope changes from client, negligence
	Risk of not being paid	Client's bankruptcy, cash flow issues of the client, client's attitudes, poor performance of the contractor, approval problems
	Risk of appointing a wrong consultant	Client's decision making problem
	Materials quality problems	Problems in the manufacturing and processing, poor awareness about how to use the product by the contractor, problems in the machineries, problems in transport and storage, quality problems in the raw materials

Stakeholder	Immediate risks indicated	Reasons after probing- Supply chain thinking
	Labour problem	Less motivation towards construction industry, regulations, seasonal issues, better industries, high salaried opportunities in other countries
	Sand, gravel, ABC, problems	Regulatory initiatives, natural resource limitations
	Machine breakdowns	Poor planning of the contractor, resource limitations,
	Unforeseen site conditions	Poor site investigations,
Materials Suppliers	Competitor actions	Relationship issues with consultant's, client's and contractors, high price, low quality products, poor service, poor communication, poor planning, poor business development and marketing, underperforming sales team, supply inconsistency, complaints from construction sites,
	Order cancellations	Poor planning of the contractor, poor follow up from the materials supplier, mistakes of the designs and estimates done by consultants, climatic related reasons and natural disasters, cash flow problems of the contractor, fund supply issues of the client, consultant rejecting materials, complaints from the construction sites, shortage of other materials, transport problems, high price
	Contractor's issues	Planning issues, attitude issues, decision making issues, communication issues, financial issues, transport issues, relationship with competitors, sub-contractor issues, contractor's issues with consultant, contractor's internal problems
	Rain, drought, flood	Forecasting issues of the materials supplier,
	Consultant rejecting materials	Product quality problems, compliance issues, poor relationship with the consultant, competitor actions, complaints from the construction site

Stakeholder	Immediate risks indicated	Reasons after probing- Supply chain thinking
	Compliance issues	Materials supplier's planning and decision making, communication issues, Material's suppliers ignorance
	Not being paid	Contractor's cash flow issues, contractor bankruptcy, cash flow issues of the client, contractor’s attitudes, problems in the supplied materials
	Inability to supply on time	Manufacturing and processing problems, logistics and transport problems, port issues, strikes, regulatory problems,
	Quality issues	Problems in the manufacturing and processing, poor awareness about how to use the product by the contractor, problems in the machineries, problems in transport and storage, quality problems in the raw materials
	Government regulations	Policy changes, political decisions, environmental concerns, health and safety issues, legal requirements, social requirements, demands from general public

Appendix II – Extract from Data Set 01 (Sample Data Set)

1. Data set collected from Respondent One.

Table 2: Data Set 01 - Sample Data Set

Response	Risk Factor	Probability	Impact
R1	No proper construction plan for contractor	5	5
	Relocation of villagers to a new location	1	5
	Language problem as contractor is Chinese	5	1
	Delay in construction drawings submission	4	4
	Concrete cracks due to no proper thermal insulation	4	5
	Lack of dam filling materials	4	5
	Unforeseeable cast cavities while excavating	5	3

	River should be diverted before predicted date for flood	2	4
	Weather condition(unexpected)	2	3

2. Sample Data Sheet – Data Set 1

R1

T.W.A.S.L. Jayasinghe
158964R
CECB
Planning Engineer.
8 years of exper[ience]
0777116627.

Risk Register – Govt. Project

Risk Factor	Probability	Impact	Risk
1. ~~River diversion & No~~ No proper construction Program for Contractor.	5	5	25
2. Unforseeable Karst cavities while excavating	5	3	15
3. Delay in invoice settlement. monthly.	4	4	16
4. Lack of Dam filling material.	4	5	20
5. No proper occupancy of Borrow areas from Villagers.	5	4	20
6. River should be diverted before ~~the~~ Oct 2016. predicted flood.	2	4	8
7. Relocation of villages to a new location	1	5	5
8. Concrete Cracks due to no proper thermal insulation.	4	5	20
9. Language problem as Contractor is Chinese	5	1	5
10. Lack of officials to work in rural area	4	3	12
11. Congested program	5	5	25
12. Lack of Resources	5	4	20
13. Delay of Construction drawings Submission	4	4	16
14. Lack of geotechnical investigation	5	3	15
15. Weather condition (unexpected)	2	3	6

Prob.	
Weekly	5
Monthly	4
3 M	3
Yearly	2
Other	1

Impact	
Very. high	5
high	4
Reasonable	3
low	2
very low	1

Figure 1: Sample Data Sheet – Data Set 1

Appendix III - Calculating the Frequency of Common Risk Topics

Table 3: Quoted Risk Factor as Against the Frequency of Quoting

Risk	Number of Respondents
Security issues	11
Geological issues	3
Political risks	13
Policy changes	5
general public intervention	11
Construction quality issues	24
Strikes	3
Safety issues	22
Resignation of engineers/PMs	8
Approval delays	8
Transport Problems	4
Drought	3
Language problems	2
Poor construction program	13
Change of Project manager/engineer	3
Drawing delays	38
Poor performance of the sub-contractors	7
Utility delay	9
Contractual disputes	2
Lack of money	28
Poor labour performance	4
Approval delays from contractor	2
Unsuitable contractor	2
Unsuitable PM/Engineer	3
Conflict between consultant and contractor	1
Conflict between engineer and architect	1
Stakeholder satisfaction issues	3
Delayed payments from clients	6
Conflict at sites	3
Staff management problems	2
Sand problem	14
Lack of Soil/gravel/sub base/ABC	10
Lack of officers for rural areas	1
Shortage of machines/equipment	23
Resource limitations	1

Risk	Number of Respondents
Shortage of materials	23
Shortage of labour	23
Quality of materials	14
Shortage of staff	10
Price fluctuations of materials	3
On time delivery issue	2
Rain	31

Appendix IV - Data Set 02: List of Names of the Reviewed Construction Projects

1) Sri Lanka Navy - Accommodation Building
2) Rehabilitation/Improvement of 10.275km Length of Jaffna-Pannai-Kayts Road
3) Piling Works for Proposed Divisional Secretariat Complex at Wattala
4) Proposed Innovation/Incubation Center (TIC) at Pitipana, Homagama
5) Amari Havooda/Project
6) Colombo Port Expansion Project - Harbour Infrastructure Works
7) Construction of Pavilion at Henry Pedris Ground, Colombo 05
8) Weras Ganga Basin Storm Water Drainage and Environment Improvement Project
9) Piling Project - Defense Head Quarters Complex - Akuregoda
10) Weras Ganga Storm Water Grainage and Environmental Improvement Project
11) Horana – Mathugama (B157) Improvement Project
12) Proposed Extension to Dye House and Finishing Buildings at Abc Exprots(Pvt)Ltd. Horana
13) Improvements to Naula-Elahera-Laggala-Pallegama Road
14) Upcountry Mini Hydropower Project
15) Construction of Pre-Fabricated Dormitory for Workers of Lak-Vijaya Power Station - Stage 02
16) Improvement to Puliyadiirakkamam - Madhu Road
17) Rehabilitation and Improvement of Damana, Ambalanoya, Pannalgama Road
18) Contruction of Eight Stored Epilepsy Unit, Ai National Hospital, Colombo

19) Construction of Pre-Fabricated Dormitory for Staff Water Supply and Drainage Board
20) Mehewara Piyasa Project
21) Construction of Zonal Information and Communication Technology Center
22) Re-Construction of Northern Railway Line from Omantha to Pallai
23) Proposed Ministry of Interior Headquarters
24) Reconstruction of Vocational Training Center at Karainagar in Jaffna District
25) Bridge across Gin Ganga on Hammaliya - Agaliya - Mulkada Road
26) Rehabilitation and Upgraging of Puttalam - Trincomalee Road
27) Construction of Laboratory Building for the Trincomalee Campus of the Eastern University
28) Housing Scheme at Loundry Watta, Paradise Place
29) Proposed Landscape Improvement for Viharamahadevi Park

Appendix V - Data Set 02

Sample Data collected from a respondent on a finished project.

Table 4: Sample Data Set - Data set 02

Item	Estimated Cost as per Contract	Actual Cost	Estimated Duration (Days)	Actual Duration (Days)	Reason for the Difference
Preliminaries	2,500,000.00	2,028,000.00	365	365	
Excavation and earthwork	503,085.00	1,884,999.00	22	84	Additional scope such as demolition and changes in the quantities
Concrete work	2,570,413.38	2,722,992.40	43	54	Additional work
Masonry work	417,036.10	331,992.60	36	47	
Asphalt work	32,527.00	0.00	31		
Concrete work	7,053,605.00	9,322,938.72	91	120	Additional work
Masonry work	2,520,163.35	1,927,441.86	104	133	

Item	Estimated Cost as per Contract	Actual Cost	Estimated Duration (Days)	Actual Duration (Days)	Reason for the Difference
Carpentry and joinery work	10,224,130.00	13,040,830.72	43	72	Scope changes and additional quantities
Metal work	0.00	925,559.10	31	31	Additional works
Floor, wall, ceiling finishes	8,275,941.45	20,662,943.02	78	126	Scope revised
Water proofing	764,295.00	1,138,455.93	74	103	Specification changes
Painting and decorating	1,469,440.00	677,208.00	134	168	
Electrical installation	668,550.00	1,853,970.25	230	294	Scope changes and additional quantities
Plumping installation	0.00	2,891,367.64		294	New scope added
Total	**36,999,186.28**	**59,408,699.24**			

Appendix VI - Data Set 03

Table 5: Data Set 03 – Perceived Data on RRD Diagram

Response	Construction Industry Specified Risks	Stakeholder Generated Risks	Materials Supply Related Risks	Sand Problem	Regulations	Seasonal Trends	Risk on labour supply	Contractor generated Risks	Client generated Risks	Consultant generated Risks	Price Risks	Quality Risks	Availability Risks	On-time delivery Risks	Decision Making Risks	Communication Risks	Sub-contractor Risks	Financial Risks	Planning Risks	Risk on communicating the scope of the work	Risk on supply of funding	Risk on submitting accurate design and estimate
R1	0.20	0.40	0.40	0.30	0.20	0.20	0.30	0.40	0.20	0.40	0.20	0.30	0.20	0.30	0.20	0.30	0.15	0.15	0.20	0.30	0.70	1.00
R2	0.30	0.40	0.30	0.20	0.20	0.25	0.35	0.60	0.20	0.20	0.30	0.25	0.15	0.30	0.15	0.15	0.25	0.30	0.15	0.40	0.60	1.00
R3	0.30	0.40	0.30	0.25	0.15	0.25	0.25	0.40	0.30	0.30	0.20	0.30	0.30	0.20	0.20	0.25	0.15	0.15	0.25	0.60	0.40	1.00
R4	0.25	0.20	0.55	0.20	0.20	0.25	0.35	0.40	0.20	0.40	0.25	0.35	0.15	0.25	0.20	0.30	0.15	0.20	0.15	0.50	0.50	1.00
R5	0.25	0.45	0.30	0.20	0.15	0.25	0.40	0.40	0.30	0.30	0.20	0.35	0.20	0.25	0.20	0.30	0.10	0.20	0.20	0.60	0.40	1.00
R6	0.40	0.30	0.30	0.20	0.15	0.25	0.40	0.40	0.20	0.40	0.20	0.25	0.25	0.30	0.15	0.20	0.25	0.20	0.20	0.60	0.40	1.00
R7	0.20	0.50	0.30	0.25	0.25	0.25	0.25	0.35	0.30	0.35	0.30	0.20	0.30	0.20	0.10	0.10	0.10	0.40	0.20	0.60	0.40	1.00
R8	0.20	0.40	0.40	0.25	0.25	0.25	0.25	0.40	0.30	0.30	0.20	0.30	0.25	0.25	0.15	0.30	0.15	0.20	0.30	0.70	0.30	1.00
R9	0.20	0.50	0.30	0.20	0.15	0.25	0.40	0.35	0.30	0.35	0.30	0.30	0.20	0.20	0.10	0.15	0.25	0.25	0.25	0.40	0.60	1.00
R10	0.50	0.30	0.20	0.20	0.20	0.25	0.35	0.35	0.30	0.35	0.30	0.40	0.10	0.20	0.20	0.20	0.10	0.30	0.20	0.40	0.60	1.00
R11	0.20	0.50	0.30	0.20	0.20	0.25	0.35	0.60	0.20	0.20	0.20	0.30	0.40	0.10	0.20	0.15	0.15	0.20	0.30	0.40	0.60	1.00
R12	0.30	0.40	0.30	0.20	0.10	0.20	0.50	0.20	0.25	0.55	0.40	0.15	0.15	0.40	0.10	0.20	0.40	0.10	0.20	0.40	0.60	1.00
R13	0.20	0.60	0.20	0.15	0.10	0.15	0.60	0.40	0.20	0.40	0.20	0.20	0.20	0.40	0.20	0.25	0.15	0.15	0.25	0.60	0.40	1.00

R14	0.20	0.45	0.35	0.25	0.25	0.25	0.25	0.40	0.30	0.30	0.30	0.30	0.20	0.20	0.25	0.30	0.10	0.15	0.20	0.60	0.40	1.00
R15	0.25	0.40	0.35	0.20	0.15	0.25	0.40	0.44	0.22	0.34	0.20	0.20	0.35	0.25	0.18	0.22	0.15	0.22	0.23	0.35	0.65	1.00
R16	0.25	0.40	0.35	0.20	0.10	0.20	0.50	0.60	0.20	0.20	0.20	0.20	0.30	0.30	0.30	0.30	0.20	0.05	0.15	0.60	0.40	1.00
R17	0.30	0.50	0.20	0.20	0.20	0.25	0.35	0.40	0.30	0.30	0.20	0.30	0.30	0.20	0.20	0.25	0.15	0.10	0.30	0.60	0.40	1.00
R18	0.30	0.40	0.30	0.20	0.20	0.20	0.40	0.40	0.20	0.40	0.25	0.25	0.20	0.30	0.10	0.30	0.10	0.30	0.20	0.40	0.60	1.00
R19	0.20	0.50	0.30	0.20	0.15	0.25	0.40	0.40	0.30	0.30	0.20	0.30	0.20	0.30	0.15	0.30	0.15	0.20	0.20	0.70	0.30	1.00
R20	0.25	0.35	0.40	0.20	0.10	0.20	0.50	0.60	0.20	0.20	0.25	0.30	0.15	0.30	0.20	0.20	0.15	0.30	0.15	0.60	0.40	1.00
R21	0.30	0.40	0.30	0.25	0.15	0.15	0.45	0.40	0.20	0.40	0.25	0.25	0.25	0.25	0.20	0.20	0.10	0.20	0.30	0.70	0.30	1.00
R22	0.35	0.35	0.30	0.15	0.10	0.15	0.60	0.40	0.20	0.40	0.20	0.30	0.25	0.25	0.15	0.20	0.15	0.25	0.25	0.70	0.30	1.00
R23	0.20	0.30	0.50	0.20	0.20	0.20	0.40	0.30	0.40	0.30	0.40	0.20	0.20	0.20	0.15	0.40	0.20	0.10	0.15	0.60	0.40	1.00
R24	0.20	0.50	0.30	0.25	0.25	0.25	0.25	0.20	0.25	0.55	0.30	0.30	0.30	0.10	0.20	0.30	0.10	0.20	0.20	0.60	0.40	1.00
R25	0.20	0.30	0.50	0.25	0.15	0.15	0.45	0.60	0.20	0.20	0.30	0.30	0.20	0.20	0.20	0.20	0.05	0.05	0.30	0.75	0.25	1.00
R26	0.30	0.50	0.20	0.25	0.25	0.25	0.25	0.40	0.30	0.30	0.30	0.30	0.20	0.20	0.20	0.30	0.10	0.10	0.30	0.70	0.30	1.00
R27	0.20	0.50	0.30	0.25	0.15	0.15	0.45	0.60	0.20	0.20	0.20	0.50	0.15	0.15	0.20	0.40	0.20	0.10	0.10	0.30	0.70	1.00
R28	0.25	0.45	0.30	0.16	0.12	0.32	0.40	0.44	0.22	0.34	0.20	0.27	0.20	0.33	0.20	0.13	0.23	0.18	0.22	0.45	0.55	1.00
R29	0.30	0.40	0.30	0.20	0.15	0.25	0.40	0.60	0.20	0.20	0.20	0.30	0.30	0.20	0.10	0.15	0.25	0.25	0.25	0.60	0.40	1.00
R30	0.30	0.40	0.30	0.20	0.10	0.20	0.50	0.40	0.20	0.40	0.20	0.30	0.20	0.30	0.20	0.30	0.15	0.15	0.20	0.60	0.40	1.00
R31	0.50	0.30	0.20	0.25	0.25	0.25	0.25	0.40	0.30	0.30	0.30	0.25	0.15	0.30	0.20	0.30	0.15	0.15	0.20	0.40	0.60	1.00
R32	0.40	0.30	0.30	0.16	0.12	0.32	0.40	0.40	0.20	0.40	0.20	0.35	0.20	0.25	0.15	0.30	0.15	0.20	0.30	0.40	0.60	1.00
R33	0.30	0.40	0.30	0.15	0.10	0.15	0.60	0.40	0.20	0.40	0.20	0.30	0.30	0.20	0.20	0.30	0.15	0.20	0.15	0.70	0.30	1.00
R34	0.20	0.40	0.40	0.20	0.15	0.25	0.40	0.40	0.20	0.40	0.20	0.30	0.20	0.30	0.10	0.15	0.25	0.25	0.25	0.70	0.30	1.00
R35	0.40	0.30	0.30	0.20	0.10	0.20	0.50	0.40	0.30	0.30	0.30	0.25	0.15	0.30	0.20	0.25	0.15	0.15	0.25	0.40	0.60	1.00
R36	0.30	0.40	0.30	0.25	0.15	0.15	0.45	0.60	0.20	0.20	0.25	0.35	0.15	0.25	0.20	0.30	0.15	0.15	0.20	0.60	0.40	1.00

R37	0.50	0.30	0.20	0.25	0.25	0.25	0.25	0.60	0.20	0.20	0.30	0.20	0.30	0.20	0.20	0.30	0.15	0.20	0.15	0.60	0.40	1.00
R38	0.40	0.30	0.30	0.20	0.20	0.20	0.40	0.40	0.20	0.40	0.20	0.30	0.30	0.20	0.15	0.30	0.15	0.20	0.30	0.35	0.65	1.00
R39	0.20	0.40	0.40	0.20	0.20	0.20	0.40	0.40	0.30	0.30	0.20	0.30	0.30	0.20	0.20	0.30	0.15	0.15	0.20	0.50	0.50	1.00
R40	0.30	0.40	0.30	0.15	0.10	0.15	0.60	0.40	0.20	0.40	0.30	0.40	0.10	0.20	0.20	0.25	0.15	0.15	0.25	0.40	0.60	1.00
R41	0.30	0.40	0.30	0.20	0.10	0.20	0.50	0.40	0.20	0.40	0.25	0.35	0.15	0.25	0.10	0.15	0.25	0.25	0.25	0.70	0.30	1.00
R42	0.40	0.30	0.30	0.20	0.15	0.25	0.40	0.35	0.30	0.35	0.40	0.15	0.15	0.40	0.20	0.30	0.15	0.15	0.20	0.60	0.40	1.00
R43	0.50	0.30	0.20	0.25	0.25	0.25	0.25	0.20	0.25	0.55	0.20	0.30	0.20	0.30	0.20	0.30	0.15	0.15	0.20	0.60	0.40	1.00
R44	0.25	0.45	0.30	0.25	0.15	0.15	0.45	0.60	0.20	0.20	0.30	0.25	0.15	0.30	0.15	0.30	0.15	0.20	0.30	0.30	0.70	1.00
R45	0.30	0.40	0.30	0.25	0.15	0.15	0.45	0.40	0.20	0.40	0.20	0.35	0.20	0.25	0.20	0.30	0.15	0.15	0.20	0.50	0.50	1.00
R46	0.30	0.50	0.20	0.20	0.10	0.20	0.50	0.40	0.30	0.30	0.30	0.20	0.30	0.20	0.20	0.25	0.15	0.15	0.25	0.50	0.50	1.00
R47	0.25	0.45	0.30	0.18	0.14	0.32	0.40	0.44	0.22	0.34	0.20	0.30	0.30	0.20	0.10	0.15	0.25	0.25	0.25	0.70	0.30	1.00
R48	0.30	0.40	0.30	0.25	0.25	0.25	0.25	0.60	0.20	0.20	0.25	0.35	0.15	0.25	0.10	0.15	0.25	0.25	0.25	0.70	0.30	1.00
R49	0.30	0.50	0.20	0.20	0.20	0.20	0.40	0.40	0.20	0.40	0.30	0.40	0.10	0.20	0.20	0.30	0.15	0.20	0.15	0.40	0.60	1.00
R50	0.40	0.30	0.30	0.20	0.20	0.20	0.40	0.60	0.20	0.20	0.20	0.30	0.20	0.30	0.15	0.30	0.15	0.20	0.30	0.40	0.60	1.00
R51	0.20	0.40	0.40	0.20	0.15	0.25	0.40	0.40	0.20	0.40	0.30	0.25	0.15	0.30	0.20	0.30	0.15	0.15	0.20	0.50	0.50	1.00
R52	0.40	0.30	0.30	0.20	0.10	0.20	0.50	0.40	0.30	0.30	0.40	0.15	0.15	0.40	0.20	0.30	0.15	0.15	0.20	0.50	0.50	1.00
R53	0.30	0.40	0.30	0.25	0.25	0.25	0.25	0.35	0.30	0.35	0.20	0.35	0.20	0.25	0.20	0.20	0.10	0.30	0.20	0.70	0.30	1.00
R54	0.30	0.40	0.30	0.25	0.25	0.25	0.25	0.60	0.20	0.20	0.20	0.30	0.30	0.20	0.20	0.20	0.10	0.30	0.20	0.60	0.40	1.00
R55	0.25	0.45	0.30	0.25	0.25	0.25	0.25	0.40	0.20	0.40	0.25	0.35	0.15	0.25	0.20	0.25	0.15	0.15	0.25	0.60	0.40	1.00

Sample Data Sheet - Data Set 03

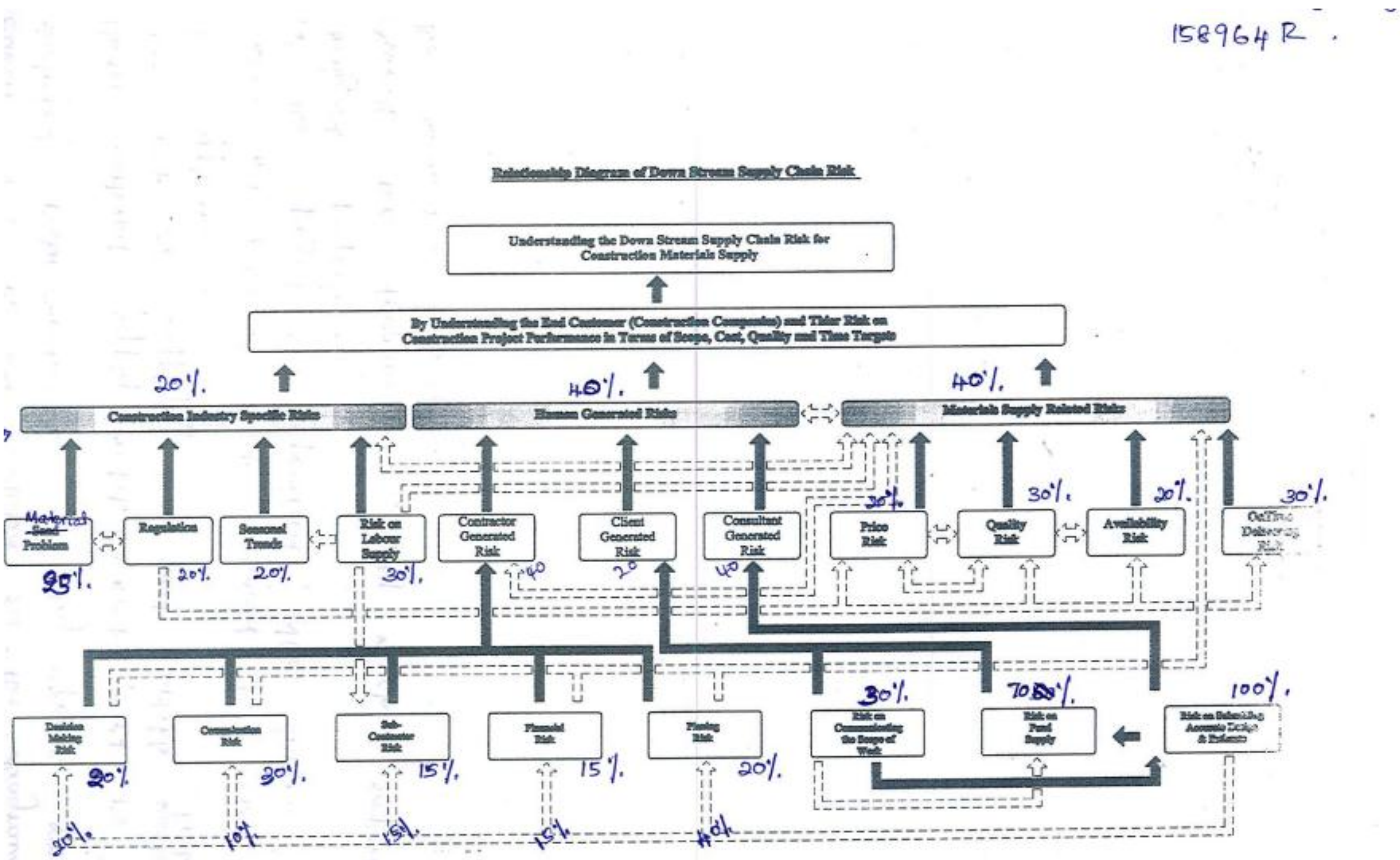


Figure 2: Sample Data Sheet - Data Set 03

Appendix VII - Data Set 03: Descriptive Analysis

Table 6: Descriptive Analysis of the Data Set 03

Variable	Count	Mean	SE Mean	St Dev	Variance	Median	Range
Construction Industry Specified Risks Y1	55	0.2927	0.0116	0.0863	0.0074	0.3000	0.3000
Stakeholder Generated Risks Y2	55	0.3982	0.0105	0.0782	0.0061	0.4000	0.4000
Materials Supply Related Risks Y3	55	0.3091	0.0099	0.0739	0.0054	0.3000	0.3500
Sand Problem Y4	55	0.2136	0.0045	0.0335	0.0011	0.2000	0.1500
Regulation Risks Y5	55	0.1705	0.0073	0.0542	0.0029	0.1500	0.1500
Seasonal Trends Y6	55	0.2220	0.0060	0.0449	0.0020	0.2500	0.1700
Risk on Labour Supply Y7	55	0.3927	0.0138	0.1025	0.0105	0.4000	0.3500
Contractor Generated Risks Y8	55	0.4322	0.0143	0.1063	0.0113	0.4000	0.4000
Client Generated Risks Y9	55	0.2384	0.0068	0.0505	0.0025	0.2000	0.2000
Consultant Generated Risks Y10	55	0.3295	0.0125	0.0930	0.0086	0.3400	0.3500
Price Risks Y11	55	0.2509	0.0081	0.0604	0.0036	0.2500	0.2000
Quality Risks Y12	55	0.2885	0.0090	0.0671	0.0045	0.3000	0.3500
Availability Risks Y13	55	0.2146	0.0093	0.0691	0.0048	0.2000	0.3000
On-time Delivery Risks Y14	55	0.2515	0.0089	0.0661	0.0044	0.2500	0.3000
Decision Making Risks Y15	55	0.1773	0.0057	0.0428	0.0018	0.2000	0.2000

Variable	Count	Mean	SE Mean	St Dev	Variance	Median	Range
Communication Risks Y16	55	0.2509	0.0091	0.0676	0.0045	0.3000	0.3000
Sub-contractor Risks Y17	55	0.1627	0.0079	0.0587	0.0034	0.1500	0.3500
Financial Risks Y18	55	0.1909	0.0091	0.0681	0.0046	0.2000	0.3500
Planning Risks Y19	55	0.2218	0.0068	0.0507	0.0026	0.2000	0.2000
Risk on Communicating the Scope of the Work Y20	55	0.5391	0.0174	0.1293	0.0167	0.6000	0.4500
Risk on supply of funding Y21	55	0.4609	0.0174	0.1293	0.0167	0.4000	0.4500
Risk on Submitting Accurate Design and Estimate Y22	55	1.0000	0.0000	0.0000	0.0000	1.0000	0.0000

Table 7: Mode, Skewness and Kutosis – Data Set 03

Variable	Mode	Skewness	Kurtosis
Construction Industry Specified Risks Y1	0.30	0.95	0.36
Stakeholder Generated Risks Y2	0.40	-0.03	-0.10
Materials Supply Related Risks Y3	0.30	0.99	2.16
Sand Problem Y4	0.20	0.06	-0.35
Regulation Risks Y5	0.15	0.20	-1.25
Seasonal Trends Y6	0.25	-0.10	-0.31
Risk on Labour Supply Y7	0.40	0.14	-0.55
Contractor Generated Risks Y8	0.40	0.28	0.00
Client Generated Risks Y9	0.20	0.96	-0.01
Consultant Generated Risks Y10	0.40	0.24	-0.07
Price Risks Y11	0.20	1.01	0.31
Quality Risks Y12	0.30	0.15	1.04

Variable	Mode	Skewness	Kurtosis
Availability Risks Y13	0.20	0.50	-0.46
On-time Delivery Risks Y14	0.20	0.31	0.46
Decision Making Risks Y15	0.20	-0.42	0.45
Communication Risks Y16	0.30	-0.27	-0.55
Sub-contractor Risks Y17	0.15	1.48	3.82
Financial Risks Y18	0.15, 0.2	0.48	0.70
Planning Risks Y19	0.20	0.01	-0.60
Risk on Communicating the Scope of the Work Y20	0.60	-0.27	-1.19
Risk on supply of funding Y21	0.40	0.27	-1.19
Risk on Submitting Accurate Design and Estimate Y22	1.00	*	*

Appendix VIII- Data Set 02: Identify Root causes

Table 8: Data Set 02 – Identify Root Causes

Project Number	Item	Estimated Cost as per contract	Actual Cost	Estimated Duration (Days)	Actual Duration (Days)	Reason for the difference	Tier 1	Tier 2
01	Open turf	850,000.00	850,000.00	32	43	Man power and machinery problems	Contractor generated planning, decision making, communication, financial and sub-contractor risks	Contractor generated risks and construction industry specified risk on labour supply
	Soft landscaping	16,165,071.30	13,313,013.00	93	91	Labour and machinery problems	Contractor generated planning, decision making, communication, financial and sub-contractor risks	Contractor generated risks and construction industry specified risk on labour supply
	Grassing, guard stones and rip rap protection	2,193,000.00	2,317,000.00	30	46	Equipment and skilled labour shortage	Contractor generated planning, decision making, communication, financial and sub-contractor risks	Contractor generated risks and construction industry specified risk on labour supply

	Form work	3,250,000.00	3,180,469.00	14	21	Lack of skilled labours	Contractor generated planning, decision making, communication, financial and sub-contractor risks	Contractor generated risks and construction industry specified risk on labour supply
	Excavation and shoring work	1,815,000.00	1,236,000.00	1	3	**Cost-**Due to a design change excavation depth and shoring area reduces Time-Unforeseen sewer line diversion had to be done during excavation work as an additional work, Additional work approval got delayed, Due to bad weather condition shoring and excavation got delayed, Taking electrical power supply got delayed due to client's fault	Client and Consultant generated Risk on submitting accurate design and estimate	Client and Consultant generated Risks, Construction Industry Specified Regulations and Seasonal Trends
	Concrete woks	2,171,730.00	2,160,335.25	3	4	**Cost**-Due to design change sump dimensions varied **Time**-Re-designing the structural work and approvals took some time	Client and consultant generated Risk on communicating the scope of the work	Client and Consultant generated Risks

Appendix IX - Data Set 02: Sample Calculations

Table 9: Data Set 03 – Sample Calculations

Project Number	Item	Estimated Cost as per contract	Actual Cost	Risk Impact	Risk Impact - Cost	Risk Impact - Time
1	Open turf	850,000.00	850,000.00	0.00	0.00	-0.34
1	Soft landscaping	16,165,071.30	13,313,013.00	2,852,058.30	0.18	0.02
1	Grassing, guard stones and rip rap protection	2,193,000.00	2,317,000.00	-124,000.00	-0.06	-0.53
1	Form work	3,250,000.00	3,180,469.00	69,531.00	0.02	-0.50
2	Excavation and shoring work	1,815,000.00	1,236,000.00	579,000.00	0.32	-2.00
2	Concrete woks	2,171,730.00	2,160,335.25	11,394.75	0.01	-0.33
2	Formwork	881,745.00	896,444.55	-14,699.55	-0.02	-0.33
2	Reinforcement work	3,304,800.00	2,261,798.40	1,043,001.60	0.32	-0.33
2	Brick work	138,168.00	123,890.64	14,277.36	0.10	0.00
2	Waterproofing work	1,281,200.00	1,706,257.50	-425,057.50	-0.33	-0.50
2	Floor and Wall finishes	553,455.00	868,979.25	-315,524.25	-0.57	-0.50
2	Plumbing work	3,600,480.00	2,174,070.10	1,426,409.90	0.40	-1.00

Appendix X - Comments about Risk Relationship Diagram (RRD): Data Set 01

01. Project Manager from a construction company - "We basically understand some construction risks through intuition and take necessary actions proactively. Sometimes we never assess the risks until it occurs and the approach is reactive and we may not be able to do the full at this point. However, this RRD can be effectively used as tool to underrate the interaction natures of construction risks and thereby to improve the intuitive judgments."

02. Consultant Structural Engineer - "As design engineers, we very less think about the impact of our performance to the final construction program and the client. We in our best try to introduce safe and economical structural designs. However, by looking at this RRD, I understand the importance of submitting accurate designs once and for all at the agreed timelines. It will help the contractor and other supply chain partners to complete the project in the planned way. Additionally, as engineers we used to change the structural drawings time to time and now I understand the impact of that to the entire construction supply chain."

03. Project Manager from a construction company - "This model relating to risk management found to be a very useful one. It covers most of the aspects in risk identification at a glance. It will be more useful if the effect of use of machinery or equipment can be reflected in this model even though it is included as sub-contractor risk in the diagram. Groups like environmental societies, legal bodies plays a major role in construction and their involvement can be taken in to account even though it is addressed as a regulatory risk in the diagram."

04. Client's Engineer for a semi government project- "The RRD will help to understand the risk associated in construction supply chains to a good extent Even though political risks is addressed under the risk of regulation, it might come through the client generated risks in the government projects."

05. Senior Engineer Representing the client organization - "As client's engineer we generally used to put the blame on contractors and sometimes the consultants, but this RRD clearly shows us the impact of our communication particularly the scope of the work on the entire construction work. Hence, as client's engineer this diagram is helpful for me to get the inputs of client accurately at the planning stage to achieve

our construction objectives as a team rather than passing the ball to others specially the contractor."

06. Owner of a construction company -"The RRD taught me what I knew and what I had in mind. This is a useful tool to assess the risk together as a team and take risk management actions. From this diagram, I understand the importance of communication, right decision making, planning and sub- contractor management. This teaches us the importance of employing talented engineers and other staff to minimize many risks."

07. Quantity Surveyor - "RRD should have arrived with very good analysis and tool that can be used practically. Risk triggers are grouped really well with suitable headings and if more other risk triggers are added, it will become complex to an extent where it may not be able to use as an effective practical tool."

08. Consultant Structural Engineer - "This is well plan structure of the project risk management divided in to three headings. Submitting and accurate design and drawings in time is one of the main risk at the construction industry as it will affect all the parties to the structure. It is very Cleary indicated in the chart. Material supply related risk has been link to large number of links and which is more appropriate. Material supply related risk have been indicated very is very clearly indicated in the chart. Government regulation will affect and the levels of the parties has been mentioned very effectively in the chart."

09. Client's Engineer-"The identified sub categories are covering almost all parts of the risks available in the main topics. The placement of the arrows is easy to understand the link of each and every identified risk. In the planning stage if we go through the arrows we can give solution to the problems as arrows helps to find the risk easily."

10. Contractor's Engineer- "It is nicely breakdown the major important risks. Ex. Consultant industry specific risks, human resources risk and material supply risks. Each and every stakeholder can identify the risks that they have and they can mitigate the risks using the RRD."

11. Contractor's Project Manager- "The RRD is very useful in identify risk involved in construction industry in general and to do a risk assessment prior to commence a project. This diagram is very useful to explain stakeholders to do a good

assessment of risk involved with the construction supply chains. This diagram is helpful to understand all stakeholders involved in construction as to how their simple mistake will effect whole system of construction."

12. Contractor's Engineer- "It is a good piece of work. This sort of model would definitely alert the people who are involving in to the local construction industry. Nice way of giving awareness to the topic. The RRD can be further developed for specific projects such as buildings, roads etc. as well as contract type."

13. Contractor's Engineer- "RRD is very good risk identification tool. However, this model can customized to specific projects. EX. Building construction, Road construction etc. There may be different issue between government, semi government and privet organizations."

14. Contractor's Project Manager - "Trying to build a connection between each types of risks are highly appreciated. However, the major issue of current construction industry is unavailability of skill/unskilled labors. Therefor it's better to provide more weight for that. This model is more suitable for new construction projects. "

15. Contractor's Engineer- "This is as really good analyze about the risks on projects because it covers the general construction industry issues."

16. Contractor's Engineer- "Good model to understand major risk involved with present day construction."

17. Contractor's Project Manager - "This can be practiced to improve for construction risk but should be modified relevant to the project we apply this format."

18. General Manager of a construction company- "This is a good model. This has been prepared in very understanding way."

19. Contractor's Project Manager - "Since diagram shows the combination of each and every risk and the areas which affect due to particular risk. It will help to identify the actual reasons for each risk and easily can get mitigation actions towards relevant areas. This will help to continue a project with minimum delays. With the diagram, it can be easily understood activities which can be affected for the quality of the product/construction, reasons which can affect to the budget of the project. In the same way, it's clearly shows the reasons for delaying the delivery of materials to

the site. Normally when project is delayed, most of the stakeholders blame to the contractor although mostly there can be another reason for the delay. All the possible reasons which can affect for the delay are clearly mentioned in the diagram. Simply this has shown most important areas which helps to accelerate and project as well as quality construction output."

20. Contractor's Engineer- "This model will help to understand the risk associated in construction supply chains to a good extent. By understandings human generated risks, we can mitigate the impact of risk to the project. For example, the contractor has a responsible to train their employees to achieve optimum output from them. "

21. Consultant Engineer- "The RRD helps to understand and assess the risk in the construction supply chains."

22. Contractor's Project Manager - "The RRD is very important to identify risk and problems faced by each and every part of the construction industry so that most of the problems can be addressed by preplanning. The RRD can be used as check list and monitoring can be done accordingly. Mistakes that can be happened by the consultant and contractors can be reduced by educating this RRD to them."

23. General Manager of a construction company- "The RRD covered major risks most recently occurred in main part. And this chart give clear image about identification about construction risks. By using this chart, the risk can be identified deeply and can be explained to anyone about what is the risk and how can it have occurred. And also by identifying main risks before the situation can be minimum losses and automatically it will increase the profit also. According to categorization of risk occurred from main parts in industries they will also realize to minimize the possible faults. By keeping earlier attention to such of this chart it will be very helpful to take right action on right time. This model does not address for machinery and equipment supply risk because in the industry it is a highlighted risk that lack of skill operators."

24. Contractor's Engineer- "The RRD is very good and important in understanding and mitigating construction supply chain risks. The RRD can be further specified depending on the construction project type such as design and built, foreign funded projects etc."

25. Contractor's Engineer- "The RRD is very important in understanding and mitigating supply chain risks. There can be a subcategory for accident related risk, safety and security risk, health risk of workers and people and environment pollution risk even though these are covered as contractor planning and decision making risks in this model"

26. Supply Chain Manager from a construction materials supply company - "The RRD is very important in understanding and mitigating supply chain risks. Client taking a risk when choosing contractors and consultants. That relationship is not included.

27. Consultant Engineer- "Overall the RRD is very much important for the construction industry. If the project is specified the diagram can be analyzed properly."

28. Supply Chain Manager from a construction materials supply company - "This model tries to show interrelationship between various risk factors and it will enable engineers, managers to get a good idea about that risk management in complicated construction supply chains. Factors are shown in different levels in the models and it will enable us to go for a deep risk analysis. "

29. Supply Chain Manager from a construction materials supply company - "This model will help to understand the risk associated in construction supply chains to a good extent. Sand and labor related problem highly affect to the construction industry. By understanding those risk early stars of enough material and panning the project with considering seasonal trends will help to deliver the project within expected time period. By understandings human generated risks, we can mitigate the impact of risk to the project. For example, the contractor has a responsible to train their employees to achieve optimum output from them. Client generated risks and consultant generated risks is mainly having due to poor communication between them. The risk indicated relevant the material is also true.

30. Quantity Surveyor- "The RRD helps to understand and assess the risk in the construction supply chains."

31. Contractor's Engineer- "The RRD is very important to identify risk and problems faced by each and every part of the construction industry so that most of the problems can be addressed by preplanning. The RRD can be used as check list

and monitoring can be done accordingly. Mistakes that can be happened by the consultant and contractors can be reduced by educating this RRD to them.

32. Contractor's Project Manager - "The RRD covered major risks most recently occurred in main part. And this chart give clear image about identification about construction risks. By using this chart, the risk can be identified deeply and can be explained to anyone about what is the risk and how can it have occurred. And also by identifying main risks before the situation can be minimum losses and automatically it will increase the profit also. According to categorization of risk occurred from main parts in industries they will also realize to minimize the possible faults. By keeping earlier attention to such of this chart it will be very helpful to take right action on right time."

33. Consultant Architect- "The RRD is very good and important in understanding and mitigating construction supply chain risks. The RRD can be further specified depending on the construction project type such as design and built, foreign funded projects etc."

34. Contractor's Project Manager - "The RRD is very important in understanding and mitigating supply chain risks. There can be a subcategory for accident related risk, safety and security risk, health risk of workers and people and environment pollution risk even though these are covered as contractor planning and decision making risks in this model"

35. Contractor's Project Manager - "The RRD is very important in understanding and mitigating supply chain risks. Client taking a risk when choosing contractors and consultants. That relationship is not included.

36. Consultant Engineer- "Overall the RRD is very much important for the construction industry. If the project is specified the diagram can be analyzed properly."

37. Supply Chain Manager from a construction materials supply company - "The RRD model is useful to forecast accurately and take necessary actions to produce right quantities and supply them. When I saw this I felt how blind we were when it comes to assessing the supply risks to the dynamic construction industry. Additionally, the RRD helps us to proactively work with all the relevant stakeholders. This model is quite useful"

38. Consultant Architect -"Truly good model to assess the risk produce by architect to the entire construction project. We have to more listen to the client to understand the expectations accurately so that the things are easier in the construction duration"

Appendix XI - Data Set 02 Regression Analysis: A Case Study of 38 Construction Projects

Regression Analysis – Past Data

Cost and time behavior of few risk triggers were examined using correlation and regression analysis.

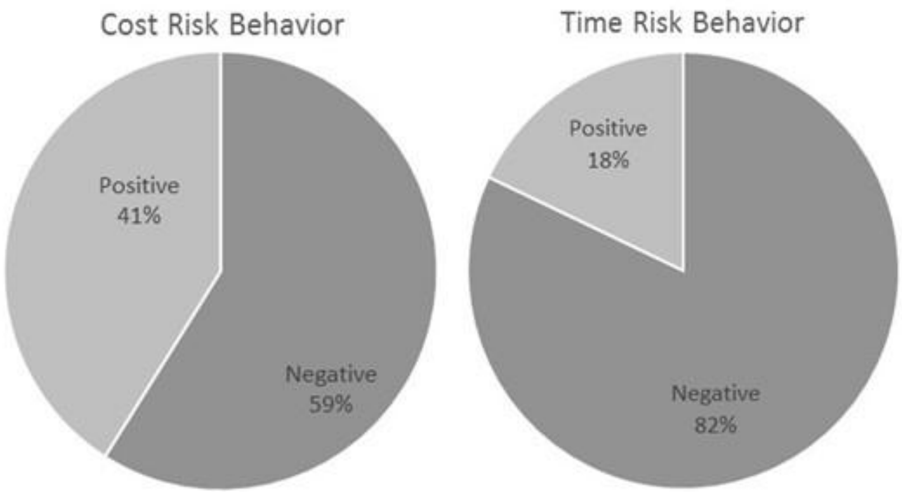
Where,

$$\text{Dependent Variable} = f\ (\text{Independent Variables})$$

Table 10: Dependent and Independent Variables

Dependent Variable	Independent Variables
Risk (Rupees)	Estimated Cost
Risk (Days)	Estimated Time

Case 1: Construction Industry specific risks on labour supply → Construction Industry Specified Risks



Case 1: Risk Behavior of Cost and Time Impact of Labour Supply Risks

Figure 3: Impact of Labour Supply Risks on Cost and Time

The regression equation is

Risk Impact = - 613413 + 0.262 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	-613413	848857	-0.72	0.482
Estimated Cost as per contract	0.26197	0.05624	4.66	0.000

S = 2404011   R-Sq = 60.8%   R-Sq (adj) = 58.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.25389E	+14	1.25389E	+14	0.000
Residual Error	14	8.09098E	+13	5.77927E	+12	
Total	15	2.06299E	+14			

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

$H_0: \rho = 0$, $H_1: \rho \neq 0$

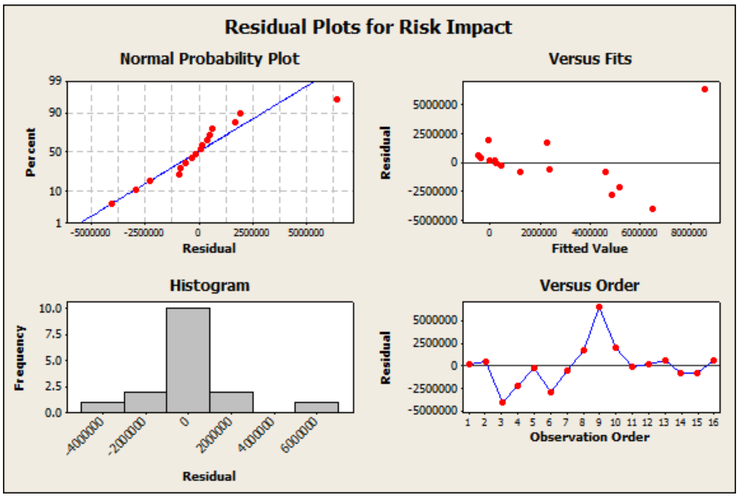
In the ANOVA table it can be seen that F value is significant;

F= 21.7, p = 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also, Coefficient of Determination R^2= 60.8%

This means that 60.8% of the observed variability is explained by the value which indicates the high accuracy of the model.



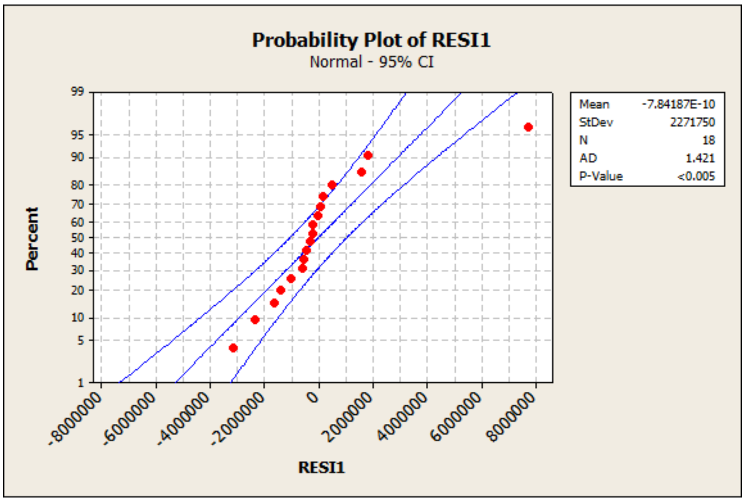
Durbin-Watson Statistic = 1.17459

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.17459) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.421 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Construction Industry specific risks on labor supply = 0.262 Estimated Cost

Regression model - Time

The regression equation is

Risk Impact Time = 5.19 + 0.471 Estimated Time as per contract

Predictor	Coef	SE	Coef	T
Constant	5.189	8.311	0.62	0.537
Estimated Time	0.47054	0.04160	11.31	0.000

S = 33.6232 R-Sq = 81.5% R-Sq(adj) = 80.9

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	144652	127.95	0.000	0.000
Residual Error	29	32785	1131		
Total	30	177437			

H_0: There is a no linear relationship in-between Risk in Time and Estimated Time

H_1: There is a no linear relationship in-between Risk in Time and Estimated Time

H_0: $\rho = 0$, H_1: $\rho \neq 0$

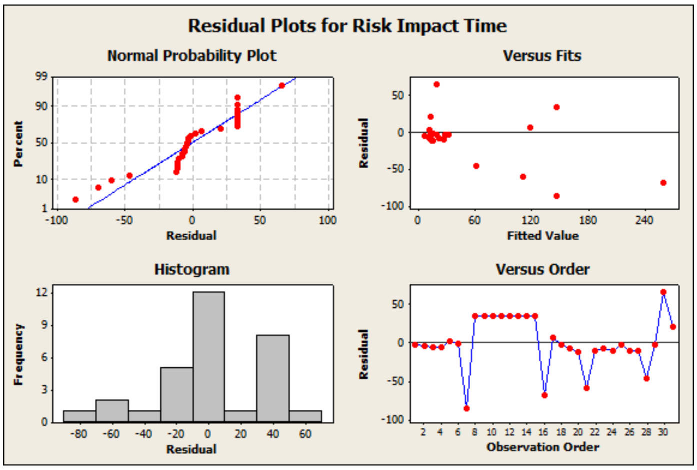
In the ANOVA table it can be seen that F value is significant;

F=127.95, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Time and Estimated Time.

And also Coefficient of Determination R^2= 81.5%

This means that 81.5% of the observed variability is explained by the value which



indicates the high accuracy of the model.

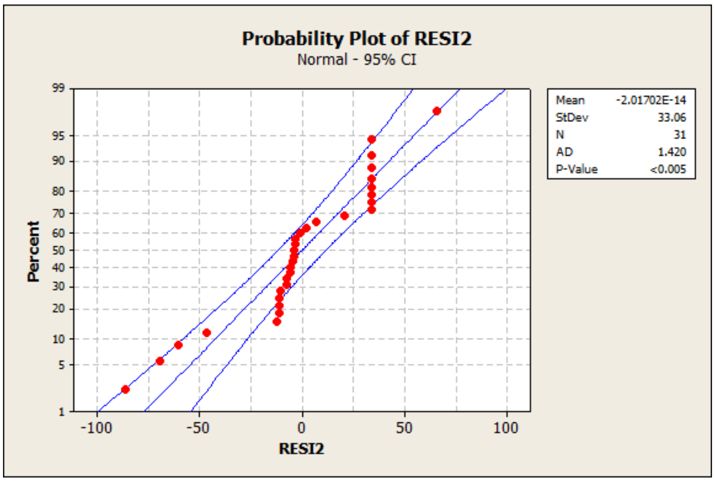
Durbin-Watson Statistic = 1.62076

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.62076 being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.420 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Risk Impact Time = 0.471 Estimated Time as per contract

Regression model – Cost Saving

The regression equation is

Risk Impact (Positive) = - 4904123 + 0.494 Estimated Cost as per contract1

Predictor	Coef	SE	Coef	T
Constant	-4904123	4425076	-1.11	0.282
Estimated Cost as per contract	0.49384	0.073	726.70	0.000

S = 17856355   R-Sq = 70.3%   R-Sq(adj) = 68.7%

Analysis of Variance

Source	DF	SS		MS	F		P
Regression	1	1.43079E	+16	1.43079E	+16	44.87	0.000
Residual Error	19	6.05814E	+15	3.18849E	+14		
Total	20	2.03661E	+16				

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

$H_0: \rho = 0$, $H_1: \rho \neq 0$

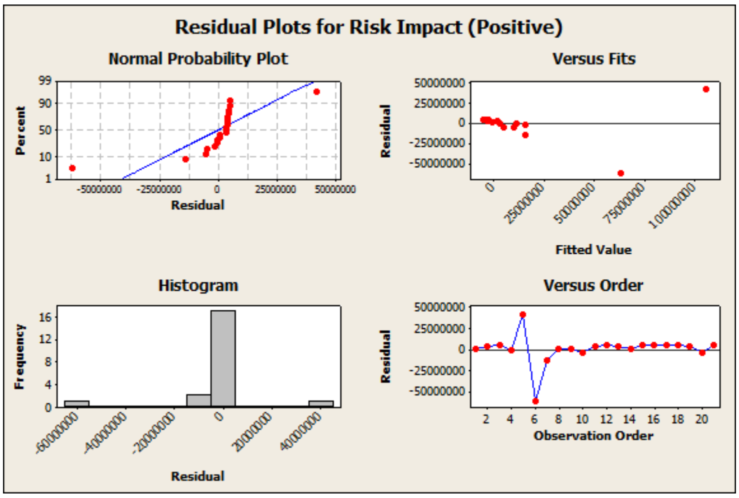
In the ANOVA table it can be seen that F value is significant;

F= 44.87, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 70.3%

This means that 70.3% of the observed variability is explained by the value, which indicates the high accuracy of the model.



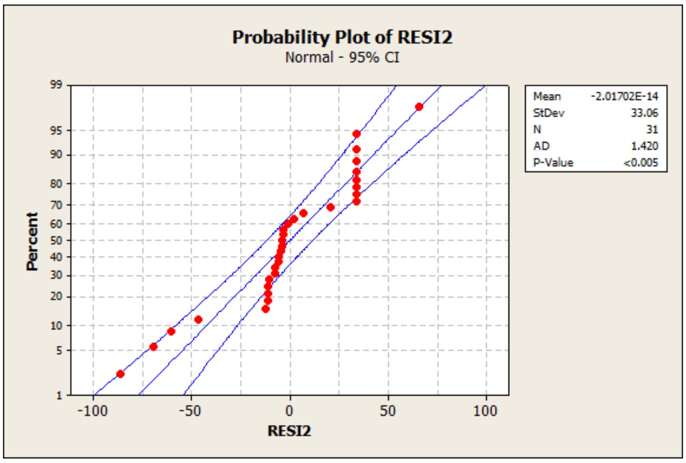
Durbin-Watson Statistic = 2.58113

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.58113 being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

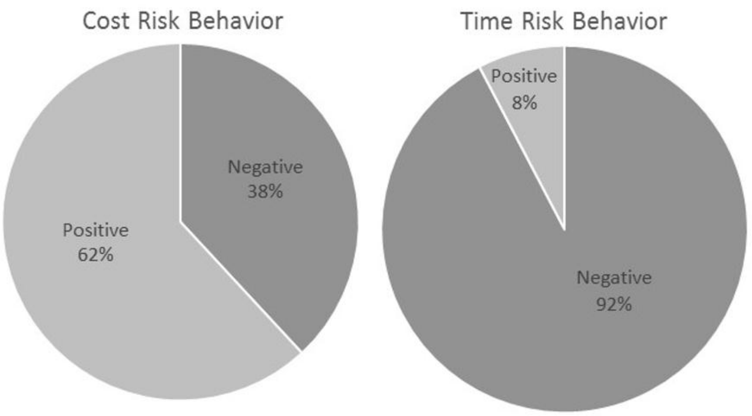
Test statistic = A-D test statistic= 1.420 and $p<0.005$ which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Risk Impact (Positive) = 0.494 Estimated Cost as per contract

Case 02: Risk Behaviour of Cost and Time Impact of Seasonal Trends



Risks

Figure 4: Impact of Seasonal Trends Risks on Cost and Time

Regression Analysis: Estimated Cost/Time and Risk in Rupees/Risk in days (Construction industry specified seasonal trends risks)

Regression model - Cost

The regression equation is

Risk = - 20012144 + 1.40 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	-20012144	30324776	-0.66	0.534
Estimated Cost as per contract	1.3982	0.2124	6.58	0.001

S = 75825526 R-Sq = 87.8% R-Sq(adj) = 85.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1 2.49176E	+17	2.49176E	+17 43.34	0.001
Residual Error	6 3.44971E	+16	5.74951E	+15	
Total	7 2.83673E	+17			

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

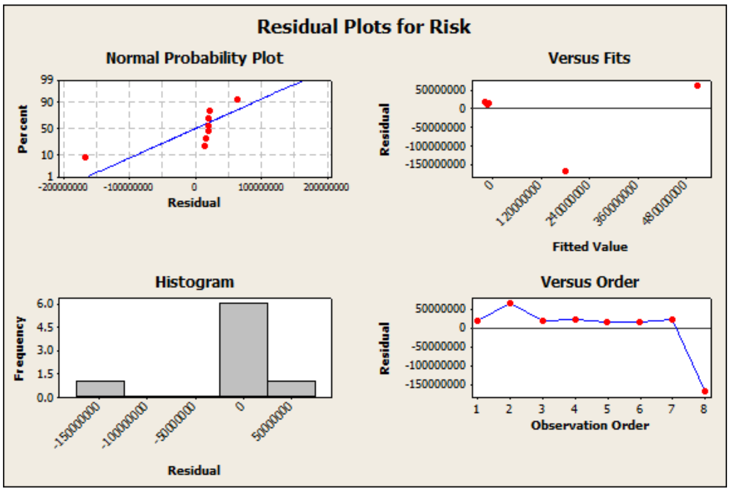
In the ANOVA table it can be seen that F value is significant;

F=43.34, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 87.8%

This means that 87.8% of the observed variability is explained by the value which



indicates the high accuracy of the model.

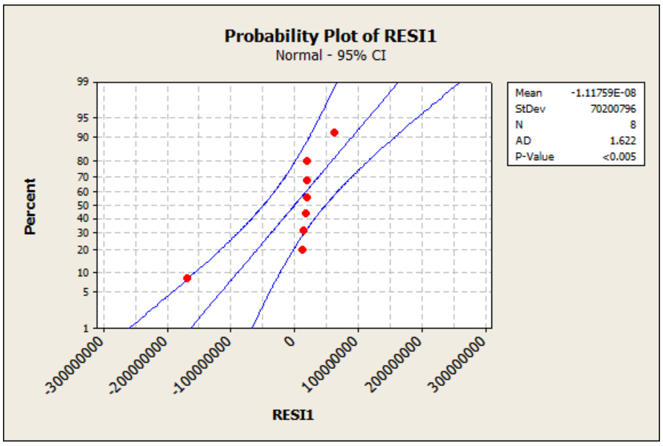
Durbin-Watson Statistic = 1.15909

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.15909) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.622 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Risk = 1.40 Estimated Cost as per contract

Regression model - Time

The regression equation is

Risk in Time = - 13.1 + 0.791 Estimated Time as per contract

Predictor	Coef	SE	Coef	T
Constant	-13.060	6.739	-1.94	0.066
Estimated Time as per contract	0.79059	0.06904	11.45	0.000

S = 27.5382   R-Sq = 85.6%   R-Sq(adj) = 85.0%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	99454	99454	131.14	0.000
Residual Error	22	16684	758		
Total	23	116138			

H_0: There is a no linear relationship in-between Risk in Time and Estimated Time

H_1: There is a no linear relationship in-between Risk in Time and Estimated Time

H_0: $\rho = 0$, H_1: $\rho \neq 0$

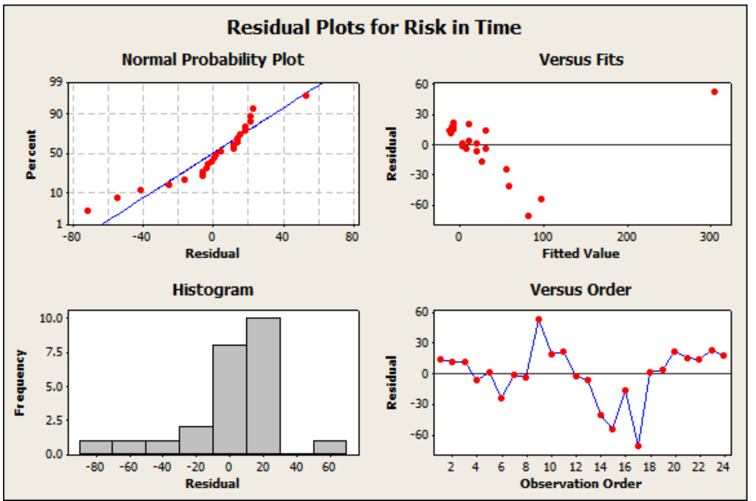
In the ANOVA table it can be seen that F value is significant;

F=131.14, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 85.6%

This means that 85.6% of the observed variability is explained by the value which



indicates the high accuracy of the model.

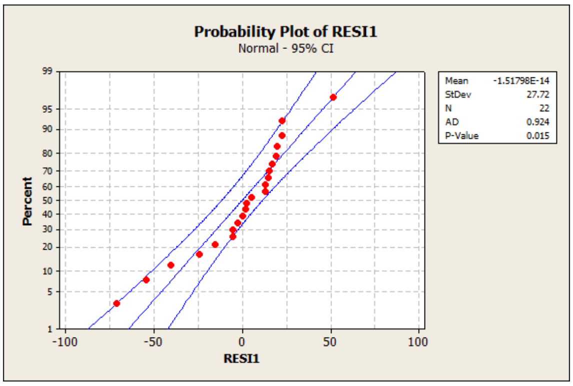
Durbin-Watson Statistic = 1.10209

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.10209 being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 0.924 and $p<0.005$ which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Risk in Time = 0.791 Estimated Time as per contract

Positive Risk

Regression Analysis: Estimated Cost and Positives Risk (Cost Saving) in Rupees related to Construction industry specified seasonal trends risks

The regression equation is

Positive Risk in Cost = - 36172932 + 0.977 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	-36172932	28132525	-1.29	0.225
Estimated Cost as per contract	0.976903	0.001834	532.66	0.000

S = 97372754   R-Sq = 100.0%   R-Sq(adj) = 100.0%

Source	DF	SS	MS	F	P
Regression	1	2.69014E +21	2.69014E +21	283726.71	0.000
Residual Error	11	1.04296E +17	9.48145E +15		
Total	12	2.69025E +21			

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

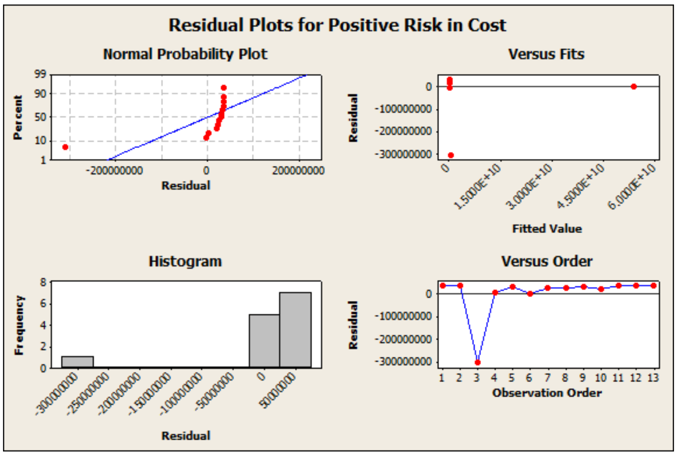
H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

In the ANOVA table it can be seen that F value is significant;

F=283726.71, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.



And also Coefficient of Determination R^2= 100%

This means that 100% of the observed variability is explained by the value which indicates the high accuracy of the model.

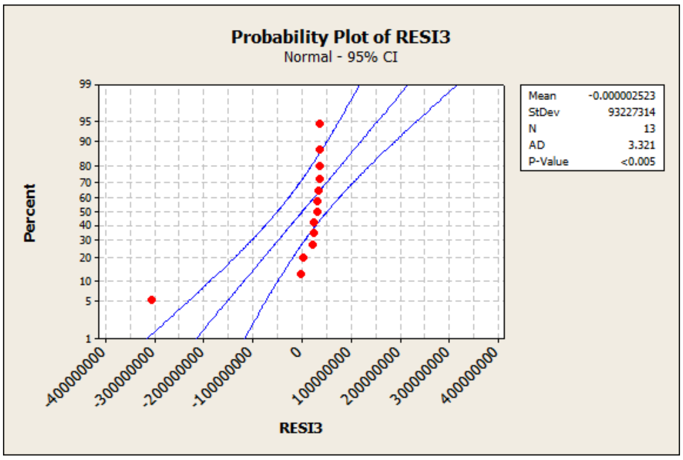
Durbin-Watson statistic = 2.06704

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.06704 being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

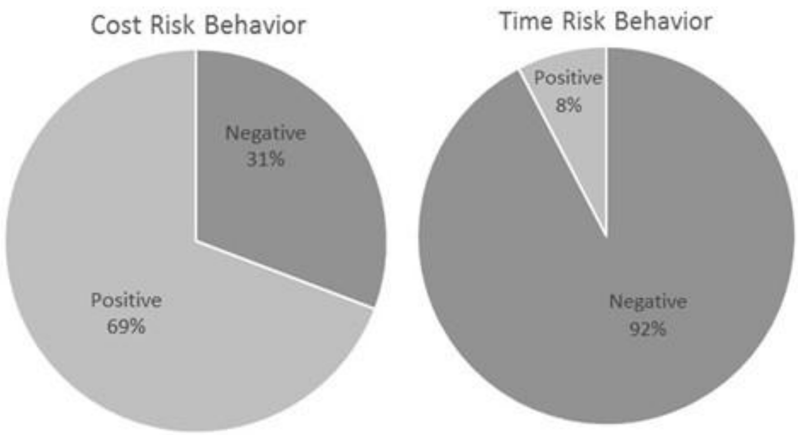
Test statistic= A-D test statistic= 3.321 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefor the regression model is,

Positive Risk in Cost = 0.977 Estimated Cost as per contracct

<u>Case 03: Risk Behaviour of Cost and Time Impact of Client/consultant</u>



<u>Generated Risk on Communicating the Scope of the Work</u>

Figure 5: Cost and Time Impact of Client/Consultant Generated Risks on Communicating the Scope of Work

Regression Analysis: Estimated Cost/Time and Risk in Rupees/Risk in days and Client/consultant generated risk on communicating the scope of the work

Regression model - Cost

The regression equation is

Negative Risk Impact = - 20012144 + 1.40 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	-20012144	30324776	-0.66	0.534
Estimated Cost as per contract	1.3982	0.2124	6.58	0.001

S = 75825526   R-Sq = 87.8%   R-Sq(adj) = 85.8%

Analysis of Variance

Source	DF	SS		MS	F	P
Regression	1 2.49176E	+17 2.49176E		+17	43.34	0.001
Residual Error	6 3.44971E	+16 5.74951E		+15		
Total	7 2.83673E	+17				

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

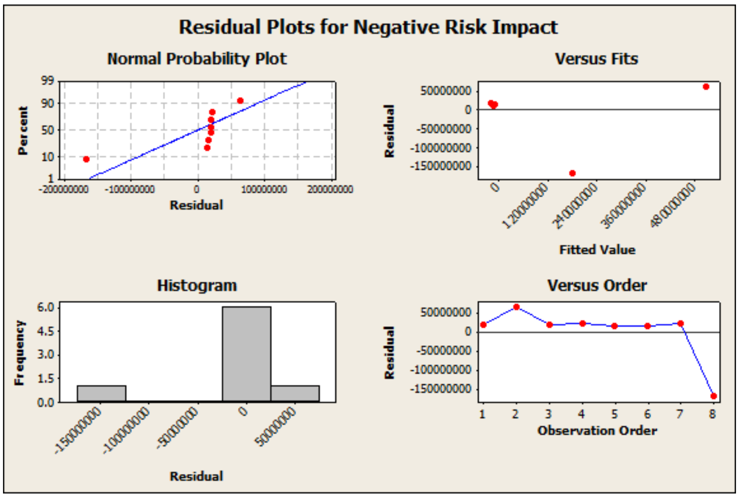
In the ANOVA table it can be seen that F value is significant;

F= 43.34, p= 0.001 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 87.8%

This means that 87.8% of the observed variability is explained by the value, which



indicates the high accuracy of the model.

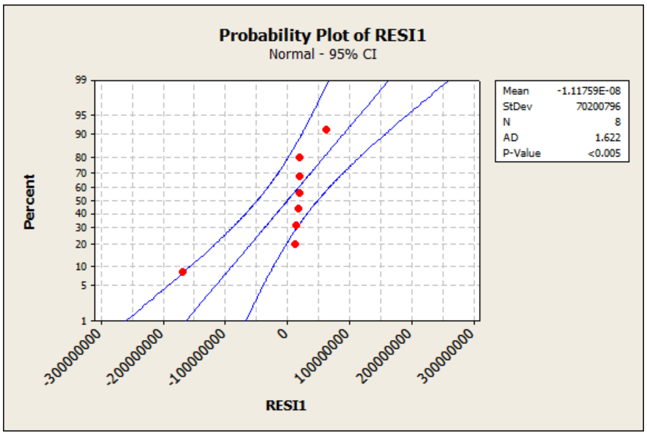
Durbin-Watson Statistic = 1.15909

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.15909) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.622 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Client/consultant generated risk on communicating the scope of the work

= 1.40 Estimated Cost

Regression model - Time

The regression equation is

Time Risk Impact = - 13.1 + 0.791 Estimated Duration (Days)

Predictor	Coef	SE	Coef	T
Constant	-13.060	6.739	-1.94	0.066
Estimated Duration (Days)	0.79059	0.06904	11.45	0.000

S = 27.5382   R-Sq = 85.6%   R-Sq(adj) = 85.0%

Analysis of Variance

Source	DF	nSS	MS	F	P
Regression	1	99454	99454	131.14	0.000
Residual Error	22	16684	758		
Total	23	116138			

H_0: There is a no linear relationship in-between Risk in Time and Estimated Time

H_1: There is a no linear relationship in-between Risk in Time and Estimated Time

H_0: $\rho = 0$, H_1: $\rho \neq 0$

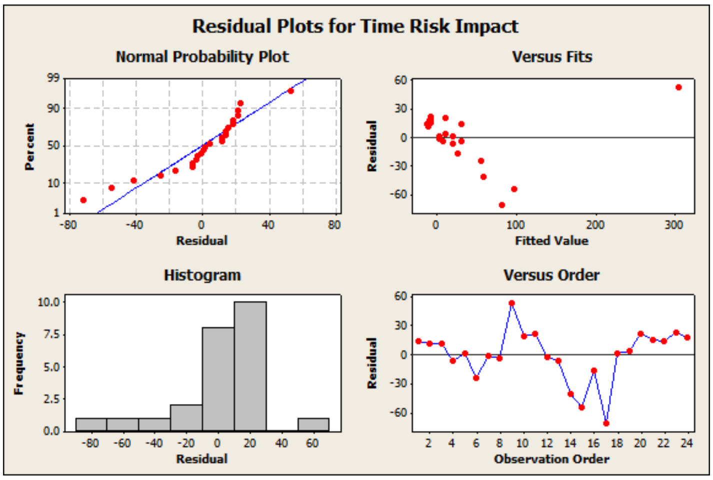
In the ANOVA table it can be seen that F value is significant;

F= 131.14, p= 0.00 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Time and Estimated Time.

And also Coefficient of Determination R^2= 85.6%

This means that 85.6% of the observed variability is explained by the value, which



indicates the high accuracy of the model.

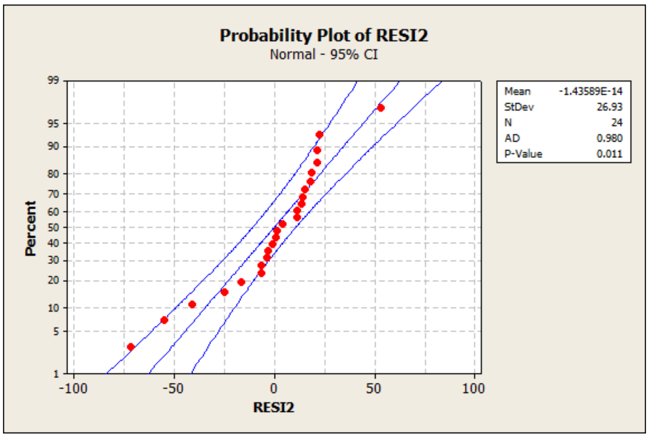
Durbin-Watson Statistic = 1.10209

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.10209) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph, which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 0.980 and p=0.011 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Time Risk Impact = 0.791 Estimated Duration (Days)

Negative Impact

Regression Analysis: Estimated Cost/Time and Risk in Rupees/Risk in days and Client/consultant generated risk on submitting accurate design and estimate

Regression model - Cost

The regression equation is

Negative Cost Risk Impact = 1356245 + 0.0928 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	1356245	992657	1.37	0.185
Estimated Cost as per co	0.09278	0.02115	4.39	0.000

S = 4469116   R-Sq = 44.5%   R-Sq(adj) = 42.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3.84452E +14	3.84452E +14	19.25	0.000
Residual Error	24	4.79352E +14	1.99730E +13		
Total	25	8.63804E +14			

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

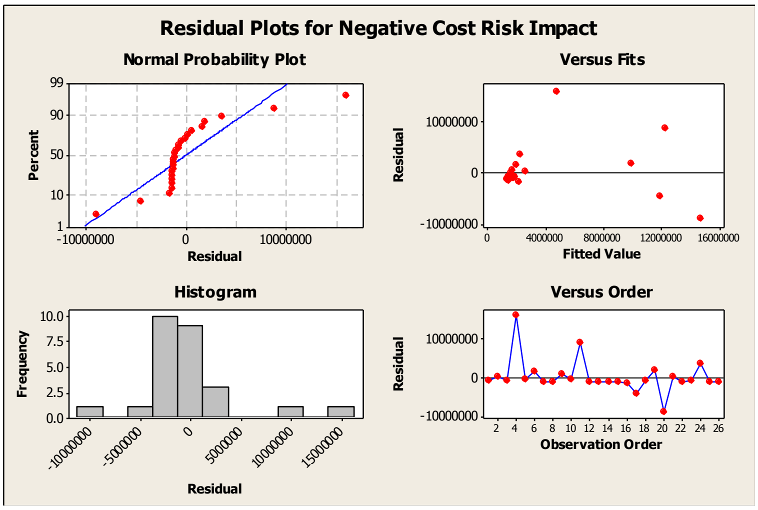
In the ANOVA table it can be seen that F value is significant;

F= 19.25, p= 0.001 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 44.5%

This means that 44.5% of the observed variability is explained by the value, which



indicates the high accuracy of the model.

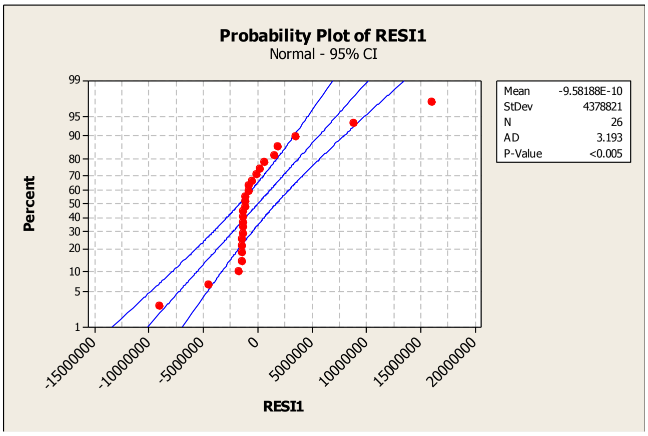
Durbin-Watson Statistic = 2.20342

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.20342) being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 3.193 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

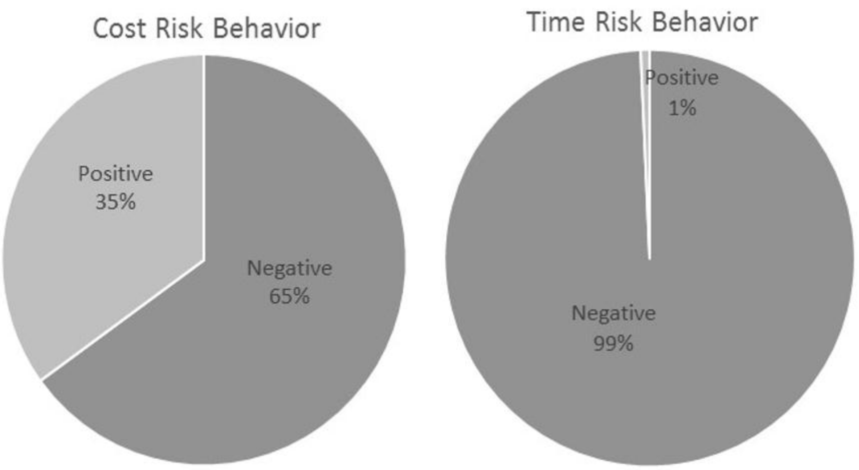
And the mean error is zero.

Therefore the regression model is,

Client/consultant generated risk on submitting accurate design and estimate

= 0.0928 Estimated Cost as per contract

<u>Case 04: Risk Behaviour of Cost and Time Impact of Client/Consultant</u>



<u>Generated Risk on Submitting Accurate Design and Estimate</u>

Figure 6: Impact of Client/Consultant Generated Risk on Submitting Accurate Design and Estimate on Cost and Time

Negative Impact

Regression Analysis: Estimated Cost/Time and Risk in Rupees/Risk in days and Client/consultant generated risk on submitting accurate design and estimate

Regression model - Cost

The regression equation is

Negative Cost Risk Impact = 1356245 + 0.0928 Estimated Cost as per contract

Predictor	Coef	SE	Coef	T
Constant	1356245	992657	1.37	0.185
Estimated Cost as per co	0.09278	0.02115	4.39	0.000

S = 4469116   R-Sq = 44.5%   R-Sq(adj) = 42.2%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	3.84452E +14	3.84452E +14	19.25	0.000
Residual Error	24	4.79352E +14	1.99730E +13		
Total	25	8.63804E +14			

H_0: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

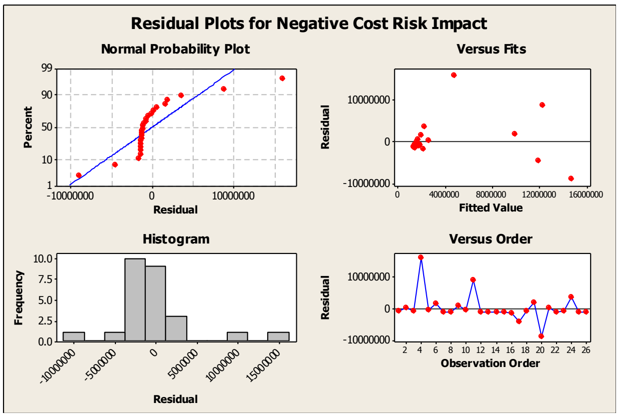
In the ANOVA table it can be seen that F value is significant;

F= 19.25, p= 0.001 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 44.5%

This means that 44.5% of the observed variability is explained by the value, which



indicates the high accuracy of the model.

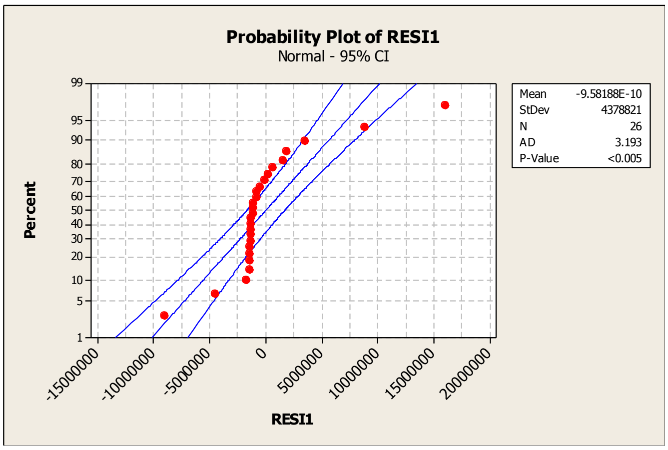
Durbin-Watson Statistic = 2.20342

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.20342) being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 3.193 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Client/consultant generated risk on submitting accurate design and estimate

= 0.0928 Estimated Cost as per contract

Regression model - Time

The regression equation is

Time Risk Impact = 11.8 + 0.199 Estimated Duration (Days)

Predictor	Coef	SE	Coef	T
Constant	11.836	4.295	2.76	0.011
Estimated Duration	0.19940	0.06140	3.25	0.003

S = 14.2226   R-Sq = 30.5%   R-Sq(adj) = 27.6%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	2133.4	2133.4	10.55	0.003
Residual Error	24	4854.8	202.3		
Total	25	6988.2			

H_0: There is a no linear relationship in-between Risk in Time and Estimated Time

H_1: There is a no linear relationship in-between Risk in Time and Estimated Time

H_0: $\rho = 0$, H_1: $\rho \neq 0$

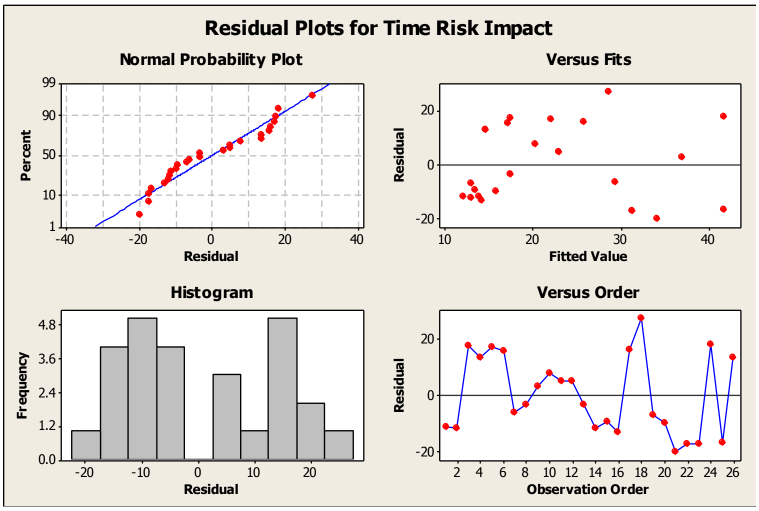
In the ANOVA table it can be seen that F value is significant;

F= 10.55, p= 0.003 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Risk in Time and Estimated Time.

And also Coefficient of Determination R^2= 30.5%

This means that 30.5% of the observed variability is explained by the value, which indicates the high accuracy of the model.



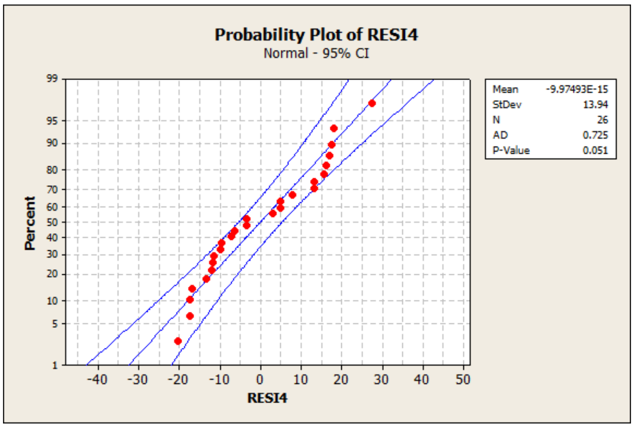
Durbin-Watson Statistic = 1.51162

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.51162) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph, which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 0.725 and p=0.051 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Therefore the regression model is,

Time Risk Impact = 11.8 + 0.199 Estimated Duration (Days)

The regression equation is

Positive Cost Risk Impact = 1195896 + 0.0315 Estimated Cost

Predictor	Coef	SE	Coef	T
Constant	1195896	535110	2.23	0.045
Estimated Cost	0.03145	0.01610	1.95	0.075

S = 1630433   R-Sq = 24.1%   R-Sq(adj) = 17.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	1.01400E	+13 1.01400E	+13 3.81	0.075
Residual Error	12	3.18997E	+13 2.65831E	+12	
Total	13	4.20397E	+13		

H_0: There is a no linear relationship in-between positive Risk in Rupees and Estimated Cost

H_1: There is a no linear relationship in-between positive Risk in Rupees and Estimated Cost

H_0: $\rho = 0$, H_1: $\rho \neq 0$

In the ANOVA table it can be seen that F value is significant;

F = 3.81, p = 0.075 at 95% confidence level

Therefore, it can be concluded that there are no significant linear relationships between positive Risk in Rupees and Estimated Cost.

And also Coefficient of Determination R^2= 24.1%, which does not explain the accuracy of the model.

Is not significant

Appendix XII - Regression Analysis Chapter 5 (From Data Set 3)

Case 01

Dependent Variable	**Independent Variables**
Construction Industry Specified Risks Y1	Sand Problem Y4
	Regulations Y5
	Seasonal Trends Y6
	Risk on labour supply Y7

Pearson correlation of Yi(i = 4 to 7) and Y1 and their P-Values

Correlations: Y1, Y4, Y5, Y6, Y7

	Y1	Y4	Y5	Y6
Y4	0.883			
	0.000			
Y5	0.730	0.865		
	0.000	0.000		
Y6	0.856	0.770	0.756	
	0.000	0.000	0.000	
Y7	0.662	0.326	0.020	0.322
	0.000	0.015	0.883	0.016

Cell Contents: Pearson correlation

P-Value

H_0: Correlation between Y1 and Yi (i = 4 to 7) is significantly not different from zero.

H_1: Correlation between Y1 and Yi (i = 4 to 7) is significantly different from zero.
$H_0: \rho = 0$, $H_1: \rho \neq 0$

P (Y1 and Yi) value =0.000, which is less than 0.05 at 95% of confidence level

Therefore, correlations between Y1- Y4, Y1-Y5, Y1-Y6, and Y1-Y7 are significantly different from zero.

According to the table, the relationship in-between construction industry specified risks and four independent variables; sand problem, regulations, seasonal trends and risk on labour supply are high, because all four Pearson correlation coefficients are close to 1.

The highest positive relationship is identified in-between sand problem and construction industry specified risks. Secondly, when seasonal trends increases construction industry specified risks also increases considerably.

When regulations and risk on labour supply increases construction Industry Specified Risks also increases significantly.

Regression Analysis: Y1 versus Y4, Y5, Y6, Y7

Regression model

$$\boldsymbol{Y1 = \beta 0 + \beta 1 Y4 + \beta 2 Y5 + \beta 3 Y6 + \beta 4 Y7 \pm \varepsilon}$$

β0 Constant = 0, β1 – Coefficient of Y4, β2 - Coefficient of Y5, β3 - Coefficient of Y6, β4 - Coefficient of Y7, ε – Error

Hypothesis

H_0: $\beta\,1 \leq 0, \beta\,2 \leq 0\ \ \beta\,3 \leq 0, \beta\,4 \leq 0$

H_1: At least one regression coefficient is not less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

When null hypothesis is rejected a relationship between Y1 and Yi (i= 4 to 7) variables exists. The relationship will always remain positive.

If p-value ≤ 0.05 reject the null hypothesis at 95% confidence level.

P values = 0, Therefor H_i: $\beta_i > 0$

The regression equation is

Y1 = - 0.00004 + 1.19 Y4 + 0.848 Y5 + 1.02 Y6 + 0.956 Y7

S = 0.00655915 R-Sq = 99.8% R-Sq(adj) = 99.8%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	1.02720	0.25680	5968.99	0.000
Residual Error	50	0.00215	0.00004		
Total	54	1.02935			

H_0: There is a no linear relationship in-between Y1 and Yi (i= 4 to 7).

H_1: There is a no linear relationship in-between Yi (i= 4 to 7).

H_0: $\rho = 0$, H_1: $\rho \neq 0$

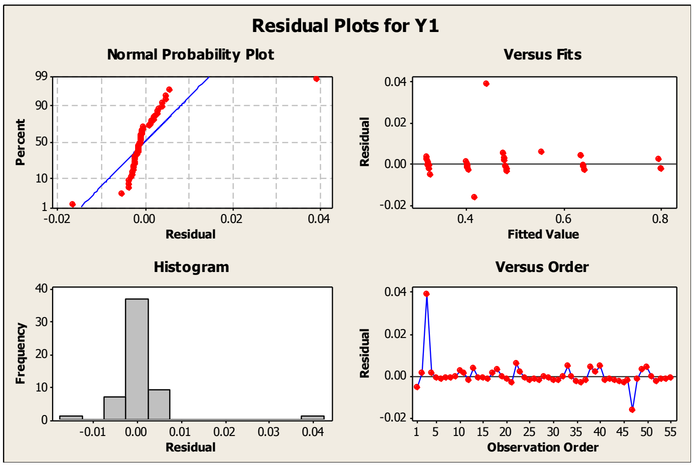
In the ANOVA table it can be seen that F value is significant;

F= 5968.88, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between construction industry specified risks and Yi (i= 4 to 7) variables.

And also Coefficient of Determination R^2= 99.8%

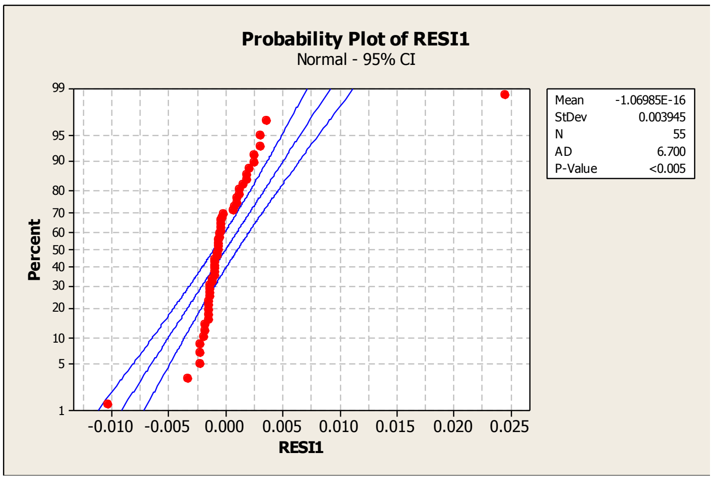
This means that 99.8% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Durbin-Watson Statistic = 1.77189

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.77189) being close to 2, confirms that errors are random.
ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.
iii. Normality.



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 6.7 and p<0.005 which is lower than 0.05 at 95% confidence level. It can be concluded that errors are distributed normally.

And the mean error is zero.

Fits and Diagnostics for Unusual Observations

Obs Y4 Y1 Fit SE Fit Residual St Resid

3 0.075	0.300000	0.275432	0.001818	0.024568	6.69R
32 0.064	0.400000	0.400244	0.002347	-0.000244	-0.07 X
47 0.045	0.250000	0.260324	0.001350	-0.010324	-2.67R

Also there are three unusual observations in the model too.

Therefore coefficients of degree of risks derived from the regression analysis,

Coefficient of Y4 = 1.19

Coefficient of Y5 = 0.848

Coefficient of Y6 = 1.02

Coefficient of Y7 = 0.956

Risk Equation

$$\boldsymbol{Y1 = f(Y4, Y5, Y6, Y7)}$$

Risk equation coefficients;

Coefficient of Y4 = Mean value * 1.19 = 0.21*1.19 = 0.25

Coefficient of Y5 = Mean value * 0.848 = 0.17*0.848 = 0.14

Coefficient of Y6 = Mean value * 1.02 = 0.22*1.02 = 0.22

Coefficient of Y7 = Mean value * 0.956 = 0.39*0.956 = 0.37

$Y1 = 0.25\,Y4 + 0.14\,Y5 + 0.22\,Y6 + 0.37\,Y7$

<u>Case 02</u>

Dependent Variable	**Independent Variables**
Stakeholder Risks Y2	Contractor generated Risks Y8
	Client generated Risks Y9
	Consultant generated Risks Y10

Pearson correlation of Y2 and Yi (i= 8, 9, 10) and their P-Values

Correlations: Y2, Y8, Y9, Y10

	Y2	Y8	Y9
Y8	0.602		
	0.000		
Y9	0.705	0.155	
	0.000	0.257	

Y10	0.579	-0.227	0.413
	0.000	0.096	0.002

Cell Contents: Pearson correlation

P-Value

H_0: Correlation between Y2 and Yi (i= 8,9,10) is significantly not different from zero.

H_1: Correlation between Y2 and Yi (i= 8,9,10) is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P (Y2 and Xi) value =0.000, which is less than 0.05 at 95% of confidence level Therefore, correlations between Y2- Y8, Y2-Y9, and Y2-Y10 are significantly different from zero.

According to the table, there is a high positive relationship in-between stakeholder generated risks and client generated Risks, because Pearson correlation coefficients is near to o.705 which is the closest to 1.

With 95% confidence level that as the p value more than 0.05, correlations between Y8-Y9 and Y8-Y10, are significantly zero, but correlations between Y9-Y10 is significantly different from zero.

Regression model

$$\boldsymbol{Y2 = \beta 0 + \beta 1 Y8 + \beta 2 Y9 + \beta 3 Y10 \pm \varepsilon}$$

β0 Constant = 0, β1 – Coefficient of Y8, β2 - Coefficient of Y9, β3 - Coefficient of Y10, ε – Error

The regression equation is

Y2 = 0.000000 + 1.00 Y8 + 1.00 Y9 + 1.00 Y9

Y2 = 1.00 Y8 + 1.00 Y9 + 1.00 Y10

S = 0 R-Sq = 100.0% R-Sq(adj) = 100.0%

And also Coefficient of Determination R^2= 100%

This means that 100% of the observed variability is explained by the value which indicates the higher accuracy of the model.

Therefore coefficients of degree of risks derived from the regression analysis,

Coefficient of Y8 = 1

Coefficient of Y9 = 1

Coefficient of Y10 = 1

Risk Equation

$Y2 = f(Y8, Y9, Y10)$

Risk equation Coefficients;

Coefficient of Y8 = Mean value * 1 = 0.43*1 = 0.25

Coefficient of Y9 = Mean value * 1 = 0.24*1 = 0.14

Coefficient of Y10 = Mean value * 1 = 0.33*1 = 0.22

$Y2 = 0.43\ X5 + 0.24\ X6 + 0.33\ X7$

<u>Case 03</u>

Dependent variable	**Independent variable**
Materials Supply Related Risks Y3	Price Risks Y11
	Quality Risks Y12
	Availability Risks Y13
	On-time delivery Risks Y14

Pearson correlation of Y3 and Yi (i= 11 to 13) and their P-Values

Correlations: Y3, Y11, Y12, Y13, Y14

	Y3	Y11	Y12	Y13
Y11	0.725			
	0.000			
Y12	0.723	0.289		
	0.000	0.032		
Y13	0.555	0.159	0.263	
	0.000	0.245	0.052	
Y14	0.668	0.555	0.254	0.085
	0.000	0.000	0.062	0.537

Cell Contents: Pearson correlation

P-Value

H_0: Correlation between Y3 and Yi (i= 11 to 13) is significantly not different from zero.

H_1: Correlation between Y3 and Yi (i= 11 to 13) is significantly different from zero.

H_0: ρ = 0, H_1: ρ ≠ 0

P (Y3 and Xi) value =0.000, which is less than 0.05 at 95% of confidence level.

Therefore, correlations between Y3- Y11, Y3-Y12, Y3-Y13, and Y3-Y14 are significantly different from zero.

According to the table, the relationship in-between Material Supply related Risks and four independent variables; price, quality, availability and on-time delivery risks are high, because all four Pearson correlation coefficients are close to 1.

Regression model

$$\boldsymbol{Y3 = \beta 0 + \beta 1 Y11 + \beta 2 Y12 + \beta 3 Y13 + \beta 4 Y14 \pm \varepsilon}$$

β0 Constant, β1 – Coefficient of Y11, β2 - Coefficient of Y12, β3 - Coefficient of Y13, β4 - Coefficient of Y14, ε – Error

Hypothesis

H_0: β 1 ≤ 0, β 2 ≤ 0 β 3 ≤0, β 4 ≤ 0

H_1: At least one regression coefficient is not equal or less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

When null hypothesis is rejected a relationship between Y and Yi variables exists. The relationship will always remain positive.

If p-value ≤ 0.05 reject the null hypothesis at 95% confidence level.

P values = 0, Therefor H_i: $\beta_i > 0$

The regression equation is

Y3 = - 0.00193 + 0.920 Y11 + 1.12 Y12 + 1.04 Y13 + 0.911 Y14

S = 0.00833137 R-Sq = 99.5% R-Sq(adj) = 99.5%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	0.75289	0.18822	2711.69	0.000

Residual Error	50	0.00347	0.00007
Total	54	0.75636	

H_0: There is a no linear relationship in-between Y1 and Yi.

H_1: There is a no linear relationship in-between Y1 and Yi.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

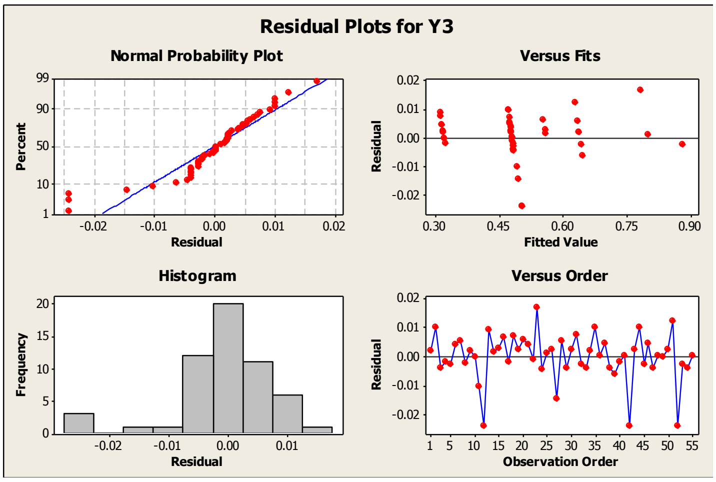
In the ANOVA table it can be seen that F value is significant;

F= 2711.69, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between material supply related risks and Yi (i= 11 to 14) variables.

And also Coefficient of Determination R^2= 99.5%

This means that 99.5% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Fits and Diagnostics for Unusual Observations

Unusual Observations

Obs	Y11	Y3	Fit	SE Fit	Residual	St Resid
4	0.220	0.88000	0.88201	0.00449	-0.00201	-0.29 X
12	0.192	0.48000	0.50410	0.00339	-0.02410	-3.17R
23	0.320	0.80000	0.78295	0.00548	0.01705	2.72RX
42	0.192	0.48000	0.50410	0.00339	-0.02410	-3.17R
52	0.192	0.48000	0.50410	0.00339	-0.02410	-3.17R

There are five unusual observations in the model too.

Durbin-Watson Statistic

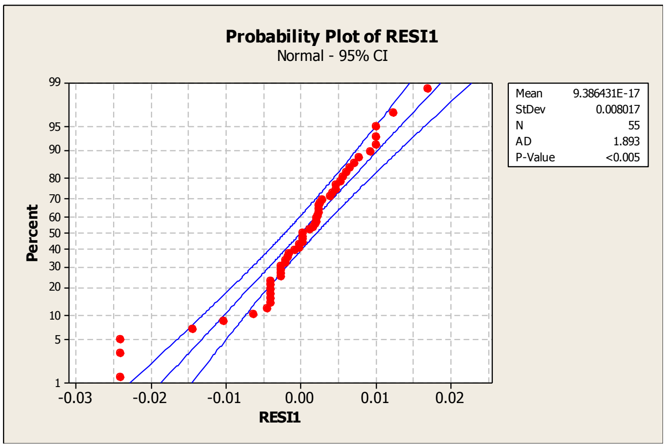
Durbin-Watson Statistic = 2.23108

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.23108) being more than two, confirms that errors are random and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.893

It can be concluded with 95% confidence level (A-D=893 and p<0.005 which is lower than 0.05) errors are distributed normally.

And the mean error is zero.

Therefore coefficients of degree of risks derived from the regression analysis,

Coefficient of Y11 = 0.920

Coefficient of Y12 = 1.120

Coefficient of Y13 = 1.040

Coefficient of Y14 = 0.911

Risk Equation

$Y3 = f(Y11, Y12, Y13, Y14)$

Risk equation coefficients;

Coefficient of Y11 = Mean value * 0.92 = 0.25*0.92 = 0.23

Coefficient of Y12 = Mean value * 1.12 = 0.29*1.12 = 0.33

Coefficient of Y13 = Mean value * 1.04 = 0.21*1.04 = 0.22

Coefficient of Y14 = Mean value * 0.911 = 0.25*0.911 = 0.23

$Y3 = 0.23\,Y11 + 0.33\,Y12 + 0.22\,Y13 + 0.23\,Y14$

Case 04

Dependent Variable	**Independent Variable**
Contractor generated Risks Y8.1	Decision Making Risks Y15
	Communication Risks Y16
	Sub-contractor Risks Y17
	Financial Risks Y18
	Planning Risks Y19

Pearson correlation of Y8.1 and Yi and their P-Values

Correlations: Y8.1, Y15, Y16, Y17, Y18, Y19

	Y8.1	Y15	Y16	Y17
Y18				
Y15	0.714			
	0.000			
Y16	0.589	0.677		
	0.000	0.000		
Y17	0.615	0.188	0.164	
	0.000	0.169	0.231	
Y18	0.567	0.069	-0.047	0.459
	0.000	0.618	0.735	0.000
Y19	0.674	0.312	0.215	
	0.303	0.349		
	0.000	0.020	0.114	0.025
	0.009			

Cell Contents: Pearson correlation
P-Value

H_0: Correlation between Y8.1 and Yi (i=15 to 19) is significantly not different from zero.

H_1: Correlation between Y8.1 and Yi (i=15 to 19) is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P (Y8.1 and Yi) value =0.000, which is less than 0.05 at 95% of confidence level.

Therefore, correlations between Y8.1-Y15, Y8.1-Y16, Y8.1-Y17, Y8.1-Y18 and Y8.1-Y19 are significantly different from zero.

According to the table, the relationship in-between contractor generated Risks and four independent variables; decision making risks, communication risks, sub-contractor risks, financial risks, and planning risks are high, given that all four Pearson correlation coefficients are close to 1.

Regression Analysis: Y8.1 versus Yi

Regression model

$$\boldsymbol{Y8.1 = \beta 0 + \beta 1 Y15 + \beta 2 Y16 + \beta 3 Y17 + \beta 4 Y18 + \beta 5 Y19 \pm \varepsilon}$$

β0 Constant, β1 – Coefficient of Y15, β2 - Coefficient of Y16, β3 - Coefficient of Y17, β4 - Coefficient of Y18, β5 - Coefficient of Y19, ε – Error

Hypothesis

H_0: $\beta\ 1 \leq 0, \beta\ 2 \leq 0\ \ \beta\ 3 \leq 0, \beta\ 4 \leq 0, \beta\ 5 \leq 0$

H_1: At least one regression coefficient is not less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

When null hypothesis is rejected a relationship between Y8.1 and Y variables exists. The relationship will always remain positive.

If p-value ≤ 0.05, reject the null hypothesis at 95% confidence level.

P values = 0, Therefor H_i: $\beta_i > 0$

The regression equation is

Y8.1 = 0.0189 + 1.47 Y15 + 0.637 Y16 + 0.921 Y17 + 0.891 Y18 + 0.971 Y19

S = 0.0201329   R-Sq = 96.7%   R-Sq(adj) = 96.4%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	0.59048	0.11810	291.35	0.000
Residual Error	49	0.01986	0.00041		
Total	54	0.61034			

H_0: There is a no linear relationship in-between Y8.1 and Yi.

H_1: There is a no linear relationship in-between Y8.1 and Yi.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

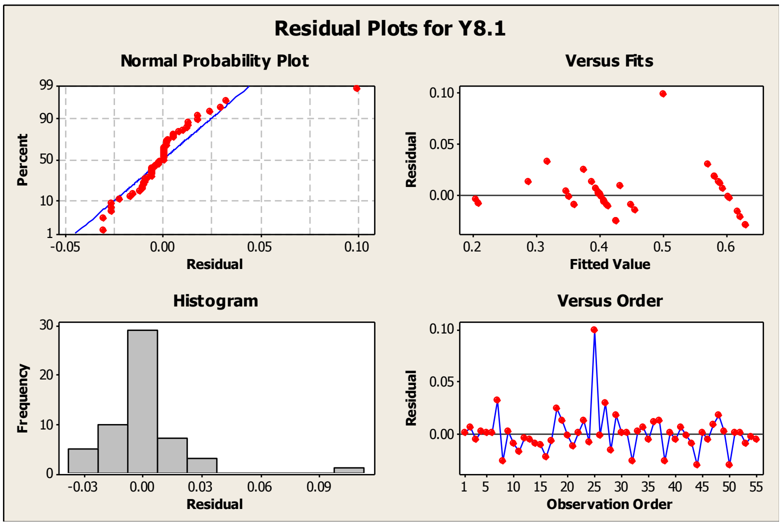
In the ANOVA table it can be seen that F value is significant;

F= 291.35, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between Contractors generated risks and Y variables.

And also Coefficient of Determination R^2= 96.4%

This means that 96.4% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Fits and Diagnostics for Unusual Observations

Obs	X12	X5	Fit	SE Fit	Residual	St Resid
16	0.180	0.60000	0.62231	0.01324	-0.02231	-1.47 X
25	0.120	0.60000	0.50049	0.01118	0.09951	5.94R
27	0.120	0.60000	0.57006	0.01222	0.02994	1.87 X

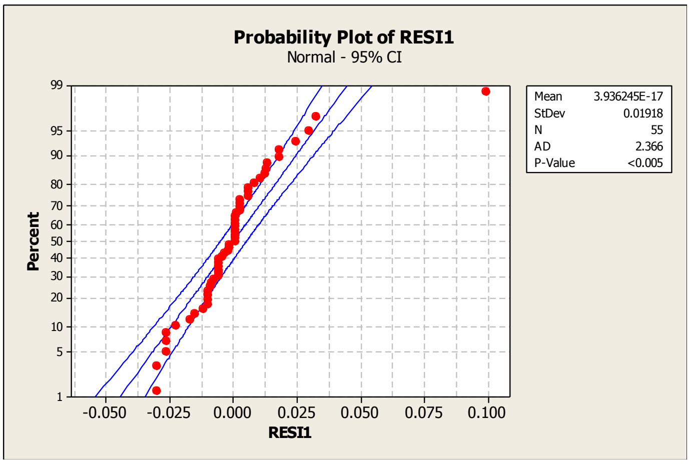
Durbin-Watson Statistic = 2.20431

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.20431) being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 2.37

It can be concluded with 95% confidence level (A-D=2.37 and p<0.005 which is lower than 0.05) errors are distributed normally.

And the mean error is zero.

Also there are three unusual observations in the model too.

Therefore coefficients of degree of risks derived from the regression analysis,

Coefficient of Y15 = 1.47

Coefficient of Y16 = 0.637

Coefficient of Y17 = 0.921

Coefficient of Y18 = 0.891

Coefficient of Y19 = 0.971

Y8.1 = 0.0189 + 1.47 Y15 + 0.637 Y16 + 0.921 Y17 + 0.891 Y18 + 0.971 Y19

Risk Equation

$Y8.1 = f(Y15, Y16, Y17, Y18, Y19)$

Risk equation coefficients;

Coefficient of Y15 = Mean value * 1.47 = 0.18*1.47 = 0.26

Coefficient of Y16 = Mean value * 0.647 = 0.25*0.647 = 0.16

Coefficient of Y17 = Mean value * 0.921 = 0.16*0.921 = 0.15

Coefficient of Y18 = Mean value * 0.891 = 0.19*0.891 = 0.17

Coefficient of Y19 = Mean value * 0.971 = 0.22*0.971 = 0.21

$Y8.1 = 0.26\,Y15 + 0.16\,Y16 + 0.15\,Y17 + 0.17\,Y18 + 0.21\,Y19$

Case 05

Dependent Variable	**Independent Variables**
Client generated Risks Y9.1	Risk on communicating the scope of the work Y20
	Risk on supply of funding Y21

Pearson correlation of Y9.1 and Yi and their P-Values

Correlations: Y9.1, Y20, Y21

	Y9.1	Y20
Y20	0.732	
	0.000	
Y21	0.536	-0.183
	0.000	0.182

Cell Contents: Pearson correlation
P-Value

H_0: Correlation between Y9.1 and Yi (i= 20,21) is significantly not different from zero.

H_1: Correlation between Y9.1 and Yi (i= 20,21) is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P (X5 and Xi) value =0.000, which is less than 0.05 at 95% of confidence level.

Therefore, correlations between Y9.1- Y20, and Y9.1-Y21 are significantly different from zero.

According to the table, the relationship in-between client generated risks and two independent variables; Risk on communicating the scope of the work and Risk on supply of funding are high, because Pearson correlation coefficients are close to 1.

$$\boldsymbol{Y9.1 = \beta 1 Y20 + \beta 2 Y21}$$

Where,

β1 – Coefficient of Y20 = 1, β2 - Coefficient of Y21 = 1

Y9.1 = 1.00 Y20 + 1.00 Y21

Risk Equation

Risk equation coefficients;

Coefficient of Y15 = Mean value * 1.00 = 0.54*1.00 = 0.54

oefficient of Y16 = Mean value * 1.00 = 0.46*1.00 = 0.46

$$\boldsymbol{Y9.1 = 0.54\, Y20 + 0.46\, Y21}$$

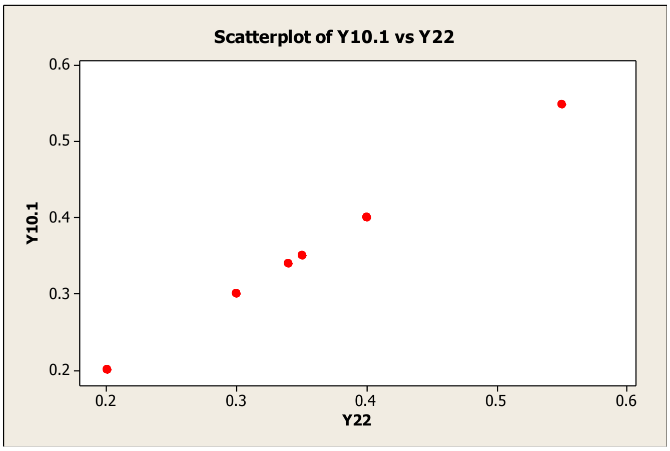
<u>Case 06, 07 and 08</u>

	Variable 1	**Variable 2**
06	Consultant generated Risks Y10.1	Risk on submitting accurate design and estimate Y22
07	Risk on submitting accurate design and estimate Y22.1	Risk on communicating the scope of the work Y20.1
08	Risk on supply of funding Y21.1	Risk on submitting accurate design and estimate Y22.2

<u>Case 06</u>

Y10.1 = Y22

Risk of consultant generated risks equal to the risk on submitting accurate design and estimate.



Risk Equation

$$\boldsymbol{Y10.1 = f(\,Y22)}$$

Risk equation coefficients;

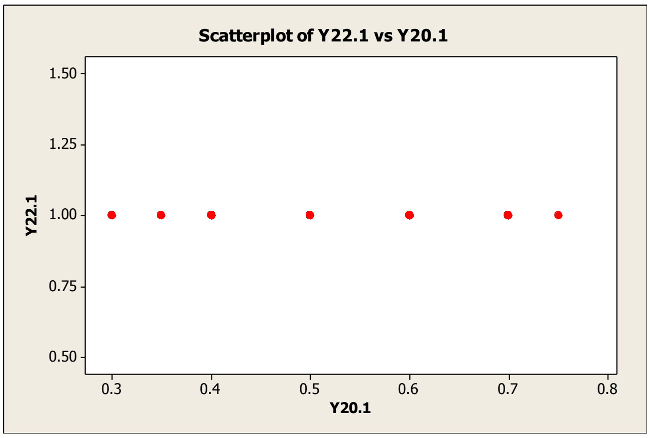
Coefficient of Y22 = Mean value * 1.00 = 1.00*1.00 = 1.00

$$\boldsymbol{Y10.1 = \; Y22}$$

<u>Case 07</u>

Y22.1 = Y20.1 = 1

Degree of Risk on submitting accurate design and estimate is not dependent on Degree of Risk on communicating the scope of the work, as it always remain 1. Probability of occurring Risk on submitting accurate design and estimate is always 1.



Risk Equation

$$\boldsymbol{Y22.1 = f(\,Y20.1)}$$

Risk equation coefficients;

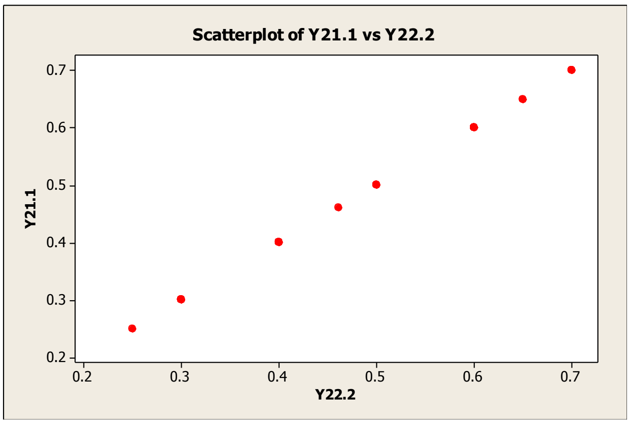
Coefficient of Y20.1 = Mean value * 1.00 = 0.54*1.00 = 0.54

$$\boldsymbol{Y22.1 = \ 0.54\,Y20.1}$$

Case 08

Y21.1 = Y22.2

Degree of Risk on supply of funding equals to Degree of Risk on submitting accurate



design and estimate.

Risk Equation

$\boldsymbol{Y21.1 = f(Y22.2)}$

Risk equation coefficients;

Coefficient of Y22.2 = Mean value * 1.00 = 1.00*1.00 = 1.00

$\boldsymbol{Y21.1 = Y22.2}$

Case 09

Dependent variable	**Independent Variable**
Materials Supply Related Risks Y3.1	Risk on labour supply Y7.1

Pearson correlation of Y3.1 and Y7.1 = 0.702

P-Value = 0.000

H_0: Correlation between Y3.1 and Y7.1 is significantly not different from zero.

H_1: Correlation between Y3.1 and Y7.1 is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P (Y3.1 and Y7.1) value =0.000, which is less than 0.05 at 95% of confidence level. Therefore, correlation between materials supply related risks and risk on labour supply are significantly different from zero.

Regression Analysis: Y3.1 versus Y7.1

Regression model

$$\boldsymbol{Y3.1 = \beta 0 + \beta 1 Y7.1 \pm \varepsilon}$$

β0 - Constant, β1 – Coefficient of Y7.1, ε – Error

Hypothesis

H_0: β 1 is less than or equal to zero

H_1: β 1 is not less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

When null hypothesis is rejected a relationship between Y3.1 and Y7.1 variables exists. The relationship will always remain positive.

If p-value ≤ 0.05, reject the null hypothesis at 95% confidence level.

P values = 0, Therefor H_i: $\beta_i > 0$

The regression equation is

Y3.1 = 0.159 + 1.23 Y7.1

S = 0.0531859   R-Sq = 49.3%   R-Sq(adj) = 48.3%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	1	0.37256	0.37256	51.45	0.000
Residual Error	53	0.38380	0.00724		
Total	54	0.75636			

H_0: There is a no linear relationship in-between Y3.1 and Y7.1.

H_1: There is a no linear relationship in-between Y3.1 and Y7.1.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

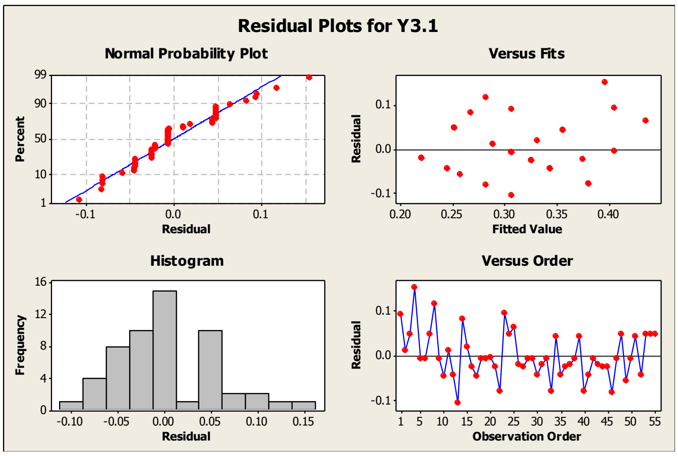
In the ANOVA table it can be seen that F value is significant;

F= 51.45, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between material supply related risks and risk on labour supply.

And also Coefficient of Determination R^2= 49.3%

This means that 49.3% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Unusual Observations

Obs	Y7.1	Y3.1	Fit	SE Fit	Residual-St	Resid
4	0.193	0.55000	0.39601	0.01408	0.15399	3.00R
8	0.100	0.40000	0.28226	0.00809	0.11774	2.24R
13	0.120	0.20000	0.30685	0.00718	-0.10685	-2.03R
25	0.225	0.50000	0.43598	0.01909	0.06402	1.29 X

There are four unusual observations in the model too.

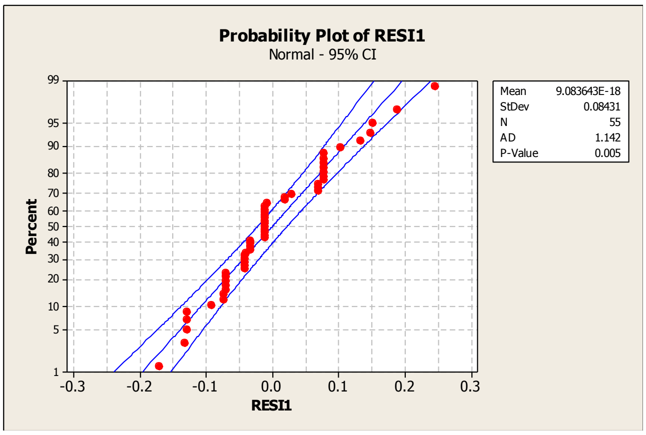
Durbin-Watson statistic = 1.76974

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.769) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed

H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 1.142

It can be concluded with 95% confidence level (A-D=1.142 and p<0.005 which is lower than 0.05) errors are distributed normally.

And the mean error is zero.

Risk Equation

$$\boldsymbol{Y3.1 = f(\,Y7.1)}$$

Degree of Risk of Y3.1

Y3.1 = 0.159 + 1.23 Y7.1

Risk equation coefficients;

Coefficient of Y7.1 = 0.159+ Mean value * 0.39 = 0.159+ 1.29*0.39 = 0.66

$$\boldsymbol{Y3.1 = \ 0.66\,Y7.1}$$

<u>Case 10</u>

Dependent variables	**Independent variable**
Price Risks Y11.1	Regulations Y5.1

Quality Risks Y12.1	
Availability Risks Y13.1	
On-time delivery Risks Y14.1	

Pearson correlation of Y11.1 and Y5.1 = 0.559

P-Value = 0.000

Pearson correlation of Y12.1 and Y5.1 = 0.632

P-Value = 0.000

Pearson correlation of Y13.1 and Y5.1 = 0.741

P-Value = 0.000

Pearson correlation of Y14.1 and Y5.1 = 0.391

P-Value = 0.003

H_0: Correlation between Yi (i=11 to 14) and Y5.1 is significantly not different from zero.

H_1: Correlation between Yi (i=11 to 14) and Y5.1 is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P (Yi and Y5.1) value =0.000, which is less than 0.05 at 95% of confidence level.

Therefore, correlations between regulations and price, quality, and availability related risks and regulations related risks are significantly different from zero, except for on time delivery risks and regulations.

Risk Equation

$f(Y11.1, Y12.1, Y13.1, Y14.1) = Y\ 5.1$

Risk equation coefficients;

Coefficient of Y11.1 = 0.18

Coefficient of Y12.1 = 0.25

Coefficient of Y13.1 = 0.16

Coefficient of Y14.1 = 0.19

$$0.18\,Y11.1 + 0.25\,Y12.1 + 0.16\,Y13.1 + 0.19\,Y14.1 = Y5.1$$

Case 11

Dependent Variable	**Independent Variable**
Materials Supply Related Risks Y3.2	Decision Making Risks Y15.1
	Communication Risks Y16.1
	Sub-contractor Risks Y17.1
	Financial Risks Y18.1
	Planning Risks Y19.1

Correlations: Y3.2, Y15.1, Y16.1, Y17.1, Y18.1, Y19.1

Y3.2	Y15.1	Y16.1	Y17.1	Y18.1
Y15.1	0.702			
	0.000			
Y16.1	0.707	0.689		
	0.000	0.000		
Y17.1	0.498	0.037	0.215	
	0.000	0.788	0.115	
Y18.1	0.398	-0.041	-0.056	0.252
	0.003	0.769	0.686	
	0.063			
Y19.1	0.633	0.299	0.250	
	0.182	0.205		
	0.000	0.026	0.066	
	0.183	0.133		

Cell Contents: Pearson correlation

P-Value

H_0: Correlation between Y3.2 and yi (i=15 to 19) is significantly not different from zero.

H_1: Correlation between Y3.2 and yi (i=15 to 19) is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P Y3.2 – Yi value = 0.000, which is less than 0.05 at 95% of confidence level; so reject the null hypothesis.

The correlation between material supply related risks and xi significantly different from 0.

But,

Pearson Correlation Coefficients;

Y3.2-Y15 = 0.702; close to 1

Y3.2-Y16 = 0.625; close to 1

Y3.2-Y17 = 0.463; not close to 1

Y3.2-Y18 = 0.388; not close to 1

Y3.2-Y19 = 0.548; close to 1

Therefor it can be concluded that there is high correlation between material supply related risks and decision making risk, communication risks and planning risks but not with sub-contractor or financial risks.

Regression Analysis: Y3.2 versus Y15.1, Y16.1, Y19.1

Regression model

$$\boldsymbol{Y3.2 = \beta 0 + \beta 1 Y15.1 + \beta 2 Y16.1 + \beta 3 x Y19.1 \pm \varepsilon}$$

β0 Constant, β1 – Coefficient of Y15, β2 – Coefficient of Y16, β3– Coefficient of Y19, ε – Error

Hypothesis

H_0: β i is less than or equal to zero

H_1: β i is not less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

When null hypothesis is rejected a relationship between Y3 and Xi variables exists. The relationship will always remain positive.

If p-value ≤ 0.05, reject the null hypothesis at 95% confidence level.

Y3.2 = 0.0705 + 1.15 Y15.1 + 0.907 Y16.1 + 1.54 Y19.1

Predictor	Coef	SE Coef	T	P
Constant	0.07048	0.01953	3.61	0.001
Y15.1	1.1517	0.3616	3.19	0.002
Y16.1	0.9066	0.2181	4.16	0.000

Y19.1	1.5410	0.2452	6.28	0.000

P value of Y16.1 = 0.210, $p>0.05$

So β2 is equal to zero; H_0: $\beta_i \leq 0$

Therefore the regression can be modeled as;

$$\boldsymbol{Y3.2 = \beta0 + \beta1Y15.1 + \beta3xY19.1 \pm \varepsilon}$$

Regression Analysis: Y3.2 versus Y15.1, Y19.1

The regression equation is

Y3.2 = 0.0821 + 2.15 Y15.1 + 1.61 Y19.1

Predictor	Coef	SE	Coef	T
Constant	0.08211	0.02214	3.71	0.001
Y15.1	2.1499	0.3097	6.94	0.000
Y19.1	1.6058	0.2804	5.73	0.000

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

If p-value ≤ 0.05, reject the null hypothesis at 95% confidence level.

P = 0; H_1: $\beta_i > 0$

The relationship between the Y3.2 variable Materials Supply Related Risks and Y15.1 and Y19.1 variables decision making, planning risks exists.

S = 0.0420489 R-Sq = 68.9% R-Sq(adj) = 67.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	0.20351	0.10176	57.55	0.000
Residual Error	52	0.09194	0.00177		
Total	54	0.29545			

H_0: There is a no linear relationship in-between Y3.2 and Y15.1, Y19.1.

H_1: There is a no linear relationship in-between Y3.2 and Y15.1, Y19.1.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

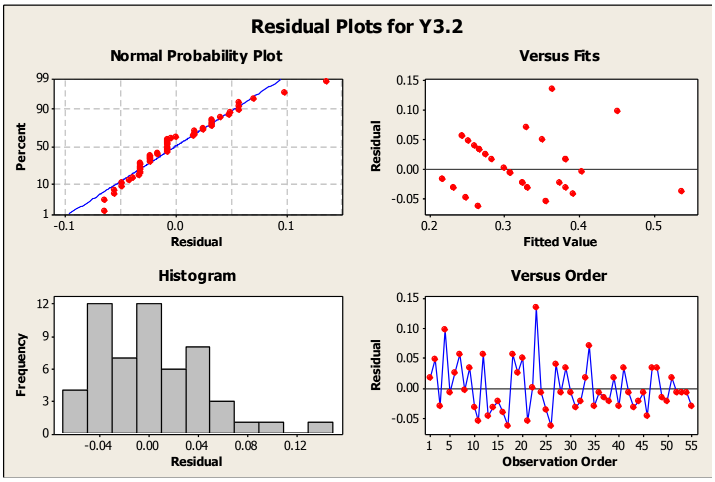
In the ANOVA table it can be seen that F value is significant;

F= 43.42, p= 0.000 at 95% confidence level.

Therefore, it can be concluded that there are significant linear relationships between material supply related risks and x variables decision making, planning risks.

And also Coefficient of Determination R^2= 68.9%

This means that 68.9% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Unusual Observations

Obs	Y15.1	Y3.2	Fit	SE Fit	Residual	St Resid
4	0.110	0.55000	0.45109	0.01734	0.09891	2.58RX
16	0.105	0.35000	0.39216	0.01830	-0.04216	-1.11 X
23	0.075	0.50000	0.36380	0.00826	0.13620	3.30R
25	0.100	0.50000	0.53798	0.02373	-0.03798	-1.09 X

There are three unusual observations in the model too.

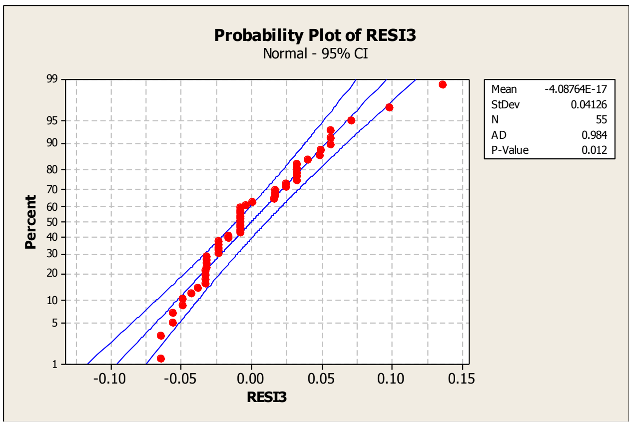
Durbin-Watson statistic = 2.19376

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 2.193) being more than 2, confirms that errors are random, and negatively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 0.984

It can be concluded with 95% confidence level (A-D=0.984 and p=0.012which is more than 0.05) errors are not distributed normally.

And the mean error is zero.

Conclusion is that the model Y3.2 = 0.0821 + 2.15 Y15.1 + 1.61 Y19.1 is not significant.

Therefore coefficients of degree of risks derived from the regression analysis,

Coefficient of Y15.1 = 2.15

Coefficient of Y19.1 = 1.61

Risk Equation

$Y3.2 = f(Y15.1, Y19.1)$

Risk equation coefficients;

Coefficient of Y15.1	= Mean value * 2.15	= 0.18*1.19	= 0.21
Coefficient of Y19.1	= Mean value * 1.61	= 0.25*1.61	= 0.40

$Y3.2 = 0.21\, Y15.1 + 0.40\, Y16.1$

<u>Case 12</u>

Dependent variable	**Independent Variable**
Sub-contractor Risks Y17.2	Risk on labour supply Y7.1

Pearson correlation of Y17.2 and Y7.1 = 0.871

P-Value = 0.000

H_0: Correlation between Y17.2 and Y7.1 is significantly not different from zero.

H_1: Correlation between Y17.2 and Y.1 is significantly different from zero.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

P Y17.2 – Y7.1value = 0.000, which is less than 0.05 at 95% of confidence level; so reject the null hypothesis. The correlation between material supply related risks and xi significantly different from 0.

According to Pearson correlation coefficient value, which is 0.871, close to 1, the correlation in-between subcontractor risks and risk on labour supply is significantly high.

Regression Analysis: Y17.2 versus Y7.2

Regression model

$$\boldsymbol{Y17.2 = \beta 0 + \beta 1 Y7.2 \pm \varepsilon}$$

β0 Constant, β1 – Coefficient of Y7.2, ε – Error

Hypothesis

H_0: β 1 is less than or equal to zero

H_1: β 1 is not less than zero

H_0: $\beta_i \leq 0$, H_1: $\beta_i > 0$

If p-value ≤ 0.05, reject the null hypothesis at 95% confidence level.

P values = 0, Therefore H_i: $\beta_i > 0$

When null hypothesis is rejected a relationship between X17.2 and Y7.2 variables exists. The relationship will always remain positive.

The regression equation is

Y17.2 = 0.0577 + 1.61 Y7.2

S = 0.0290639   R-Sq = 75.9%   R-Sq(adj) = 75.5%

Analysis of Variance

Source	F	SS	MS	F	P
Regression	1	0.14132	0.14132	167.30	0.000
Residual Error	53	0.04477	0.00084		
Total	54	0.18609			

H_0: There is a no linear relationship in-between Y17.2 and Y7.2.

H_1: There is a no linear relationship in-between Y17.2 and Y7.2.

H_0: $\rho = 0$, H_1: $\rho \neq 0$

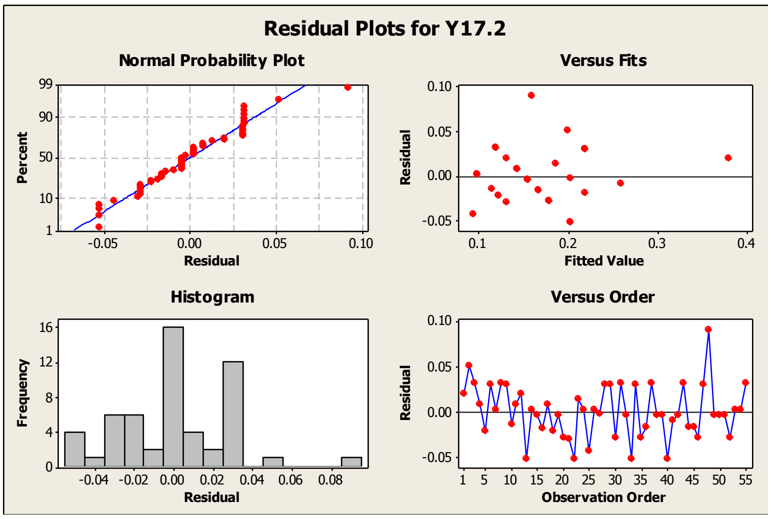
In the ANOVA table it can be seen that F value is significant;

F= 167.3, p= 0.000 at 95% confidence level

Therefore, it can be concluded that there are significant linear relationships between material supply related risks and risk on labour supply.

And also Coefficient of Determination R^2= 75.9%

This means that 75.9% of the observed variability is explained by the value which indicates the higher accuracy of the model.



Unusual Observations

Obs	Y7.2	Y17.2	Fit	SE	Fit Residual	St Resid
12	0.200	0.40000	0.38016	0.01726	0.01984	0.85 X
48	0.063	0.25000	0.15848	0.00393	0.09152	3.18R

There are two unusual observations in the model too.

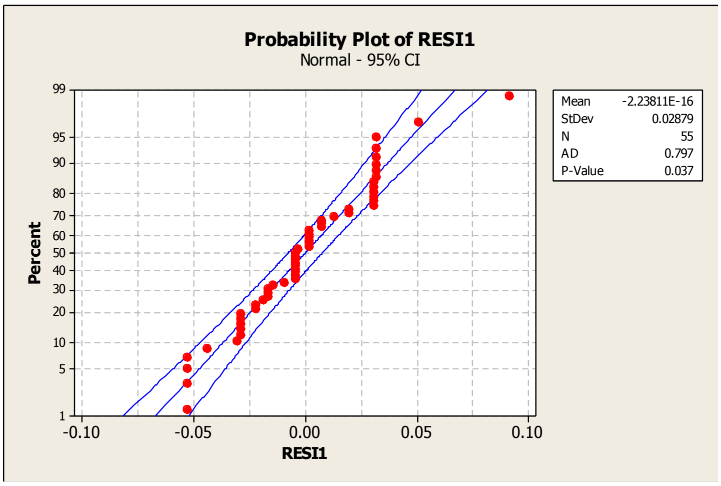
Durbin-Watson statistic = 1.86958

When looking at the diagnostic statistics for Errors,

i. Randomness: DW statistic (Durbin-Watson Statistic = 1.86958) being less than 2, confirms that errors are random, and positively correlated.

ii. The random a/nature or pattern in the graph which is plotted between residuals and the fitted values confirms the constant variance for errors.

iii. Normality



With the details shown in the above graph, it can be tested whether errors are normally distributed or not.

H_0: Errors are normally distributed Vs H_1: Errors are not distributed normally

Test statistic= A-D test statistic= 0.797

It can be concluded with 95% confidence level (A-D=0.797 and p=0.037 which is lower than 0.05) errors are distributed normally.

And the mean error is zero.

Y17.2 = 0.0577 + 1.61 Y7.2

Coefficient of Y7.2 = 1.61

Risk equation

$Y17.2 = f(Y7.2)$

Risk equation coefficients;

Coefficient of Y7.2 = 0.577+ Mean value * 1.61 = 0.577+ 0.39*1.61 = 1.20

$Y17.2 = 1.2\,Y7.2$

Case 13

Dependent Variable	**Independent Variable**
Risk on Supply of Funding Y21.2	Risk on communicating the scope of the work Y20.2

Correlations: Y21.2, Y20.2

Pearson correlation of X18 and X17 = 0.375

P-Value = 0.005

H_0: Correlation between X18 and X17 is significantly not different from zero.

H_1: Correlation between X18 and X17 is significantly different from zero.

$H_0: \rho = 0, H_1: \rho \neq 0$

P X18 – X17 value = 0.005, which is less than 0.05 at 95% of confidence level; so reject the null hypothesis. The correlation between Risk on supply of funding and risk on communicating the scope of the work significantly different from 0.

According to Pearson correlation coefficient value, 0.375, which is not close to 1, describes that the correlation in-between subcontractor risks and risk on labour supply is significantly low.

<u>Case 14</u>

Dependent Variable	**Independent Variable**
Decision Making Risks Y15.2	Risk on submitting accurate design and estimate Y22.3
Communication Risks Y16.2	
Sub-contractor Risks Y17.2	
Financial Risks Y18.2	
Planning Risks Y19.2	

Y22.3 = 1

$Y15.2 + Y\ 16.2 + Y17.2 + Y18.2 + Y19.2 = \text{ Y22.3 } = 1$

Risk Equation

$Y22.3 = f(Y15.2, Y16.2, Y17.2, Y18.2, Y19.2)$

Risk equation coefficients;

Coefficient of Y15.2 = 0.18

Coefficient of Y16.2 = 0.25

Coefficient of Y17.2 = 0.16

Coefficient of Y18.2 = 0.19

Coefficient of Y19.2 = 0.22

$0.18Y15.1 + 0.25\ Y16.2 + 0.16\ Y17.2 + 0.19\ Y18.2 + 0.22\ Y19.2 = Y22.3$

Appendix XIII – Deep Rooted Primary Risk Triggers of Material Suppliers' Risk Topics

Table 11: Analysis to find the deep rooted primary risk triggers

Risk Topic	Tier 1	Tier 2	Tier 3
Consultant rejecting the materials	There is a gap between the standards and the actual materials	Quality issue in the production process	Human Generated Risks, Resource Limitation/Infrastructure Risks, Unavoidable Risks
Order cancellation	Contractor has planned it poorly Schedule changes Payment issues Consultant's influence	Rain Delays in approvals	Human Generated Risks, Resource Limitation/Infrastructure Risks, Unavoidable Risks
Government policy changes	Regulation Risks Risk	Unavoidable Risks, Human Generated Risks	
Competitor initiatives	There is a space for the competitor to act over us in the market	Planning problems of the Material supplier Organizing problems of the material supplier Quality problems of the products Communication gaps between us and the contractor	Human Generated Risks, Resource Limitation/Infrastructure Risks, Unavoidable Risks
Transport issues	Planning problems of the material supplier Organizing problems of the material supplier Communication gaps of the material supplier	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks	
Cost of production increases	Price of raw materials increases Overheads increases	Planning problems of the material supplier Organizing problems of the material supplier	Resource Limitation/Infrastructure Risks, Human Generated Risks Unavoidable Risks