A BAYESIAN ANALYSIS APPROACH TO QUANTIFY THE COST OVERRUN FACTORS IN ROAD CONSTRUCTION PROJECTS

Thesis of

Masters of Science

In

Construction Engineering and Management

By

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Thesis titled

A BAYESIAN ANALYSIS APPROACH TO QUANTIFY THE COST OVERRUN FACTORS IN ROAD CONSTRUCTION PROJECTS

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has been accepted towards the partial fulfillment

of the requirements for the degree of

Master of Science in Construction Engineering and Management

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This thesis is dedicated to my parents and respected teachers

ACKNOWLEDGEMENT

First and foremost our greatest regards to the Almighty Allah for bestowing upon us the courage to face the complexities of life and complete this report successfully. Here I would pay my deepest gratitude to my supervisor Dr. M. Jamaluddin Thaheem (Head of Construction Engineering & Management Department), for his guidance, motivation, support, time and encouragement, to accomplish my research. I am extremely thankful to my committee members, Dr. Hamza Farooq Gabriel (NICE) and Dr. Muhammad Bilal Khurshid and Engr. Fahim Ullah for supporting me during this work.

I owe my special thanks to my batch mates of CEM-05 for their support and motivation throughout the research work. I also owe my special thanks to the respondents for their valuable contribution to this research task.

In the end, I pay gratitude to my family for their endless support, encouragement, prayers and patience.

ABSTRACT

Almost every project in the construction industry is facing cost overrun problem due to several risks involved which results into poor performance in terms of delay and cost overrun in construction projects. In order to ensure project success by addressing those challenges, risk management is considered an integral part of project management. Although many studies have proposed a variety of processes and techniques, and Project Risk Management (PRM) is rapidly evolving as a result, handling uncertainty in complex projects still remains a challenge. Cost overrun is universal phenomena in construction industry and road projects are no exception in it. The economy of every country is measured through the development of infrastructure. Many studies have been carried out globally to identify the causes of cost overrun in road construction projects. However, these studies lack in providing a probabilistic analysis in order to capture the uncertainty of causes of cost overrun. This points toward a clear need of using a quantitative approach in road sector. The current study provides an application of an expert elicitation method based on Bayesian analysis approach to quantify the uncertainty of cost overrun causes in road construction projects of Pakistan. *Bayesian* method is a powerful analytical tool that will help the decision makers to understand the perception about the risks or causes that affect project performance in terms of cost. The probabilities from Bayesian analysis are simulated with the help of Monte Carlo technique which is quantitative risk analysis approach used to generate most probable outcomes. The significance of results is that they help in developing new effective strategies for risk management in road projects to enhance project performance. It is concluded that instead of using arbitrary contingency sums to account for all risks involved in road projects it is better to identify critical causes and to capture the uncertainty involved in risk identification step that will ultimately improve the efficiency of road construction industry

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ABBREVIATIONS

PVA = Probability of Cost Overrun due to Variation Order

PMPE = Probability of Cost Overrun due to Material Price Escalation

PIE = Probability of Cost Overrun due to Inaccurate Estimate

PSD = Probability of Cost Overrun due to Schedule Delay

PDEC = Probability of Cost Overrun due to Design Error Changes

PDSC = Probability of Cost Overrun due to Differing Site Conditions

PLAP = Probability of Cost Overrun due to Land Acquisition Problem

PRUS = Probability of Cost Overrun due to Relocation of Utilities & Services

PMC = Probability of Cost Overrun due to Market Conditions

PLGP = Probability of Cost Overrun due to Local Government Pressures

MCS = Monte Carlo simulation

BN = Bayesian Networks

Chapter 1

INTRODUCTION

1.1 BACKGROUND

The construction industry is the mechanism through which society's goals of urban and rural development are achieved. Not only does it offer the development, it also has a great impact on the economy of the country (Leibing, 2001). However, the construction process is highly influenced by stochastic and unanticipated variables which could result from different sources (Andi, 2006). These sources include performance of construction parties, financial and managerial issues, resource unavailability, and external conditions (Enshassi et al., 2009; Flanagan and Norman, 1993; Smith, 1999). This results into poor performance in terms of delay and cost overrun in construction projects (Mahamid and Dmaidi, 2013).

Estimating reliable cost for construction projects is one of the most important and challenging tasks for the project managers (Cornick, 1999). In order to evaluate the success of a project, there is a need to consider the cost overrun which is a difference between the estimated and actual costs (Al-Hazim, 2015). Risks that incur in the project causing cost overrun due to external circumstances will affect the performance in terms of cost, time and quality (Smith et al., 2009). Underestimation of project cost and resources is a common contributor to project failure (Lim, 2015). In order to ensure project success by addressing these challenges, risk management is considered an integral part of project management (Hillson, 2002). Although many studies have proposed a variety of processes and techniques, and Project Risk Management (PRM) is rapidly evolving as a result, handling uncertainty in complex projects still remains a challenge.

The wide range of studies for analyzing the factors of cost overrun in road projects includes regression analysis (Creedy et al., 2010), sensitivity analysis (Molenaar, 2005), and statistical process control techniques like Pareto chart and cause and effect diagrams (Nassar et al., 2005). Also, some of these factors are grouped using cost data of sample infrastructure projects (Lee, 2008). Further, attempts are made to analyze the causes of cost and time overrun in highway projects with the help of documents and reports of several past projects (Al-Hazim, 2015; Vidalis and Najafi, 2002). Ranking of key factors is also performed using frequency occurrence index (Wijekoon and Attanayake, 2013). But every research does not necessarily rely upon previous data, in some cases the cost and schedule overrun key factors of road projects are analyzed using weighted opinion average or relative importance (Chileshe et al., 2010; Kaliba et al., 2009; Mahamid et al., 2011; Nasir et al., 2012). The unavailability of previous data, which is a major challenge and driver towards opinion-based studies, has created an opportunity to use mature analytical techniques such as Bayesian method. Bayesian method is a subjective approach that compute the uncertainties of risks based on expert opinion that can be combined with sample evidence if available to get posterior probability that can be used for formal risk analysis (Adams, 2008).

Bayesian method is a powerful technique used worldwide in different fields to model uncertainty involved in different decision making problems (Cheng et al., 1997). To compute subjective probabilities from experts Bayesian approach is one of the most suitable probabilistic statistical methods to capture the uncertainty of risks with an in-depth mathematical background. It is capable of modelling the causal relationship and conditional dependencies between the variables to quantify the uncertainty in projects.

Bayesian approach has been used in different fields of science. A new unifying approach is proposed for modelling continuous variables in BN called dynamic discretization which approximates continuous variables without recourse to the traditional approach of Monte Carlo simulation methods and illustrated the practical usefulness of the approach with an application involving the fusion of diverse sources of temporal data for fault diagnosis, classification and prediction of system behavior (Neil et al., 2000). BN is applied in real-world problems such as diagnosis, forecasting, automated vision, sensor fusion and manufacturing control (Heckerman et al., 1995).

BNs also provide an intuitively compelling approach for handling causal relationships and external influences (Mittnik and Starobinskaya, 2010). The application of BNs as a tool for mapping causal dependencies between frequencies and severities of risk events is demonstrated for modelling financial institution's operational risk. A quantitative assessment framework is proposed integrating the inference process of BNs to traditional probabilistic risk analysis for modelling dependencies between cost items (Khodakarami and Abdi, 2014). Bayesian method is used for presenting an expert elicitation model for the analysis of payments delay as a risk in international construction project subjective probability is combined with the historical data to get the posterior probability (Adams, 2008). This approach is taken as the basis for the research that will be carried on construction projects in Pakistan. Yet, application of Bayesian analysis in project management is uncommon.

1.2 PROBLEM STATEMENT

To measure the success of a project, the gap between the originally estimated cost and the same at completion, known as cost overrun, is considered of paramount importance(Al-Hazim, 2015). Projects facing cost overrun lead to client dissatisfaction. Any project not matching the schedule and funding requirements are prone to have damaging effect for developing countries whose prosperity is greatly dependent on infrastructure development, especially in terms of road construction projects (Kaliba et al., 2009). Like building, road construction projects also faces cost overruns. Currently construction industry of Pakistan is facing cost overrun problems in road construction projects.

Many research studies are found on causes of cost overrun in building projects, only a few are found related to road projects, but they lack in providing a probabilistic analysis. With advance research in risk management, common causes or risks factors are need to be identified by performing a quantitative risk analysis to elicit the subjective probabilities of causes through expert opinion based on Bayes theorem to achieve better rigor in risk analysis. Due to little or no data available, this study will provide a probabilistic risk analysis approach that aimed at assessing the causes of cost overrun in road construction projects using expert elicitation based on Bayes theorem.

1.3 RESEARCH OBJECTIVES

The proposed approach gives a quantitative measure to assess the causes of cost overrun in road construction projects through expert elicitation based on Bayesian method. To capture the uncertainty of each cost overrun cause that leads to accuracy of cost estimation. Following objectives are considered:

1. To identify the common causes of cost overruns in road construction projects.
2. To determine the significant cost overrun factors in road construction projects.
3. To quantify the uncertainty of significant cost overrun factors in road construction projects.

1.4 SCOPE AND LIMITATION OF THE STUDY

Due to cost overrun issues faced by the project stakeholders in almost every road project in the construction industry of Pakistan many research endeavors have been done but they lack in assessing the cost overrun causes probabilistically based on Bayesian method. Since very little or no historical data is available in such a situation, Bayesian analysis is the most suitable approach. One of the limitations of the research is that it is only based on subjective expert opinion that are prone to some human error due to lack of data.

1.5 ORGANIZATION OF THESIS

Chapter 1 includes about the background, problem statement, research objectives, scope and limitations of the study. It provides a general overview.

Chapter 2 discusses about previous studies have been done related to the topic, extensive literature review is carried out to identify the causes of cost overrun, and to explain hoe Bayesian method works.

Chapter 3 describes the methodology adopted to perform in order to capture the uncertainty of causes. It also describes about the tools and techniques used in this research.

Chapter 4 explains the results obtained from the analysis that is carried out after gathering data from the experts.

Chapter 5 describes that how objectives of the research are achieved. Final conclusions and recommendations are presented.

Chapter 2

LITERATURE REVIEW

This chapter focuses on the past research carried out to identify the cost overrun causes in road construction projects. It will discuss about project management, risk management, cost overrun, the causes of cost overrun factors in road construction industry through literature review, basic concept of Bayesian analysis based on Bayes theorem and various research work done on it in different fields. The basic idea is to describe as to how Bayesian theorem works.

2.1 DEFINITIONS

2.1.1 PROJECT MANAGEMENT

The Project Institute (2002) defines project management as:

"Application of knowledge, skills, tools and techniques to project activities in order to meet or exceed stakeholder's needs and expectations from a project."

2.1.2 RISK AND RISK MANAGEMENT

There is some level of uncertainty in a project's outcome. There may be external circumstances or events that must not occur for the project to be successful. If such an event is probable, then it would be a risk. Risk is defined as:

"Likelihood of occurrence and the degree of impact of a negative event adversely affecting an activity" (Chapman, 2001).

It is the nature of projects that circumstances change as they are being planned and executed. Project risk management addresses about the uncertainty in project estimates and assumptions. According to PMBOK, (Guide, 2001):

"Risk Management is seen as the processes concerned with identifying, analyzing and responding to uncertainty throughout the projects lifecycle. It includes the maximizing the results of positive events and minimizing the consequences of adverse events".

2.2 QUALITATIVE AND QUANTITATIVE RISK ASSESSMENT

Risk assessment is complex systematic process that require qualitative and quantitative data for decision makers to use later for project risk management (Ayyub and Wilcox, 2000). It is an effective tool in improving project decision making that ultimately helps in successful project by achieving cost, time and performance objectives and meet client's needs in project delivery (Halpin, 1998). Qualitative and Quantitative risk analysis are two processes within the project risk management knowledge area in the planning process.

2.2.1 QUALITATIVE RISK ASSESSMENT

Qualitative risk assessment is used when there numerical data is insufficient, limited resources and time allowed is short. In this process, risk factors are classified into categories such as low, medium and high (Radu, 2009). A qualitative risk analysis prioritizes the identified risk using a pre-defined rating scale to compute the probability and impact of risk.

2.2.2 QUANTITATIVE RISK ASSESSMENT

Quantitative risk assessment is performed after risk identification and qualitative risk assessment. It is basically the further analysis of high priority risk factors to which a numerical rating is assigned in order to develop a probabilistic analysis of the project. Various methods are used to perform quantitative analysis, such as variance method, value at risk, Monte Carlo simulation method and Bayesian method (Radu, 2009). It is time consuming.

2.3 COST OVEERUN

Cost overrun is defined as the difference between the actual and estimated cost. Actual cost are defined as cost spend at the time of completion while estimated costs are forecasted at the time of project approval (Lee, 2008). Cost overrun is defined as percentage change in contract amount divided by the original contract award amount (Jackson, 1999).

$$\text{Cost Overrun} = \frac{\text{Final Contract Amount-Original Contract Amount}}{\text{Original Contract Amount}} \qquad \textbf{Equation 2.1}$$

Cost overrun is also known as "cost escalation", "cost increase", budget overrun (ZHU and LI, 2004). For a project to be successful it is necessary that it should be completed within budget, on time and to specified quality standards (Frimpong et al., 2003). The prosperity of developing countries is measured by the infrastructure development especially in terms of road sector (Kaliba et al., 2009). Due to more coverage and ease of accessibility, road projects indulge more financial support among other modes of transportation especially in developing countries (Abdulkareem and Adeoti, 2004). Transport is the fourth largest sector in the construction industry of Pakistan that contributes up to 10% to the Gross Domestic Product (GDP) and about 17% to the Gross Capital Formation. This sector consumes about 20-25% of annual federal Public Sector Development Program (PSDP) budget (Nasir et al., 2012). It is estimated that 2.3 million people (6% of the total employed labor of Pakistan) earn their living from this sector (Javied and Hyder, 2009). Several roads projects are planned to contribute towards GDP of the country but unfortunately they are facing cost overrun issues. Tribune (2010) published an article related to approval of $130 million loan by World Bank on the request of government of Pakistan to bear the expenses of cost overrun and delays for completion of road projects.

Extensive literature review indicates that many studies have been carried out globally to identify the causes of cost overrun in road construction projects. However, these studies lack in providing a probabilistic analysis in order to capture the uncertainty of causes of cost overrun. This points toward a clear need of using a quantitative approach in road sector. The current study provides an application of an expert elicitation method based on Bayesian analysis approach to capture the uncertainty of causes of cost overrun in road construction projects of Pakistan. The probabilities from Bayesian analysis are simulated with the help of Monte Carlo technique which is quantitative risk analysis approach used to generate most probable outcomes. The paper follows a typical outline firstly reviewing extensive literature followed by methodology adopted. Analysis is performed on data collected and results are generated. Conclusions are drawn from the results followed by recommendations for future research.

2.4 CAUSES OF COST OVEERUN IN ROAD PROJECTS

An analysis of 161 transportation projects in Korea is performed to group causes of cost overrun into changes in scope, delays during construction, unreasonable estimation and adjustment of project costs, and no practical use of earned value management system (Lee, 2008). A study of Nigerian road projects reveals top four factors: increase in global demand for construction materials, outdated estimates, traffic control planning and corruption (Isma'il et al., 2013). Major causes of cost overrun in Zambia road construction projects are bad weather, scope changes, environmental costs, schedule delays, strikes, technical challenges, inflation and local government pressures (Kaliba et al., 2009). A study of road projects in Palestine identifies material price fluctuation, insufficient time for estimate, experience in contract, size of contract and incomplete drawings as cost overrun factors (Mahamid et al., 2011). A Sri Lanka study identified causes, effects and variations in highway projects as poor scope definition, land acquisition and funding issues (Priyantha et al., 2011). Research on cost and time overrun causes in highway projects in Pakistan reveals major factors as scope changes, inappropriate government policies, improper planning, price escalation and land acquisition (Nasir et al., 2012). Findings related to delay and cost overrun in road construction projects in Jordan reveal that terrain and weather conditions are the major causes (Al-Hazim, 2015).

Based on an extensive literature review of 15 relevant studies aimed at identifying the causes of cost overrun in road construction projects, it is observed that a number of factors are common between studies and countries. Particularly, 25 factors are identified which appear in the literature published from 2002 to 2015 as shown in Table 2.1.

Table 2.1 Causes of Cost Overrun in Road Projects

Sr. #	Causes of Cost Overrun in Road projects	Authors
1	Variation order	Creedy et al.,2010; Lee, 2008; Chang, 2002; Kaliba et al., 2009; Rafiq et al.,2012; Wakjira, 2011; Chileshe et al., 2010; Al-Hazim et al., 2015; Vidalis et al., 2002

2	Design errors changes	Creedy et al.,2010; Nasser et al.,2005; Molenaar, 2005; Akoa, 2011; Al-Hazim et al., 2015; Mahamid et al.,2011; Rafiq et al.,2012; Wijekoon, 2013
3	Inaccurate estimates	Lee, 2008; Nasser et al.,2005; Chang, 2002; Chileshe et al., 2010; Rafiq et al.,2012; Mahamid et al.,2011; Al-Hazim et al., 2015; Akoa, 2011; Isma'il et al.,2013
4	Differing site conditions	Creedy et al.,2010; Molenaar, 2005; Nasser et al.,2005; Wakjira, 2011; Akoa, 2011; Al-Hazim et al., 2015; Vidalis et al., 2002
5	Material price escalation	Creedy et al.,2010; Kaliba et al., 2009; Mahamid et al.,2011; Rafiq et al.,2012; Wakjira, 2011; Chileshe et al., 2010; Wijekoon, 2013; Isma'il et al.,2013
6	Land acquisition problem	Creedy et al.,2010; Molenaar, 2005; Rafiq et al.,2012; Wakjira, 2011; Wijekoon, 2013
7	Schedule delay	Lee, 2008; Nasser et al.,2005; Chang, 2002; Kaliba et al., 2009; Wakjira, 2011; Chileshe et al., 2010
8	Market conditions	Molenaar, 2005; Wakjira, 2011; Chileshe et al., 2010; Al-Hazim et al., 2015; Wijekoon, 2013
9	Weather conditions	Nasser et al.,2005; Creedy et al.,2010; Kaliba et al., 2009; Al-Hazim et al., 2015; Vidalis et al., 2002
10	Local government pressures	Kaliba et al., 2009; Mahamid et al.,2011; Rafiq et al.,2012; Chang, 2002
11	Relocation of services and utilities	Creedy et al.,2010; Molenaar, 2005; Rafiq et al.,2012; Wijekoon, 2013; Vidalis et al., 2002
12	Construction engineering errors	Creedy et al.,2010; Nasser et al.,2005; Kaliba et al., 2009

13	Improper planning	Nasser et al.,2005; Rafiq et al.,2012; Akoa, 2011
14	Lack of communication	Chang, 2002; Chileshe et al., 2010; Rafiq et al.,2012
15	Environmental protection and mitigation cost	Creedy et al.,2010; Kaliba et al., 2009; Molenaar, 2005
16	No practical use of earned value management	Lee, 2008
17	Owner project management costs	Creedy et al.,2010
18	Corruption	Isma'il et al.,2013;
19	Change in seismic criteria (for bridges)	Molenaar, 2005;
20	Contract claim settlement	Nasser et al.,2005
21	Strikes	Kaliba et al., 2009
22	Inconsistent cash flows (claims for idle manpower and machine)	Rafiq et al.,2012
23	Experience in contracts	Mahamid et al.,2011
24	Size of contract	Mahamid et al., 2011
25	Lack of equipment	Akoa, 2011

Before conducting the pilot survey, a total of 25 causes of cost overrun in road construction projects were selected from literature and frequency analysis was performed to calculate the criticality of each cause as given in Table 2.2

Table 2.2 Criticality of Causes from Literature Review

Sr. #	Causes of Cost Overrun	Criticality of academia
1	Inaccurate estimates	6
2	Variation Orders	6
3	Material price escalation	5.333
4	Design error changes	5.333
5	Differing site conditions	4.6
6	Schedule delay	4
7	Weather Conditions	3.333

8	Land acquisition problem	3.33
9	Relocation of services and utilities	3.33
10	Market conditions	3.33
11	Local government pressures	2.67
12	Constructibility and technical complexity	2.67
13	Improper Planning	2
14	Environmental Protection and mitigation cost	2
15	Size of project	0.67
16	Corruption	0.67
17	Experience in contracts	0.67
18	Inconsistent cash flows	0.67
19	Lack of equipment	0.67
20	Lack of communication	0.67
21	Contract claim settlement	0.67
22	Lack of earned value management	0.67
23	Owner Project management cost	0.67
24	Strikes	0.67
25	Change in seismic criteria	0.67

2.5 BAYESIAN INFERENCE AND BAYESIAN ANALYSIS

The technique that is adopted to capture the uncertainty in the causes of cost overrun in road projects is Bayesian Analysis. This section outlines the basic concept of Bayesian approach based on Bayes Theorem.

2.2.1 ORIGIN OF BAYESIAN APPROACH

The term 'Bayesian' came into common usage in the 1950s, although this approach is introduced in 1763, when Thomas Bayes published his famous paper (Bayes and Price, 1763). This theory associated with his name explains that it was originally derived from elementary probability theory. The mathematicians and philosophers in the 19th century argue on the interpretation of probability, the idea of 'inverse probability' (i.e. inferring backwards from the data to parameters) was dominant in practical application of statistics (Fienberg, 2006).

In the 1950s, there was a renewed interest in foundations and statistical decision theory that led to developments surrounding the role of *'subjective probability'* and new statistical tools for scientific inference and decision-making. This was the Neo-Bayesian revival that fused the renewed emphasis on the likelihood principle with Bayes' theorem and subjective probability as the mechanisms for achieving inferential coherence (Fienberg, 2006).

2.2.2 COMPARISON BETWEEN FREQUENTIST AND BAYESIAN APPROACH

In the frequentist approach, variables are considered random and their probability is based on some physical or historical data through which inference is made by using confidence intervals. In contrast, Bayesian approach considers variables as "uncertain" and their probability is assigned by the expert opinion subjectively based on belief network and then inference is made through Bayes theorem. While the frequentist approach requires past data which is rare in the construction industries in contrast with it, Bayesian approach requires expert prior knowledge to infer about the uncertain conditional events (Khodakarami et al., 2007).

2.2.3 BAYES THEOREM

Bayes' Theorem is a theorem of probability theory originally stated by the Thomas Bayes. It provides the basic understanding about how the probability theory is affected when the new evidence arrives. In the Bayesian interpretation, probability measures a degree of belief. Bayes' theorem then links the degree of belief in a proposition before and after accounting for evidence. Formally, it is stated as per Equation 2.2.

$$\mathbf{P}\,(\mathbf{A} \mid \mathbf{B}\,) = \frac{\mathbf{P}\,(\mathbf{B}\,|\mathbf{A}) * \mathbf{P}\,(\mathbf{A})}{\mathbf{P}(\mathbf{B})} \qquad \textbf{Eq. 2. 2}$$

In many applications, for instance in Bayesian inference, the event B is fixed in the discussion and we wish to consider the impact of its having been observed on our belief in various possible events A. In such a situation the denominator of the last expression, the probability of the given evidence B, is fixed; what we want to vary is A. Bayes' theorem then shows that the posterior probabilities are proportional to the numerator:

$P(A|B) \propto P(A) \cdot P(B|A)$ (Proportionality over A for given B).

In words: posterior is proportional to prior time's likelihood. If events A_1, A_2, …… A_n are mutually exclusive and exhaustive, i.e., one of them is certain to occur but no two can occur together, and we know their probabilities up to proportionality, then we can determine the proportionality constant by using the fact that their probabilities must add up to one.

For proposition A and evidence or background B,

- P (A), the prior probability is the initial degree of belief in A.
- P (B|A), the conditional probability or likelihood is the degree of belief in B, given that the proposition A is true.
- P (A|B), the posterior probability is the probability for A after taking into account B for and against A.

In general, given 'n' mutually exclusive and exhaustive hypotheses A1, A2,…. An such that P (Ai) $\neq 0$ for all $1 \leq i \leq n$ the full version of Bayes' theorem is as shown in Equation 2.3.

$$\mathbf{P(Ai\ |B) = \frac{P\ (B\ |\ Ai\ ) * P(Ai)}{\sum P\ (B\ |\ Aj\ ) * P(Aj)}} \qquad \textbf{Equation 2.3}$$

In continuous form, Bayes' theorem is expressed as Equation 2.4.

$$\mathbf{f(\theta\ |\ X\ ) = \frac{\pi\ (\theta) * l\ (X\ |\ \theta\ )}{\int \pi\ (\theta) * l\ (X\ |\ \theta\ )\ d\theta}} \qquad \textbf{Equation 2.4}$$

2.2.4 BAYESIAN INFERENCE

Bayesian inference is an approach to statistics in which all forms of uncertainty are expressed in terms of probability. A Bayesian approach to a problem starts with the formulation of a model that we hope is adequate to describe the situation of interest. A *prior* probability for parameters of interest through subjective probabilities is quantified along with the conditional probabilities for observations given the true value of parameter (likelihood function) which is meant to capture our beliefs about the situation before seeing the data. After observing some data, we apply Bayes' rule to obtain a *posterior* distribution for these unknowns which takes account of both the prior and the data. From this posterior probability we can use it as an input variable to formal risk analysis. (Khodakarami et al., 2007).

2.3 APPLICATION OF BAYES THEOREM

Bayes' theorem has been used to perform probabilistic inference in the situation where one feature of an entity has a direct influence on another feature of that entity. Now consider the situation in which several features are related through inference chains and we are interested in probabilistic inference involving features that are not related via a direct influence. In these situations the conditional probabilities cannot be computed using a simple application of Bayes' theorem. BN have been developed to address this situation. BN enable us to perform probabilistic inference among several features in an acceptable amount of time (Khodakarami et al., 2007).

BN are a powerful and flexible tool used to capture the uncertainty between the variables. Due to their immense advantages BN have been used successfully worldwide in different fields. They are easy to use and help the decision makers. Also, they are frequently applied in real-world problems such as diagnosis, forecasting, automated vision, sensor fusion, and manufacturing control (Heckerman et al., 1995).

They have been extended to other applications including software risk management (Fan and Yu, 2004), transportation (Ülengin et al., 2007), project scheduling (Khodakarami et al., 2007), ecosystem and environmental management (Uusitalo, 2007) and assessing new product development project (Chin et al., 2009). A Bayesian network has many advantages such as suitability for small and incomplete datasets, structural learning possibility, combination of different sources of knowledge, explicit treatment of uncertainty and support for decision analysis, and fast responses (Uusitalo, 2007).

A hybrid Bayesian network is used to forecast the supplier negotiation strategy that helps the contractor in foreseeing the causal relationship between its alternative offer prices and a supplier future bidding strategies (Leu et al., 2014). A causal Bayesian network is developed to guide the cost estimators for estimating cost contingencies during tender preparation (Khalafallah et al., 2005). A study was proposed that provides a novel objective method to quantitatively assess the astrocytoma malignant level that can be used to assist doctors to diagnose the tumor (Lin et al., 2006).

A Bayesian network approach is applied to quantify the probability of construction project delays in a developing country (Kim et al., 2009). For large engineering project management systems, a Bayesian belief network is used by Korean shipbuilding industry. The research results are valuable in enabling industrial participants to manage their large engineering project risks and in extending the understanding of Korean shipbuilding risks (Lee et al., 2009). A study is proposed based on algorithms that use an information-theoretic analysis to learn Bayesian network structures from data (Cheng et al., 1997).

Lee (2001) presents Bayes probabilistic networks presented as a new methodology for encoding design Failure Modes and Effects Analysis (BN-FMEA) models of mechatronic system. Baldwin and Tomaso (2003) deal with the development of a theory on Bayesian networks. They propose a modified algorithm for solving knowledge querying and information updating, when dealing with continuous variables and with probabilistic and uncertain instantiations.

A framework for modelling the safety of offshore and marine engineering systems is developed by using fuzzy reasoning and evidential synthesis approaches. A case study of the collision risk between a Floating Production, Storage and Offloading unit (FPSO) and a shuttle tanker due to technical failure during a tandem offloading operation is used to illustrate the application of the proposed model (Ren et al., 2005).

Adams (2008) presents a Bayesian analysis approach that depicts about the perception of risk of payment delay in international construction contract risks for developing economy set in Ghana. It provide an effective strategic method to estimate the contract risks in international contracts and also considering its impact for risk management in projects. The main idea of using Bayes theorem is taken as the basis for the research in order to capture the uncertainty in causes of cost overrun. Yet application of Bayesian analysis is still uncommon.

2.4 SUMMARY

This chapter focuses on the identification of causes of cost overrun through literature review and discussion about Bayes theorem and its application in different fields.

Chapter 3

RESEARCH METHODOLOGY

This chapter discusses about the methodology that is adopted in the research. It is divided into two sections, first section discusses about the data collection that includes literature review, causes of cost overrun and pilot survey questionnaire. The second sections describes about the Bayesian analysis approach used for the main survey to elicit the prior and conditional probabilities of causes of cost overrun.

3.1 INTRODUCTION

To commence the research extensive literature review is conducted about the causes of cost overrun in road construction projects. With the help of literature, identification of causes of cost overrun in road construction is carried out. Based on that input, questions are designed for this research. The flowchart of this study is shown in Fig 3.1.

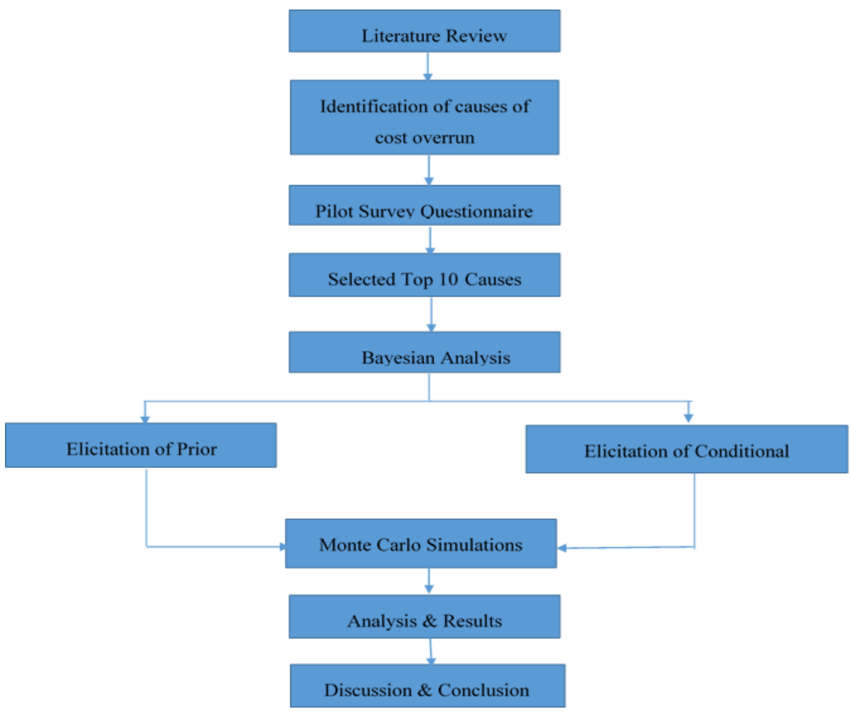


Figure 3.1 Schematic Plan for Research

3. 2 DATA COLLECTION

After literature review, causes of cost overrun in road construction projects are identified. Then frequency analysis is performed through which 25 causes are obtained. In the next step, pilot survey questionnaire is made that is responded by the field experts to check out the field expert's opinion about those identified causes.

3.2.1 PILOT SURVEY

After the identification of 25 causes of cost overrun in road construction projects, a comprehensive pilot survey questionnaire is developed in order to know about the opinion of field experts. The questionnaire had two main sections.

The first section gathers information about the qualification of the respondent, from which stakeholder party they belong to, position in their organization, professional experience and from which country they are from. The respondents include different countries of the world related to road construction projects.

The second section the respondent were requested to rate the probability of 25 identified causes of cost overrun in road construction projects as well as their impact on the Likert scale of 1-5, where 1= very low, 2= low, 3= average, 4= high and 5= very high.

After obtaining responses from field experts, the probability and impact of each cause is multiplied that give us the rating of each cause according to field experts. Then top 10 causes of cost overrun are selected by the combining the criticality of causes of cost overrun factors taken by literature and field experts. These selected top 10 causes then are used for further analysis. According to Hertzog (2008) sample size required for pilot survey study can range from 10 – 40 in order to get the precise estimate of the research.

3.2.2 FACTOR SCREENING

In order to screen out less significant factors, the criticality is computed first from the academic sources and later from the responses of pilot survey. The academia criticality is calculated using Equation 3.1.

$$\textbf{Academic Criticality} = \frac{\textbf{Frequency of Factor}}{\textbf{Total no. of Papers}} * \textbf{10} \qquad \textbf{Eq 3.1}$$

Further, with the help of PI score obtained through pilot survey, the respondent's criticality is computed using Equation 3.2.

$$\textbf{Respondents Criticality} = \frac{\textbf{Avg PI score}}{\textbf{25}} * \textbf{10} \qquad \textbf{Eq 3.2}$$

After that the overall criticality is calculated by taking the product of criticality scores obtained through Equation 2 and Equation 3. The top ten causes of cost overrun in road construction projects are selected based on the overall criticality.

3.2.3 FINAL SURVEY

After selecting the top 10 causes of cost overrun in road construction projects. Main questionnaire survey is developed based on those top ten causes to elicit the probability of each cause. The questionnaire is divided into three sections.

First section gathers information about the professional experience, qualification, probability of cost overrun in road construction projects on a scale of 0- 100. In this questionnaire, the respondents are mainly from Pakistan.

Second section, the respondents based on their experience in road construction projects are asked to elicit the probability of occurrence of all top ten causes on a scale of 0 -100%. That section gives the information about the prior probability of each cause. Then in third section, the respondents are asked to solicit the conditional probability of each cause given that cost overrun had occurred in a road construction project on a scale of 0 – 100%.

After obtaining the responses the data is normalized in order to get the sum of 100 % of all the cause for prior and conditional probability before putting the values in the Eq. 2.1. Then Bayesian analysis id performed to compute the posterior probability of each cause. The survey was made over Google forms and was dispersed to a global audience of field practitioners via emails, social and professional websites. The sample size was calculated according to Cochran (2007) and Barlish et al. (2013). A suitable 10% margin of error was taken considering that the margin of error for categorical data and continuous data was 5% and 3% respectively (Krejcie and Morgan, 1970).

$$N = \frac{t^2 * V}{d^2}$$

Where 'N' is required sample size; 't' is desired value of alpha, which is 1.645 at 90% confidence level; 'v' is estimate of variance; calculated by maximum possible proportion x(1-maximum possible proportion) translating to 0.21 for this calculation; and 'd' is acceptable margin of error which was 0.1 for this calculation. Sample size was found out to be 57.

3.3 DATA QUALITY ANALYSIS

In order to gauge the quality of data, a few analyses are performed. These are: reliability and normality tests. Reliability test is used to measure the internal consistency that describes the extent to which all the in a test measure the same concept. Joppe (2000) defines reliability as the extent to which results are consistent over time and an accurate representation of the total population under study is referred to as reliability and if the results of a study can be reproduced under a similar methodology, then the research instrument is considered to be reliable.

To measure the reliability of the data, Cronbach's alpha is used and ranges from 0 to 1. But the minimal acceptable value of Cronbach's alpha is 0.7 and its value greater than 0.7 depicts more reliable data. Internal consistency reliability of the survey feedback was tested by finding the Cronbach's alpha (α) which was calculated by (Bhattacharjee et al., 2013) that gives $\alpha = 0.96$ for prior and conditional probabilities. That assures that this data is reliable and can be used for further analysis.

Normality test is to measure that whether the data collected follow the normal distribution or not. P-value is used to declare the deviation of data from normal distribution. If p-value is greater than 0.05 than the data follows the normal distribution otherwise not.

After performing normality test on the data, p-value of the variables was found less than 0.05 that means the data collected is not normal. So in order to make data normal non-parametric test is performed.

3.4 BAYESIAN ANALYSIS

Bayesian analysis provides probabilistic inference process about the variables based on their causal relationship. This new approach explicitly quantifies the uncertainty related to causes of cost overrun in road construction projects. Bayesian analysis is based on Bayes theorem that enables subjective prior opinions to be combined with sample evidence (conditional probability) about the risk to obtain posterior probability (Adams, 2008). The following formula used for finding the posterior probability as it is stated in Eq. 2.1.

Prior probability is an initial probability value originally obtained before any additional information elicited from the experts. Sample information is required to get the conditional probability (Adams, 2008). But due to lack of historical data in Pakistan, it is obtained directly from the field experts. By combining the above two probabilities, Bayesian analysis is performed to obtain the posterior probability.

3.3 MONTE CARLO SIMULATION

To capture the range of uncertainty of cost overrun causes, Monte Carlo simulation is used by defining the probability distribution of the input variables that ultimately gives us the result related to uncertainty in the output variable.

Generally, Monte Carlo method is used to describe quantitative data through statistical sampling. It translate the uncertainties of the input variable into the uncertainties of outputs. This method distinctly presents the uncertainties as probability distribution. With the help of repeated random sampling and statistical analysis, Monte Carlo simulation compute results. It is similar to random sampling, in which result is not known in advance. With this background, it is considered as systemic approach in performing what-if analysis (Raychaudhuri, 2008). It represents the likelihood or probability of reaching results.

Monte Carlo Simulation is a quantitative approach for risk analysis. The outputs results of Monte Carlo simulation gives probability distribution that depicts about the uncertainty of the variable.

Multiple trials run with the help of software tool, by using random values of variables to get the most probable outcomes (Baccarini, 2005). After performing Bayesian analysis, the continuous probability distribution of output i.e. posterior probability is computed via Monte Carlo Simulation in order to capture the uncertainty of causes.

3.3.1 TOOL FOR MONTE CARLO SIMULATION

@Risk is used to analyze the risk and uncertainty in various fields of science. It perform analysis using Monte Carlo simulation to show all the possible outcomes in excel spread sheet model. It also helps in computing different scenarios by giving probabilities for each risk. That eventually guide about which risk to avoid leads to better decision making for project management. Palisade @Risk is the Monte Carlo simulation add in for Excel.

3.4 SUMMARY

This chapter discussed about the research methodology adopted, tools and techniques used for the analysis. It also explains about how data is gathered from experts through pilot and main survey.

Chapter 4

ANALYSIS AND RESULTS

This chapter explains about the results concluded from both questionnaire surveys. The first pilot survey questionnaire is divided into two sections: the first section gathers information about the qualification and professional experience of the respondents, their country of origin and nature of stakeholder party. The second section collects data about significant causes of cost overrun in road construction projects. The second main questionnaire survey is divided into three sections. First section describes about the qualification and experience, second section gather information about the prior probability of causes and in the third section, conditional probability of causes is asked. Then based on the collected data, analysis is performed.

4.1 PILOT SURVEY

The pilot survey was conducted with an aim to reduce the total gathered factors down to the most significant ones. For this purpose, around 60 respondents were requested against which data was received from 39 practitioners. For a pilot survey, the acceptable size of sample is between10 to 40 (Hertzog, 2008). Thus, the sample size for this pilot survey is valid for further analysis.

4.1.1 CHARACTERISTICS OF RESPONDENTS

The respondents were asked about their qualification from the three categories i.e. bachelors, masters and doctorate degree. The response rate obtained was 56.4% (22 responses) hold bachelor’s degree, 43.6% (17 responses) hold master’s degree and none of the respondent holds doctorate degree. The educational level of the respondents assures that the experts possess enough knowledge in order to respond to the survey.

Three types of stakeholder parties were targeted i.e. client, consultant and contractor. The highest response rate observed was 51.3% (20 responses) from consultants, 38.5% (15 responses) from clients and 10.3% (4 responses) from contractors as shown in Fig 4.1. The response rate achieved from the three stakeholder parties was 65% with 39 responses out of 60. This information tells that the perception of all the three stakeholders' parties about the causes is collected.

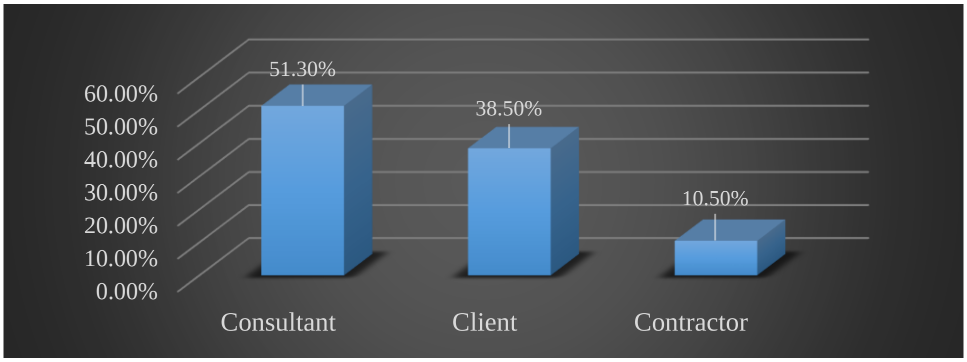


Fig 4.1 Response Rate of Stakeholders

As per the statistic given in Fig 4.2, it was found that 41% of the respondents have professional experience of 5 years or less, 25.6% have 6 to 10 years' experience, 12.8% have an experience of 11 to 15 years, 12.8% have worked for 16 to 20 years and 7.7% of the respondents have an experience of 21 to 25 years. Overall, most of the respondents were having an experience of 6 to 10 years. The professional experience of respondents in the construction industry indicate that it is sufficient to make the information gathered reliable.

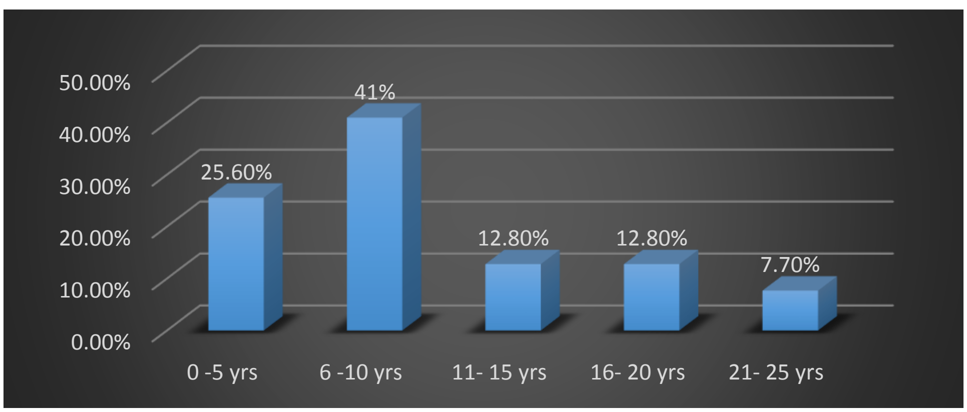


Fig 4.2 Professional Experience of Respondents

The next question inquired their country of origin and it was found that 48.7 % of the respondents are from Pakistan, 15.4% of the respondents from Saudi Arabia, 12.8% respondents from Canada, 10.3% from Qatar, 7.7% belong to UAE, 2.56% from Iraq and 2.56% respondents are from India as given in Fig 4.3. International respondent participants were 50 %, 19 responses out of a total of 39 that helped in order to get an idea also about their perception related to causes of cost overrun.

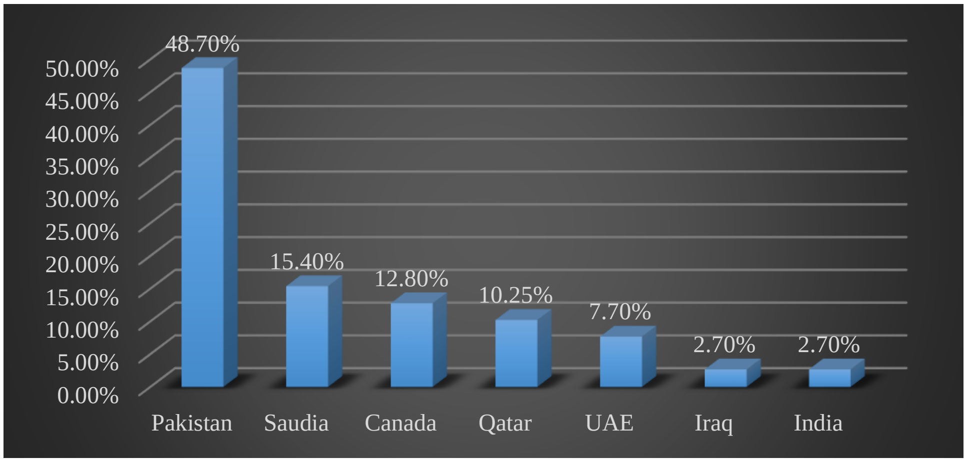


Fig 4.3 Country of Origin of Respondents

4.1.2 SIGNIFICANT CAUSES OF COST OVERRUN

After knowing about the organizational and personal profile of the respondents, they were requested to rate the probability and impact of causes of cost overrun in road construction projects on a five point Likert scale ranging from 1 to 5 where 1 = very low, 2 = low, 3 = medium, 4 = high and 5 = very high. The PI score of each cause is given in Table 4.1.

Table 4.1 P*I Score of Causes

Sr. #	Causes of Cost Overrun	P*I Score
1	Land acquisition problem	12.63
2	Schedule delay	11.95
3	Variation Orders	11.50
4	Improper Planning	10.97
5	Material price escalation	10.68
6	Local government pressures	10.61
7	Corruption	10.39
8	Relocation of services and utilities	10.24
9	Size of project	9.82
10	Differing site conditions	9.18

11	Inaccurate estimates	9.16
12	Experience in contracts	9.05
13	Market conditions	8.97
14	Inconsistent cash flows	8.84
15	Lack of equipment	8.45
16	Lack of communication	8.45
17	Design error changes	8.21
18	Constructability and technical complexity	7.82
19	Contract claim settlement	7.55
20	Weather Conditions	6.63
21	Lack of earned value management	6.18
22	Environmental Protection and mitigation cost	6.08
23	Owner Project management cost	5.89
24	Strikes	5.34
25	Change in seismic criteria	5.13

After calculating the PI score for each factor, the criticality of each cause is calculated. Then overall criticality of causes was calculated by taking a product of criticality score obtained through literature (shown in Table 2.2) and survey criticality obtained through PI score from pilot survey. This is done to determine the top ten causes of cost overrun as shown in Table 4.2.

Table 4.2 Overall Criticality of Causes

Sr.#	Causes of Cost Overrun	Criticality of Responses	Criticality of Academia	Overall Criticality
1	Variation Orders	4.6	6.0	27.6
2	Material price escalation	4.3	5.3	22.8
3	Inaccurate estimates	3.7	6.0	22.0
4	Schedule delay	4.8	4.0	19.1
5	Design error changes	3.3	5.3	17.5
6	Differing site conditions	3.7	4.7	16.9
7	Land acquisition problem	5.1	3.3	16.8
8	Relocation of services and utilities	4.1	3.3	13.6
9	Market conditions	3.6	3.3	12.0
10	Local government pressures	4.2	2.7	11.3
11	Weather Conditions	2.7	3.3	8.8

12	Improper Planning	4.4	2.0	8.8
13	Constructability and technical complexity	3.1	2.7	8.4
14	Environmental Protection and mitigation cost	2.4	2.0	4.9
15	Corruption	4.2	0.7	2.8
16	Size of project	3.9	1.3	2.6
17	Experience in contracts	3.6	0.7	2.4
18	Inconsistent cash flows	3.5	0.7	2.4
19	Lack of equipment	3.4	0.7	2.3
20	Lack of communication	3.4	2.0	2.3
21	Contract claim settlement	3.0	0.7	2.0
22	Lack of earned value management	2.5	0.7	1.7
23	Owner Project management cost	2.4	0.7	1.6
24	Strikes	2.1	0.7	1.4
25	Change in seismic criteria	2.1	0.7	1.4

4.2 FINAL SURVEY

After obtaining top ten causes of cost overrun in road construction projects, second questionnaire was designed to gather the inputs of Bayesian analysis in order to quantify the uncertainty related to cost overrun. It contains two parts: one representing the respondents profile along with their perception about the chance of occurrence of cost overrun in road construction projects. While the second part solicits the Bayesian input values. A total of 59 respondents provided their inputs fulfilling the requirements of representative sample as established in previous chapter 3.

4.2.1 CHARACTERISTICS OF RESPONDENTS

In this survey majority of the respondents were from Pakistan in order to gather findings specific to local construction sector. The respondents were asked about their qualification and professional experience. It was found that 57.6% (34 responses) respondents hold undergraduate degree and 42.4% (25 responses) have master’s degree. The educational level of the respondents indicate that they are able to access the causes of cost overrun in road construction projects.

The respondents were also asked about their professional experience as shown in Fig 4.4. It is found that 45.8% respondents having an experience of 5 years or less, 28.8% respondents were having an experience of 6 to 10 years, 8.5% respondents were having an experience of 11 to 15 years, 10.2% of respondents were having an experience of 16 to 20 years and 6.8% respondents were having an experience of more than 20 years. The working experience of the respondents assures that the data collected was reliable to use it for further research.

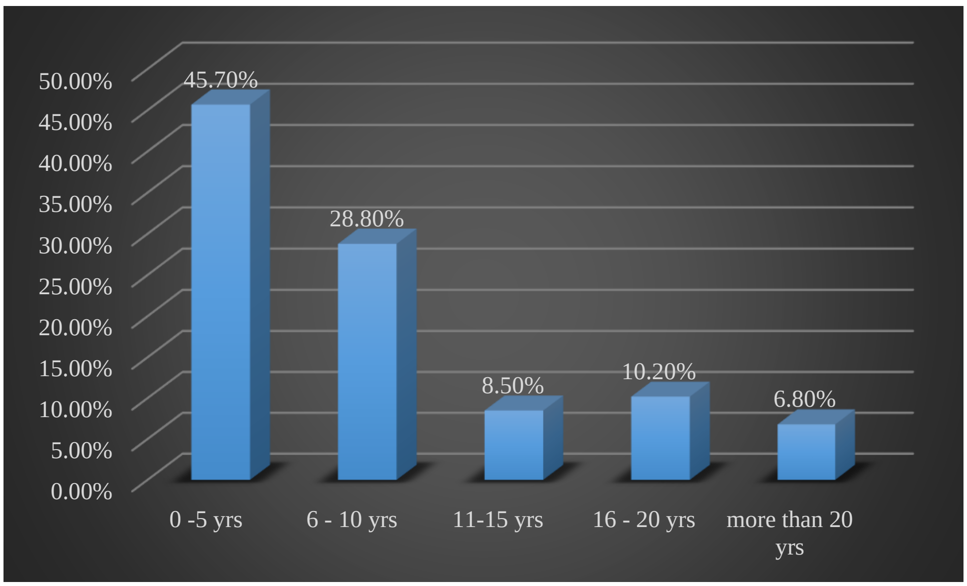


Fig 4.4 Professional Experience of Respondents

4.2.2 BAYESIAN ANALYSIS

To carry out the Bayesian analysis, one of the input required is to determine the probability of cost overrun in road construction projects, so the respondents were asked to elicit the prior probability of cost overrun on a scale of 1 to 100 in order to get their perception about it. The results indicate that chance of occurrence of cost overrun in road construction projects is 49.5% at an average.

The second part of the questionnaire deals with the other inputs of Bayesian analysis based on Bayes theorem in which prior probability is elicited from the expert while the conditional probability is taken from sample evidence (Adams, 2008). But due to non-availability of historical data in Pakistan, respondents were also asked to elicit the conditional probability. These input probabilities were asked from respondents on a scale of 1 to 100 as given in Table 4.3. After getting the Bayesian input values from the respondents, this data enables to calculate the posterior probability about the cost overrun as shown in Table 4.3 by using Bayes theorem given in Eq. 2.2.

Table 4.3 Bayesian Analysis Results

Sr. #	Causes of Cost Overrun	Prior Probability $P(A_i)$	Conditional Probability $P(A_i \mid B)$	Posterior Probability $P(B \mid A_i)$
1	Variation Orders	11.9	13.6	56.9
2	Material price escalation	9.6	8.8	45.6
3	Inaccurate estimates	8.4	9.2	54.5
4	Schedule delay	11.7	12	51.1
5	Design error changes	6.6	7.7	58.1
6	Differing site conditions	9.4	8.4	44.5
7	Land acquisition problem	12.1	12.6	51.8
8	Relocation of services and utilities	10.9	9.3	42.5
9	Market conditions	6.9	7	50.5
10	Local government pressures	12.7	11.4	44.7

The results indicate that local government pressures is most common cause that occur in road projects with a highest prior probability of 12.7%. But the chance of cost overrun due to land acquisition is 44.7% i.e. even lesser than the marginal probability of cost overrun in road projects. That depicts the impact of this factor is not much in terms of cost overrun in comparison with other common causes.

The chance of occurrence of design error changes in road projects is the lowest with a prior probability of 6.6%. Conditional probability explains that in case of completed road projects that had experienced cost overrun, there is 7.7% chance that design error changes were made. While the posterior probability indicates that if design error changes occur during a project then there is 58% of cost overrun that reveals an interesting fact that it is considered that most influencing factor in terms of cost overrun among all other factors.

Similar is the case with inaccurate estimates and market conditions. The occurrence of inaccurate estimates and market conditions are quite low among other common causes with a prior probability of 8.6% and 6.9% respectively. But if project faces change in quantities due to inaccurate estimates prepared at the time of planning and shortage of material, labor or equipment at the time of execution then it can trigger high chance of cost overrun in road projects with a probability of 54.5% and 50.5% respectively.

Variation order is considered the third most occurring factor in road projects with a high prior probability of 11.9 %. Its conditional probability explains that in case of completed road projects that experienced cost overrun, then there was 13.6% chance that variation order occurred. While it's posterior probability indicates that if variation order is initiated during the project then there is 56.9% chance of cost overrun in road construction projects.

Similar is the case with land acquisition and schedule delay. Land acquisition problem have higher chance of occurrence with a prior probability of 12.1%. Its conditional probability also explains that roads projects completed faced cost overrun due to land acquisition with a probability of 12.6%. According to results it is ranked the top fourth factor that if any road project experiences land acquisition issue it can cause cost overrun with a probability of 51.8%. This is because of the fact that the compensation paid to the private land owners can go very high. Likewise, schedule delay is considered among top five factors that have a great impact on the cost of the road projects.

Material price escalation have lower chance of occurrence and it causes lower chance of cost overrun with a posterior probability of 45.6% according to the Bayesian analysis results that indicates that in most of the projects contract price adjustment factor is already included in order to compensate the contractor for the increase in price of material. Similarly relocation of services and differing site conditions have low prior probabilities and also they have lower impact on the cost of the projects if they occur in comparison with other factors according to the results.

After getting posterior probability that can be used as an input variable to formal risk analysis (Adams, 2008), the current data of point estimates derived from Bayesian analysis for $\mathbf{P\ (B \mid A_i)}$ is converted into continuous probability distribution. It is done with the help of Monte Carlo simulation. This approach is used to get the maximum and minimum probability of cost overrun due to causes in addition with its mean value.

4.3 MONTE CARLO SIMULATION

After gathering probabilities through Bayesian analysis, range of input variables is calculated. The mean of each input is given a lower and upper limit at a distance of one standard deviation from the mean value. From each input, overall probability for chance of occurrence is calculated through the use of Monte Carlo simulations (MCS). A cumulative density function is generated via MCS which is referred to estimate the chance of occurrence of a certain value of probability.

In case of variation orders, it is considered as change in scope in a construction contract in the form of addition, substitution and omission from what is documented in original scope of work (Al-Dubaisi, 2000). Almost every project faces variation order as it progresses from design to practical implementation. Values for variation orders are in Table 4.4.

Table 4.4 Probability of Cost Overrun due to Variation Order

Probability of Cost Overrun due to Variation Order (PVA)		
Range	Minimum	Maximum
PVA	0.332	0.879
Chance of Achieving a certain value of PVA	10%	90%

The values suggest that when a variation order is initiated, there is at least 33.2% probability that cost overrun will occur in a project which can go up till 87.9% at the highest. Within a range of values of probabilities, with minimum (10%) chance, the probability of cost overrun due to variation order is 33.2% and the chance of getting a probability of 87.9% is maximum (90%). Still the value of probability will tend to approach the mean that is 58.9%. The significance of mean is that there is a 58.9% chance of cost overrun due to variation order at an average.

It might be argued that all variation orders do not necessarily incur cost overruns as they compensate for the work reduction or addition. Since the variation orders pay for the work differences but with additional scope of work, several other risks emerge from which cost is ultimately transformed. Variation order is ranked second according to the results shown in Fig 4.4. In the literature, it is ranked among top two causes of cost overrun in road construction projects (Creedy et al., 2010; Kaliba et al., 2009; Lee, 2008; Nasir et al., 2012).

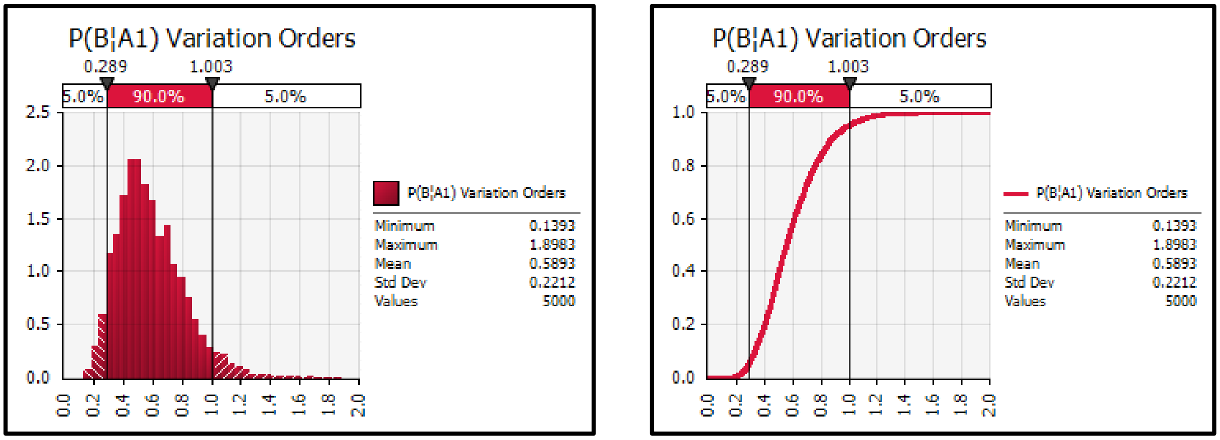


Fig 4.5 Risk Output Report for P (B/A1)

In case of material price escalation, it is considered as inflation a sustained increase in the price of goods and services with the passage of time. Cost Escalation is the change in the cost of any construction element of the original contract or base cost of a project due to passage of time. (Vamsidhar et al., 2014). Values for material price escalation are given below in Table 4.5.

Table 4.5 Probability of Cost Overrun due to Material Price Escalation

Probability of Cost Overrun due to Material Price Escalation (PMPE)		
Range	Minimum	Maximum
PVA	0.247	0.788
Chance of Achieving a certain value of PMPE	10%	90%

The values suggest that when, material price escalation occur in a road project there is at least 24.7% probability that cost overrun will occur in a project which can go up till maximum of 78.8%. The chance of minimum probability of 24.7% is 10% and that of maximum (78.8%) is 90%. Still the value of probability will tend to approach the mean of 48.8% which suggest that there is almost 48.8% chance of cost overrun due to material price escalation at an average.

In contract conditions, price adjustment formula is used to compensate the contractors for the increase in prices of materials. This amount is not included in the BOQ then as a result additional cost must be paid apart from the contract amount to the contractors that leads to more burden on the client (Nasir et al., 2012). Material Price escalation is ranked as seventh most important factor of cost overrun in road construction according to the results as shown in Fig 4.7. It is ranked as the eighth cause of cost overrun in road construction projects (Al-Hazim, 2015). Wijekoon and Attanayake (2013) ranked cost escalation as the “third” most influencing factor in srilankan road projects.

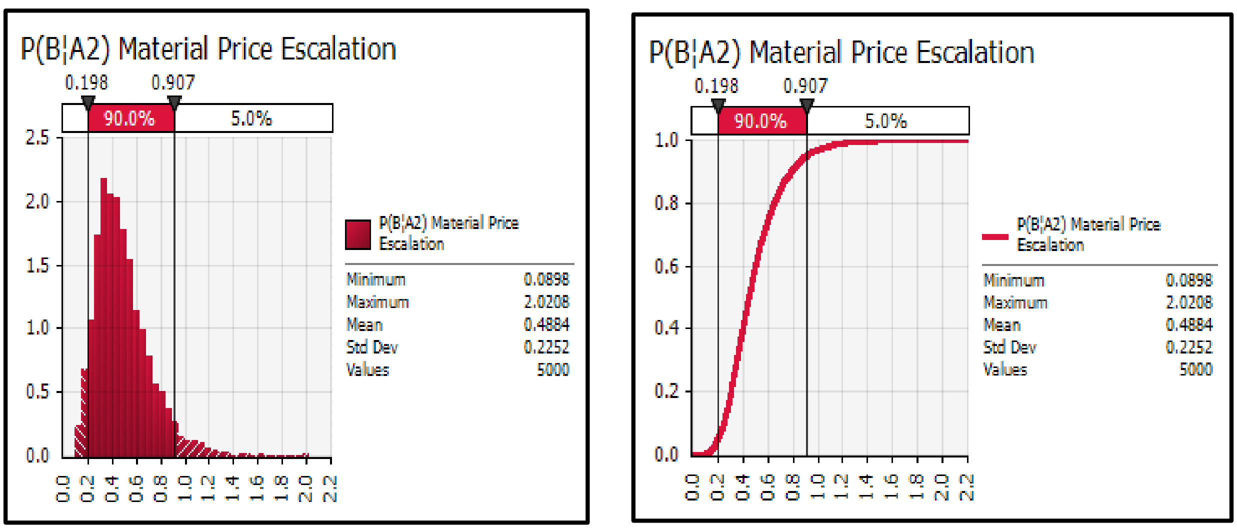


Fig 4.6 Risk Output Report for P (B/A2)

The inaccurate estimate is considered as one of the most destructive points in projects. To meet the budget constraints, impractical estimates are prepared that cause cost overrun due to change of quantities in execution (Nasir et al., 2012). Also, the estimates are deliberately underrated in order to win competitive bids. Such procurement usually results in latent cost reconsiderations or financial claims by one of the stakeholders (Ioannou and Leu, 1993). Values for inaccurate estimates are given in Table 4.6.

Table 4.6 Probability of Cost Overrun due to Inaccurate Estimates

Probability of Cost Overrun due to Inaccurate Estimate (PIE)		
Range	Minimum	Maximum
PVA	0.309	0.902
Chance of Achieving a certain value of PIE	10%	90%

The values suggest that when inaccurate estimates are prepared in a road project, there is at least 30.9% probability that cost overrun will occur. This probability can go up till 90.2%. Within a range of values of probabilities, the chance of actually having the probability of 30.9% is very low (10%) whereas the chance of getting a probability of 90.2% is very high (90%). With these extremes, there is a 57.8% chance of cost overrun due to inaccurate estimates at an average.

To commence a project early, estimates prepared at the time of planning are based on preliminary designs. Due to poor plans and specifications, bill of quantities estimated will differ during the execution phase that causes cost overrun. Inaccurate estimates is ranked third according to the results as shown in Fig 4.5. This is in accordance with the published literature of cost overrun in road construction projects (Isma'il et al., 2013; Lee, 2008). In Ghana it is ranked as fifth cause in the road construction projects (Chileshe et al., 2010). The rank variation between findings of this research and Ghanaian study are possibly due to cultural or behavioral preferences of respondents leading to different assessment (Li and Karakowsky, 2001).

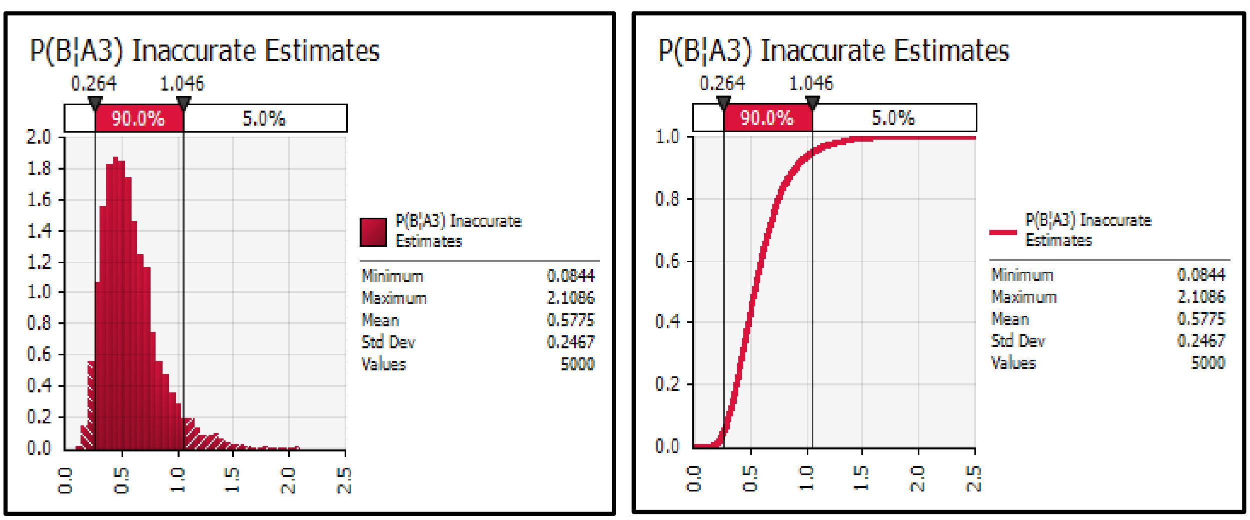


Fig 4.7 Risk Output Report for P (B/A3)

Schedule Delay is a slippage that occurs when the construction projects actual completion date differs from the planned contract date of completion (Kaliba et al., 2009). Time is an important constraint of every construction project that need to be completed according to the contract. Many construction projects usually faces schedule delay (Kaliba et al., 2009). Values for schedule delay are given below in Table 4.7.

Table 4.7 Probability of Cost Overrun due to Schedule Delay

Probability of Cost Overrun due to Schedule Delay (PSD)		
Range	Minimum	Maximum
PVA	0.309	0.771
Chance of Achieving a certain value of PSD	10%	90%

The values suggest that when schedule delay occur in a road project, there is at least 30.9% probability that cost overrun will occur in a project which can go up till 77.1% at the highest. Within a range of values of probabilities, with minimum (10%) chance, the probability of cost overrun due to variation order is 33.8% and the chance of getting a probability of 77.1% is maximum (90%). Still the value of probability will tend to approach the mean that is 52.3%. The significance of mean is that there is a 52.3% chance of cost overrun due to schedule delay occur in a road project at an average.

Construction projects facing schedule delay is not only because of scope change, but also compensation changes and changes due to unexpected construction nature and due to budget constraints of the project. That is why it is considered as one of the key factors of cost overrun (Lee, 2008). Schedule delay is ranked as “fifth” cause of cost overrun according to the results as shown in Fig 4.8. It is ranked among top four causes of cost overrun in road construction projects (Chileshe et al., 2010; Kaliba et al., 2009; Lee, 2008).

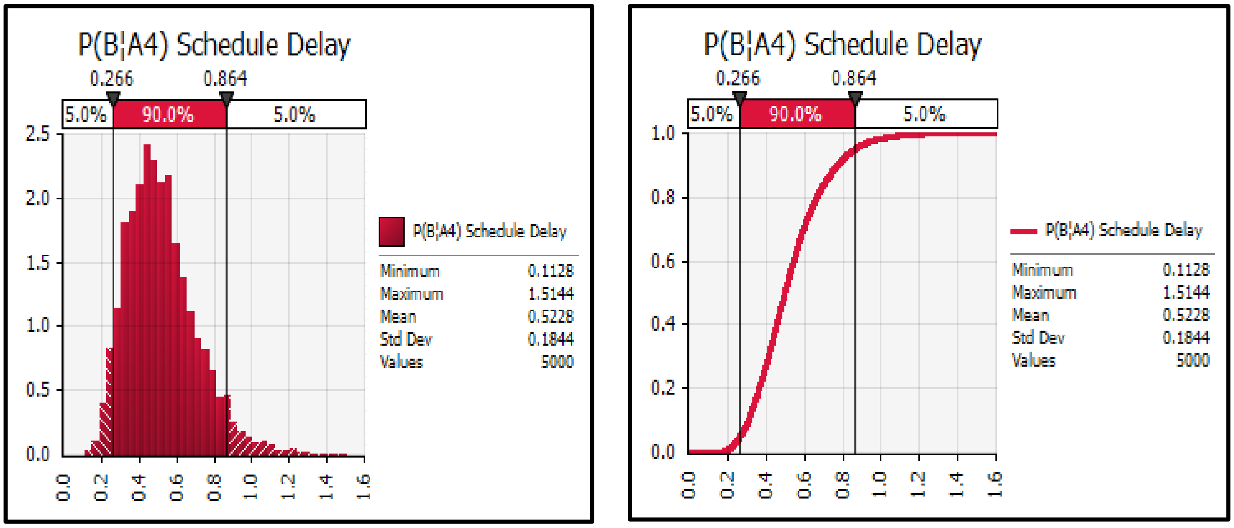


Fig 4.8 Risk Output Report for P (B/A4)

Constructability is basically the best use of construction knowledge and experience to achieve the project success but many construction projects lack constructability that causes cost overrun (Nima et al., 2001). In worsening situations, design error changes occur which represent deviations from the drawings and specification that affect the quality of facility. It is one of the major issues in controlling the project performance in terms of cost and time. Poor quality of design have direct impact on the project success (Couto, 2012). Values for design error changes are given in Table 4.8.

Table 4.8 Probability of Cost Overrun due to Design Error Changes

Probability of Cost Overrun due to Design Error Changes (PDEC)		
Range	Minimum	Maximum
PVA	0.348	0.933
Chance of Achieving a certain value of PDEC	10%	90%

The values suggest that when design error changes occur in a road project there is at least 34.8% probability that cost overrun will occur in a project which can go up till maximum of 93.3%. The chance of minimum probability of 34.8% is 10% and that of maximum (93.3%) is 80%. Still the value of probability will tend to approach the mean of 61.5% which suggest that there is almost 61.5% chance of cost overrun due to design error changes at an average.

Design error changes occur due to lack of knowledge about the field conditions that were known at the time of planning. Most of the time consultants are held responsible for making engineering design errors. They should be considered of prime importance because errors in design can change the scope of work (Nassar et al., 2005). Design error changes is ranked first according to the results as shown in Fig 4.3. Incomplete drawings is ranked among top four causes of cost overrun in road construction projects (Mahamid et al., 2011; Wijekoon and Attanayake, 2013).

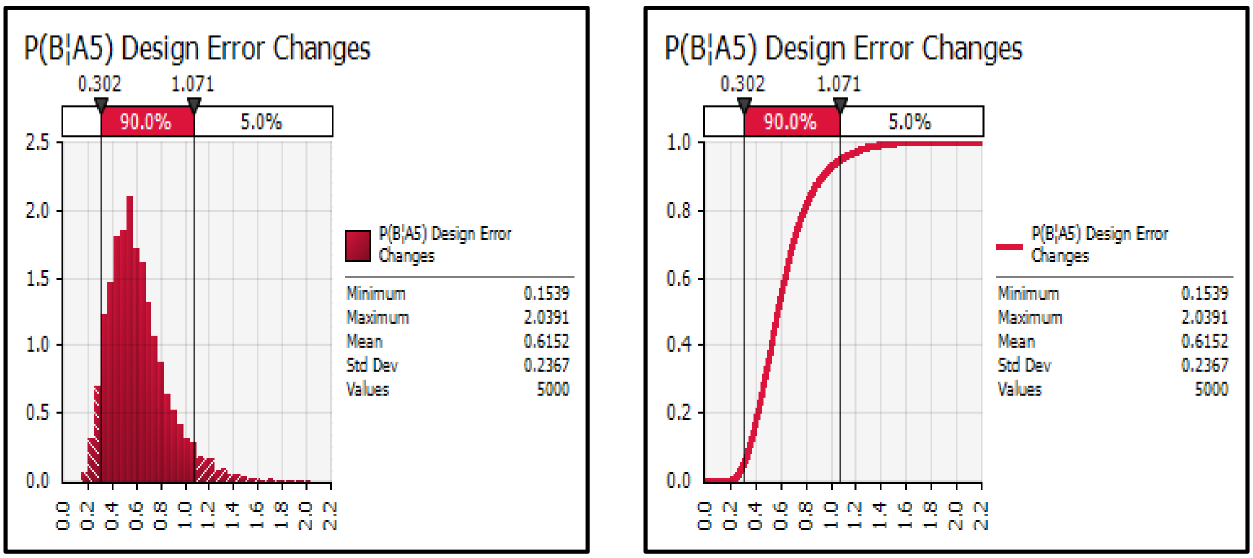


Fig 4.9 Risk Output Report for P (B/A5)

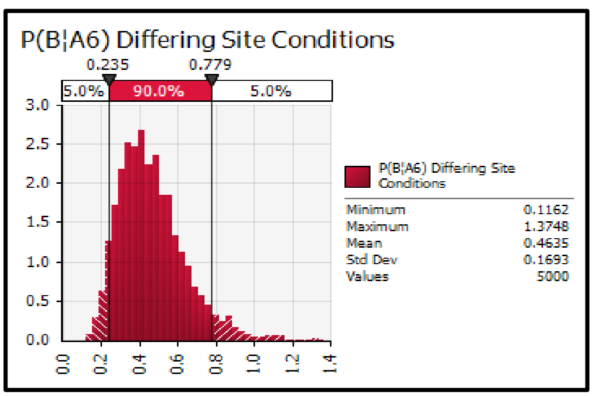
Differing site condition is situation in which the site conditions materially differ from the conditions mentioned in the contract documents or an unknown physical conditions or nature that is different from the type of work included in the contract (McClure, 1984). Values for differing site conditions are given below in Table 4.9.

Table 4.9 Probability of Cost Overrun due to Differing Site Conditions

Probability of Cost Overrun due to Differing Site Conditions (PDSC)		
Range	Minimum	Maximum
PVA	0.268	0.690
Chance of Achieving a certain value of PDSC	10%	90%

The values suggest that when differing site conditions occur in road project, there is at least 26.8% probability that cost overrun will occur. This probability can go up till 69%. Within a range of values of probabilities, the chance of actually having the probability of 26.8% is very low (10%) whereas the chance of getting a probability of 69% is very high (90%). With these extremes, there is a 46.4% chance of cost overrun due to when differing site conditions occur at an average.

Due to poor geotechnical investigations in the planning stage causes unforeseen conditions during excavation that incur additional cost to the project (Molenaar, 2005). It is also caused by poor detectable boring that fails to identify the soil type and environmental conditions, drawings prepared based on poor investigation always differ from the actual site conditions (Vidalis and Najafi, 2002). Differing site conditions is ranked ninth cause of cost overrun according to the results shown in Fig 4.10. It is ranked among top two causes of cost overrun in road construction (Al-Hazim, 2015; Creedy et al., 2010; Vidalis and Najafi, 2002). Contrast in the ranking from the results shown in Fig 4.10. , may be due to geographical difference between the countries from Pakistan.



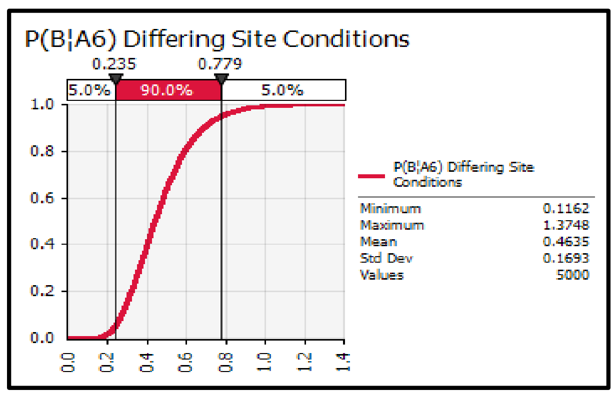


Fig 4.10 Risk Output Report for P (B/A6)

Land acquisition is referred as a process union or the state government acquires private lands for different purposes like industrialization and development of infrastructure facilities and provide compensation to the affected land owners (Ghatak and Ghosh, 2011). Values for land acquisition problem are given below in Table 4.10.

Table 4.10 Probability of Cost Overrun due to Land Acquisition Problem

Probability of Cost Overrun due to Land Acquisition Problem(PLAP)		
Range	Minimum	Maximum
PVA	0.321	0.812
Chance of Achieving a certain value of PLAP	10%	90%

The values suggest that when land acquisition problem occur in a road project, there is at least 32.1% probability that cost overrun will occur in a project which can go up till maximum 81.2%. The chance of minimum probability of 32.1% is 10% and that of maximum (81.2%) is 90%. Still the value of probability will tend to approach the mean of 54.5% which suggest that there is almost 54.5% chance of cost overrun due to land acquisition problem at an average.

Acquiring project right-of-way for the construction of road is a big challenge for the client because it can cause great impact on the project that ultimately leads to schedule delay and cost overrun due to slow regulatory framework (Nasir et al., 2012). Land acquisition problem is ranked as "fourth" cause of cost overrun according to the results as shown in fig4.11. It is ranked among top five causes of cost overrun in road construction projects (Molenaar, 2005; Nasir et al., 2012).

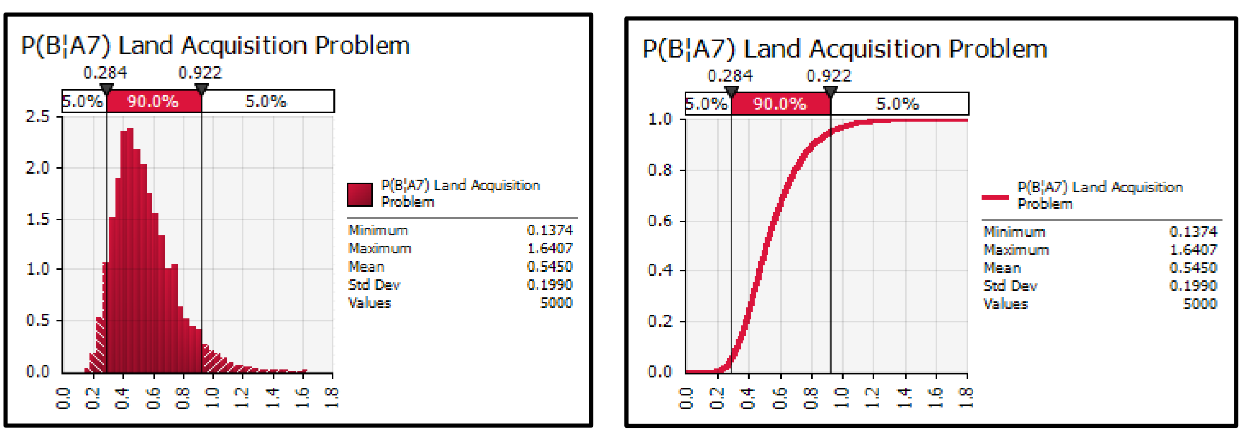


Fig 4.11 Risk Output Report for P(B/A7)

Relocation of utilities and services is usually done by the utility companies that performs routine investigation to identify and relocate the conflicting utilities throughout the alignment of the project (Molenaar, 2005). Values for the relocation of utilities and services are given below in Table 4.11.

Table 4.11 Probability of Cost Overrun due to Relocation of Utilities

Probability of Cost Overrun due to Relocation of Utilities & Services (PRSU)		
Range	Minimum	Maximum
PVA	0.262	0.649
Chance of Achieving a certain value of PRSU	10%	90%

The values suggest that when relocation of utilities and services is initiated, there is at least 26.2% probability that cost overrun will occur in a project which can go up till 64.9% at the highest. Within a range of values of probabilities, with minimum (10%) chance, the probability of cost overrun due to variation order is 28.3% and the chance of getting a probability of 64.9% is maximum (90%). Still the value of probability will tend to approach the mean that is 44.3%. The significance of mean is that there is a 44.3% chance of cost overrun due relocation of utilities and services at an average.

Inadequate records of underground utilities and in addition, utility companies not updating the utility maps can cause delay that lead to cost overrun (Vidalis and Najafi, 2002). To commence majority road projects it is necessary to relocate the utilities in order to avoid delay in construction activities (Wijekoon and Attanayake, 2013). Relocation of utilities and services is ranked tenth cause of cost overrun according to the results shown in fig 4.12. It is ranked among top five causes of cost overrun in road construction projects (Creedy et al., 2010; Wijekoon and Attanayake, 2013). While it contribute not much in cost overrun of road construction projects (Molenaar, 2005; Vidalis and Najafi, 2002).

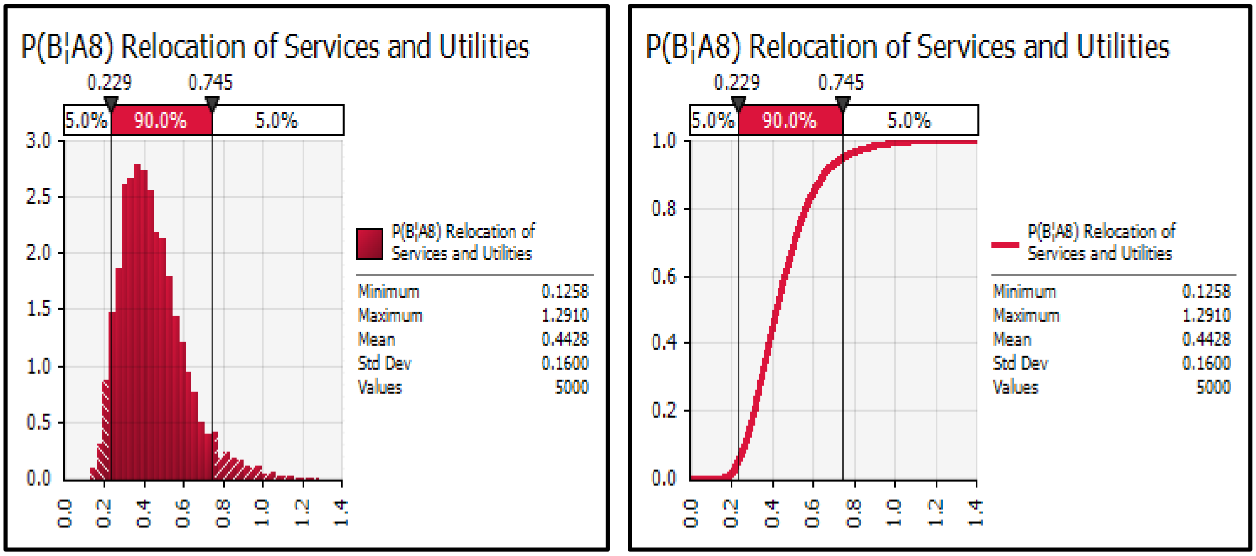


Fig 4.12 Risk Output Report for P (B/A8)

Market conditions includes the availability of funding labor, equipment and material for the construction projects (Molenaar, 2005). Values for the market conditions are given below in the Table 4.12.

Table 4.12 Probability of Cost Overrun due to Market Conditions

Probability of Cost Overrun due to Market Conditions (PMC)		
Range	Minimum	Maximum
PVA	0.307	0.783
Chance of Achieving a certain value of PMC	10%	90%

The values suggest that when market conditions deviates in road project, there is at least 30.7% probability that cost overrun will occur in a project which can go up till maximum of 78.3%. The chance of minimum probability of 30.7% is 10% and that of maximum (78.3%) is 90%. Still the value of probability will tend to approach the mean of 52.9% which suggest that there is almost 52.9% chance of cost overrun due to market conditions at an average.

When several mega projects are implemented simultaneously, it may create an issue regarding the shortage of funding's, labor, equipment and material required for the construction of projects that leads to delay in payments and work eventually causing cost overrun in the projects (Molenaar, 2005). In majority of the road projects, government act as a client so due to shortage of funding, payments delay occur that affect the contractors progress of work causing cost overrun (Wijekoon and Attanayake, 2013). Market conditions is ranked as sixth cause of cost overrun according to the results shown in fig 4.13. It is ranked among top first causes of cost overrun in road construction projects (Molenaar, 2005). This contrast may be due to difference between the market conditions of other countries from Pakistan.

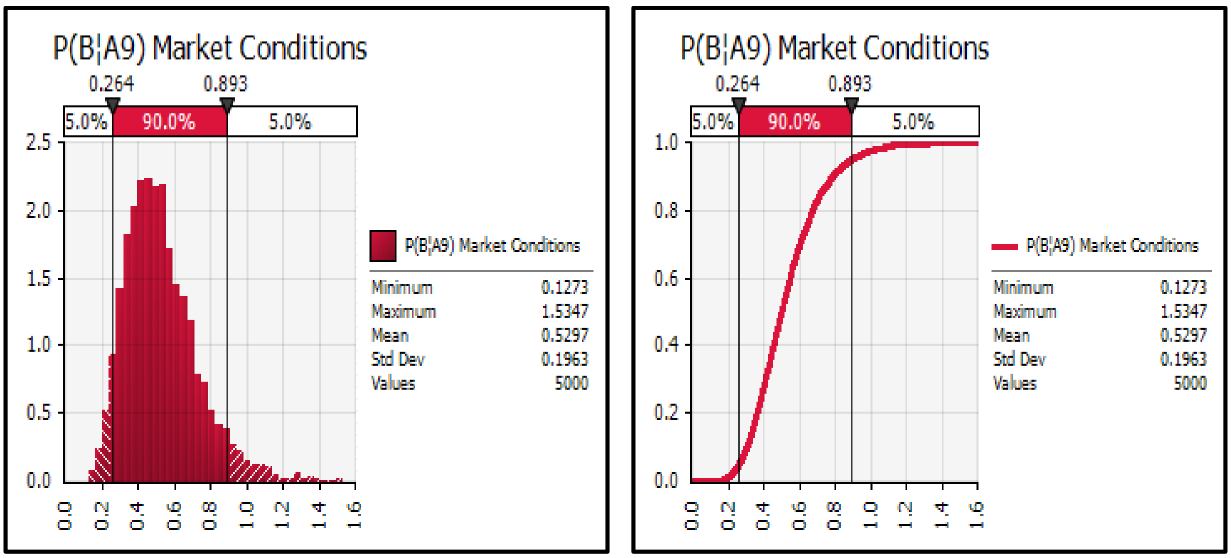


Fig 4.13 Risk Output Report for P (B/A9)

Local government pressures is an important factor that may disrupt the progress of work if not managed affectively. Due to poor financial situation, projects face very tight cash flow issues and immense delays resulting into cost overrun. Values for local government pressures are given in Table 4.13.

Table 4.13 Probability of Cost Overrun due to Local Government Pressures

Probability of Cost Overrun due to Local Government Pressures (PLGP)		
Range	Minimum	Maximum
PVA	0.252	0.755
Chance of Achieving a certain value of PLGP	10%	90%

The values suggest that these pressures in road projects may cause cost overrun with a minimum chance of 25.2%. This probability can reach a maximum of 75.5%. Within a range of values of probabilities, there is a very low (10%) chance of getting the probability of 25.2% and a very high (90%) chance of getting the probability of 75.5% with a mean of 47.4%. It signifies that on average there is 47.3% chance of cost overrun due to pressures by local government.

Since these governments are taken as client for most of the road construction projects, it is their responsibility to manage funds to maintain the progress of work in order to avoid delay that ultimately causes cost overrun. Due to government inappropriate priorities and policies, some projects face cost overrun (Nasir et al., 2012). Local government pressures is ranked as eight cause of cost overrun according to the results shown in Fig 4.14. This is in agreement with the study by Kaliba et al. (2009).

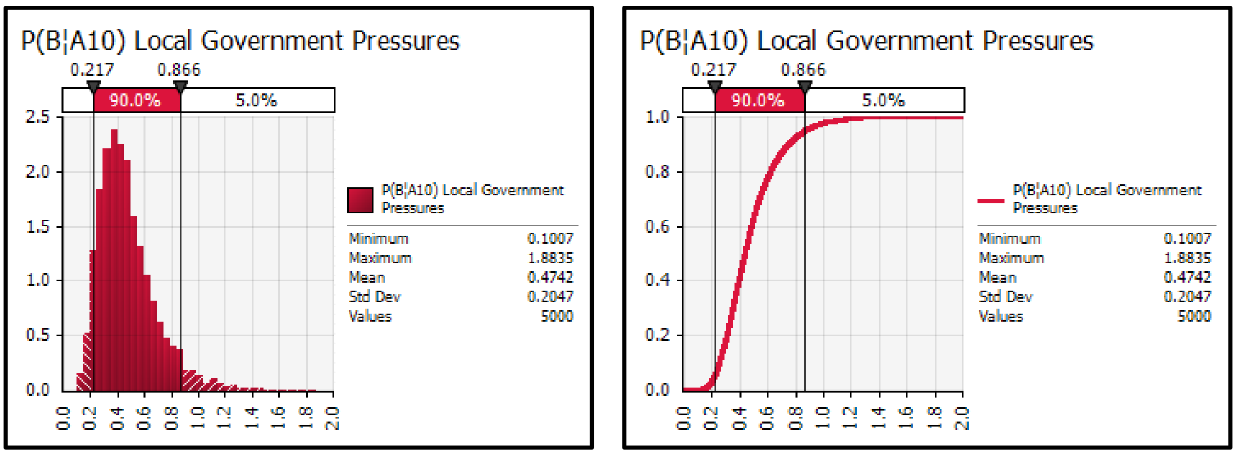


Figure 4.14 Risk Output Report for P (B/A10)

Critical causes of cost overrun are rearranged according to highest probability that helps the decision makers in recognizing the factors of cost overrun and to what extend these actors can trigger the cost overrun most significantly. Now the final ranking of causes after Monte Carlo simulations is given in Table 4.14.

Table 4.14 Final Ranking of Causes of Cost Overrun

Sr. #	Causes of Cost Overrun	Posterior Probability	Mean	Standard Deviation	Minimum at 10%	Maximum at 90%
1	Design Error Changes	**P(B │ A5)**	0.6152	0.2367	0.3484	0.9330

2	Variation Order	**$P(B \mid A_1)$**	0.5893	0.2212	0.3324	0.8799
3	Inaccurate Estimates	**$P(B \mid A_3)$**	0.5775	0.2467	0.3093	0.9025
4	Land Acquisition problem	**$P(B \mid A_7)$**	0.5450	0.1990	0.3213	0.8128
5	Market Conditions	**$P(B \mid A_9)$**	0.5297	0.1963	0.3077	0.7836
6	Schedule Delay	**$P(B \mid A_4)$**	0.5228	0.1844	0.3090	0.7717
7	Material Price escalation	**$P(B \mid A_2)$**	0.4884	0.2252	0.2471	0.7881
8	Local government pressures	**$P(B \mid A_{10})$**	0.4742	0.2047	0.2520	0.7550
9	Differing site condition	**$P(B \mid A_6)$**	0.4635	0.1693	0.2942	0.6328
10	Relocation of services and utilities	**$P(B \mid A_8)$**	0.4428	0.1600	0.2623	0.6498

4.4 DISCUSSION

An interesting finding from MCS indicates that the marginal probability of cost overrun in road construction projects is 49.5% but if any project faces design error changes this can go up to 93.3 % maximum at (90%) with a mean value of 61.5%. And if variation order is initiated in road project then (at 90 %) the chance of occurrence of cost overrun can trigger maximum up till 87.9% with a mean value of 58.9% and due to inaccurate estimates is 57.8% that can go maximum up to 90.2%. The findings depicts that design error changes, inaccurate estimates and variations orders are among the top three major contributors towards the cost overrun in road projects that need to be controlled in road construction projects.

In case of land acquisition, schedule delay and market conditions they are considered significant factors in causing cost overrun with a probability of 54.5%. 52.3% and 52.9% respectively. That is higher than the marginal probability of cost overrun in road construction projects. While material price escalation, differing site conditions and relocation of services have the lowest probability of 48.8%, 46.3% and 44.3% at an average respectively.

The importance of above findings is that it provides an effective systematic analysis approach for quantifying the factors causing cost overrun in road construction projects in Pakistan. Such approach is useful for all the construction experts who are responsible for the identification of critical risks that causes cost overrun in road projects to enhance the project performance.

4.6 SUMMARY

This chapter summarizes the results of analysis done by using Bayes theorem and Monte Carlo simulations approach. It explains about the organizational and personal profile of the respondents. The uncertainty of causes of cost overrun is captured in this chapter that was the main goal of the research.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 INTRODUCTION

This chapter concludes the research by discussing about the results, findings, limitations and recommendations. All the objectives defined in chapter 1 is explained one by one that how they are achieved.

5.2 OBJECTIVES

Table 5.1 describes about the objectives and the methodology adopted to achieve them. It also mentioned about the references in order to simplify investigation about the results.

Table 5.1 Objective to Achieve

Sr. No	OBJECTIVES	METHODOLOGY	STATUS	REFERENCE
1	To identify the common causes of cost overrun	Literature Review	Achieved	Chapter 2
2	To determine the significant causes of cost overrun	Pilot Survey Questionnaire	Achieved	Chapter 4
3	To quantify the uncertainty of causes of cost overrun	Via Bayes theorem and Monte Carlo simulations	Achieved	Chapter 4

5.3 CONCLUDING THE OBJECTIVES

1. To identify the common causes of overrun in road construction projects

To commence the research, literature review was conducted, almost 15 published studies and various online material is used to select the common causes of cost overrun in road construction projects. As a result, 25 factors were identified that effect cost of the road projects. These factors along with references is given in Table 2.1

2. To determine the significant causes of cost overrun in road construction projects

In order to further scrutinize the factors identified from the literature review, pilot survey is carried out. In which the product of probability and impact of each cause is calculated in order to determine the field expert's perspective about them. After that criticality of each cause is computed on scale of 0 to 10. By combining the criticality obtained from literature and experts, top ten significant causes of cost overrun is taken out for further analysis. The top ten causes selected are *Variation Order, Inaccurate Estimates, Design Error Changes, Material Price Escalation, Land Acquisition Problem, Schedule Delay, Differing Site Conditions, Relocation of utilities and services, Market Conditions and Local Government Pressures.* Decision maker can easily recognize that which of the factors are affecting the cost overrun in road construction projects most significantly.

3. To quantify the uncertainty of top ten causes of cost overrun in road construction projects

The top ten causes of cost overrun selected are used for further study, Bayesian analysis approach based on Bayes theorem is applied in which prior probability is elicited from the experts while the conditional probability is taken from sample evidence (Adams, 2008). But due to non-availability of historical data in Pakistan, respondents were also asked to elicit the conditional probability as shown in Table 4.3. Then the posterior probability of cost overrun due to each cause is computed by Bayes Theorem as shown in Table 4.3.

By obtaining posterior probability it can be used as an input variable to formal risk analysis (Adams, 2008). By using one point standard deviation, the input variables gets a range of minimum and maximum values explaining triangular distribution. To quantify the uncertainty of each cause, the overall probability for chance of occurrence is computed with the help of Monte Carlo simulations (MCS). A cumulative density function is generated via MCS that referred to estimate the chance of occurrence of a certain value of probability.

Results obtained after applying Bayesian analysis and Monte Carlo simulation quantifies the uncertainty of each factor causing cost overrun in road construction projects. This finding explains that *design error changes* is ranked as first cause of cost overrun in road construction project with a mean probability of 61.4% having an uncertainty varying from 37.8% to 85%. *Inaccurate estimates* is ranked as second with 59% chance of cost overrun at an average that can vary from 36.7% to 81.4%. While *variation order* is ranked third having a mean probability of 57.9% with minimum and maximum probability of 32.8% and 83%.

The posterior probability of cost overrun due to material price escalation, local government pressures, differing site conditions and relocation of services and utilities are the lowest with a mean value of probability of 48.8%, 47.4%, 46.3% and 44.2 % respectively. This indicates that their mean probability is even lower than the marginal probability of cost overrun (49.5%) in road construction projects. That's why they are ranked the lowest among top ten significant causes.

The results also indicate that the marginal probability of cost overrun in road construction projects is 49.5% but if any project faces design error changes this can go maximum up to 93.3 % with a mean value of 61.5%. And if variation order is initiated in road project the chance of occurrence of cost overrun can trigger maximum up till 87.9% with a mean value of 58.9%. The findings depicts that design error changes, inaccurate estimates and variations orders are among the top three major contributors towards the cost overrun in road projects. In case of land acquisition, schedule delay and market conditions they are considered significant factors in causing cost overrun with a probability of 54.5%. 52.3% and 52.9% respectively. The probability distribution (uncertainty) provides an ease for the visualization of causes that to what extend they can trigger the failure of project success factor i.e. cost.

Such results will facilitate the decision makers in risk management to provide an effective analysis approach for quantifying the factors causing cost overrun in road construction projects in Pakistan. That will help the project managers that instead of using arbitrary contingency sums to account for all risks in a project only key risks should be considered for mitigation in road projects to enhance the project performance (Adams, 2008).

5.4 LIMITATIONS

One of the limitations of the research is that it is based on subjective probability. Due to lack of historical data in Pakistan, subjective opinions is asked from the experts to perform the Bayesian analysis.

5.5 RECOMMENDATIONS

Variation orders are initiated due to poor definition of scope of work at the time of planning. In case of inaccurate estimates, bill of quantities prepared at the time of bidding are impractical that shows inefficiency of the project team. While design submitted at the time of bidding not fulfilling the requirements during execution is again the result of poor planning. Therefore it indicate a clear a need that project managers must focus in the planning stage because critical causes identified are mostly initiated due to poor planning and management. For future research, it is recommended to use historical data if available to make the research more reliable. This research focused on only one aspect of the project success i.e. cost. Similar study can be performed for other aspects of project success like time and quality.

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