Evaluation and Management of Construction Project Cost Risks using Simulation

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To my beloved parents,
and respectful teachers

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TABLE OF CONTENTS

Page

LIST OF TABLES vii

LIST OF FIGURES ix

LIST OF ACRONYMS… x

ABSTRACT………… xi

CHAPTER 1. INTRODUCTION 12

1.1 Background 12
1.2 Problem Statement 14
1.3 Research Objectives 15
1.4 Overview of Study Approach 15
1.5 Thesis Organization 15

CHAPTER 2. LITERATURE REVIEW 18

2.1 Introduction 18
2.2 Cost Estimation Techniquess 19
2.3 Techniques for Cost Contingencies 21
2.4 Importance of Sensitivity Analysis in Risk Management 23
2.5 Traditional and Analytical Method of Risk Analysis for Cost Contingency 23
2.6 Risk Analysis with Simulations 24
2.7 Time Line Series 25
2.8 Machine Productivity 25
2.9 Labour Productivity 26
2.10 Chapter Summary and Conclusion 26

CHAPTER 3. STUDY METHODOLOGY 28

3.1 Introduction 28
3.2 Selection of Project Types 28
3.3 Developing Project Cost Estimate Model 31
3.4 Identification of Project Cost Risks 34
3.5 Data Collection and Collation for Cost Risk Factors 34
3.6 Development of RMF Model 38
3.7 Development of Probabilistic Project Cost Model 41
3.8 Development of Time Boxing Project Cost Model 46
3.9 Chapter Summary 49

CHAPTER 4. RESULTS AND ANALYSES 51

4.1 Introduction 51

4.2 Future Cost Prediction using Time Boxing Project Cost Model 51
4.3 Validity of 'Time Boxing Project Cost Model' 53
4.4 Comparison between Model Output and Departmental Schedule of Rates........... 56
4.5 Comparison between Steady and Variable Profit for the Project by the Model.... 59
4.6 Chapter Summary and Conclusion 62

CHAPTER 5. CONCLUCIONS AND RECOMMENDATIONS 64

5.1 Synopsis of the Research 64
5.2 Research Findings.. 65
5.3 Recommendations and Direction for Future Research 66

LIST OF REFERENCES.. 67

APPENDIX…… 70

LIST OF TABLES

Table Page

Table 3.1 Summary of HR Efficiencies-Survey Based 36

Table 3.2 Summary of Machine Efficiencies-Survey Based 37

Table 4.1 Results of Time Boxing Model for Building Project..52

Table 4.2 Results of Time Boxing Model for Highways Project 52

Table 4.3 Actual Cost and Time Boxing Model Cost for Building 54

Table 4.4 Actual Cost and Time Boxing Model Cost for Highways.................................55

Table 4.5 Comparison btw Departmental Schedule of Rates and Model without Tax......57

Table 4.6 Comparison btw Departmental Schedule of Rates and Model with Tax...........57

Table 4.7 Comparison btw Departmental Schedule of Rates and Model without Tax......58

Table 4.8 Comparison btw Departmental Schedule of Rates and Model without Tax......58

Table 4.9 Comparison between Steady Profit and Variable Profit for Building 60

Table 4.10 Comparison of between Steady Profit and Variable Profit for Highway 61

APPENDIX TABLE

Appendix Page

Appendix A. Standard Efficiencies for Workmanship (Labours) 71

Appendix B. Standard Efficiencies for Construction Machinary 72

Appendix C. Machines Efficiency Questionnaire 73

Appendix D. HR Efficiency Questionnaire 79

LIST OF FIGURES

Figure Page

Figure 1.1 Overview of Study Approach 17

Figure 3.1 Typical Road X-section 29

Figure 3.2 Plan of Ten Marla House for Building Modeling 30

Figure 3.3 Flow Chart for Project Cost Estimation Model 32

Figure 3.4 Excel View for Project Cost Estimation Model 33

Figure 3.5 Project Cost Risk Factors 34

Figure 3.6 Risk Management Framework 40

Figure 3.7 Annual Growth Rates from year 2004 to 2013 42

Figure 3.8 Aggregate Rate (per 100 Cu. Ft.) from 2004-2013 43

Figure 3.9 Theoretical Normalized Aggregate Prices from 2004-2013 43

Figure 3.10 Normalized Aggregate Rates (per 100 Cu. Ft.) from 2004-2013 44

Figure 3.11 Excel View – Incorporating Cost Risks Factors in Model 45

Figure 3.12 Pert Distributions for Uncertainties in Durations 47

Figure 3.13 Excel View-Formula for Adjusted Value in Time Boxing Model 49

Figure 4.1 Comparisons between Actual Cost and Model Cost for Building Project 54

Figure 4.2 Comparisons between Actual Cost and Model Cost for Highway Project 55

Figure 4.3 Graph for Results between Steady Profit and Variable Profit for Building 60

Figure 4.4 Graph for Results between Steady Profit and Variable Profit for Building 61

LIST OF ACRONYMS

RMF	Risk Management Framework
MES	Military Engineering Services
PWD	Public Works Department
NHA	National Highway Authority
MRS	Market Rates System
BOQs	Bill Of Quantities
PEC	Pakistan Engineering Council
PICC	Pakistan Institute of Cost and Contracts
PMB	Project Management Basics
PMI	Project Management Institute
APM	Association for Project Management
WBS	Work Breakdown Structure
MCS	Monte Carlo Simulation
HR	Human Resource
MAPE	Mean Absolute Percentage Error
USDOT	U.S. Department of Transportation Federal Highway Administration

ABSTRACT

Accurate estimation of effort, time and resources for successful completion of a project is a challenging task for project managers. Several techniques are commonly practiced around the globe for project cost estimation based on the project's scope, type, and availability of resources. Also, different agencies use different techniques for estimating project contingency reserves and some of the techniques explicitly consider project duration and cost. Unfortunately Pakistan's construction industry continues to use traditional methodologies for preparation of project cost estimates and contingency reserves. There is lack of general awareness about modern project cost estimation techniques and project cost estimates are prepared considering the current market rate of different construction item and a fix percentage of the project cost is set aside to cater for future risks to the projects. Even using regularly published departmental schedule of rates (e.g. MES, PWD, NHA) most of the projects suffer from cost and duration issues. Present study developed an enhanced framework for project cost estimation and design of rational contingency reserves. The proposed framework can predict present and future cost scenarios for both building and road projects with minimum risk. The proposed framework used quantitative as well as probabilistic techniques duly incorporating past trends and actual field conditions for project cost estimation. Using data from completed projects, model validation revealed that developed model has the ability to predict precise future project cost. Using MES and PWD Schedule of Rates, Punjab finance department Market Rates System (MRS) and, NHA composite rates, a detailed comparison between project costs estimates was carried out. It was revealed that for building projects PWD Schedule of Rates and Punjab finance department MRS provides reliable cost estimates. For highway projects NHA's composite rates are more reliable and may be used for highway project cost estimation. The framework developed in this thesis can be used by highway as well as construction agencies for reliable estimation of future project cost and design of realistic project contingency reserves irrespective of project duration.

CHAPTER 1. INTRODUCTION

1.1 Background

Cost estimation is considered as the most important step in project management. It establishes the baseline for the project cost at various phases of the project development process. At a particular phase of the project development process, the cost estimate signifies the likelihood of the cost, depending upon the data availability. Underestimation of project cost and resources is one of the most common contributors to project failure [Lim, 2012]. Also poor planning and ignorance to major project risks are the reasons which may lead to cost overrun, project delays or project failure.

Several techniques have been used worldwide for project cost estimation. Based on the project's scope, type of the estimate (civil, electrical, plumbing etc.) and availability of project resources, the estimator can any technique for project cost estimation. Most commonly used techniques are: (1) bottoms-up technique (2) analogy technique (3) parametric technique (4) trend analysis technique, and (5) expert opinion technique [John, 1997]. In developed countries use of specialized project cost estimation software has become a common practice. According to Dagostino and Peterson [2011] in 2003 the American Society of Professional Estimators reported that 47% of construction companies used specialized project cost estimation software which uses spreadsheet layout combined with available resources database for project cost estimation.

Contingency has been defined as "the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization" [PMI, 2000]. Contingencies are often considered an excuse for using poor estimating practices [Popescu et al., 2005]. Popular techniques being followed around the world for establishing contingency reserves for the project are: (1) traditional percentage, (2) regression analysis, (3) monte carlo simulation, and (4) method of moments etc. [Baccarini, 2005]. In traditional percentage method some fixed percentage of the total project cost is set aside as contingency reserve. This is a simple technique that is becoming unpopular among the construction community around the world because it is an irrational approach and projects following this approach mostly become over budgeted [Hartman, 2000] and also that fixed percentage is a constant amount irrespective of project duration. In recent years project contingency reserve techniques that explicitly take care of project duration and project cost are becoming popular. Most of these techniques make use of the simulation tools i.e. Monte Carlo Simulation.

Unfortunately in Pakistan's construction industry still traditional methodologies are followed for preparation of project cost estimates and generally there is unawareness about modern techniques that are being used around the world. Generally project cost estimates are prepared by considering the current month rates of the construction item and a fix percentage of the project cost is set aside to cater for future unknown risks. Most of the organizations in Pakistan use 5-10% of the estimated project cost as contingency reserve. The total project cost is the sum of initial estimated cost (without contingency reserve) and contingency reserve. Also, a simplified practice is being used by Pakistan construction industry for the future year projects that are similar in nature to projects that have been executed or under execution. Cost of such project is estimated simply by adding a fix percentage to current year/ past year total project cost. Most of the projects following traditional methodology suffer from cost overrun as contingency reserves become inadequate.

To overcome the effects of price fluctuations (uncertainties) the Pakistan Engineering Council (PEC) has also introduced price adjustment formula (C-factor), which is being used currently in construction contracts and is based on FIDIC. In this methodology in case of variation in prices of construction items, increase / decrease in cost is adjusted to the contractor by applying this C-factor formula. Price adjustment formula has two serious flaws which are; (1) it only covers the variations in prices for main construction items depending upon the type and nature of project, and (2) the weightage of one construction item is calculated based on initial estimated quantity of that item in complete project, however with variation in scope of work this weightage may become quite irrelevant. This usually gives an unjustified increase in cost that is then paid to the contractor as per the contract clause against escalation of prices. Market risks being out of direct control of the Contractors are being owned by the clients ensuring economy and survival of projects using this cost escalation mechanism.

"Risk management is the identification, assessment, and prioritization of risks followed by coordinated and economical application of resources to minimize/ maximize, monitor, and control the probability and impact of unfortunate event or to maximize the realization of opportunities in the project life cycle" [Hubbard, 2009]. Using risk management probable risk for any project can be identified at the early stage of the project and their responses as well as monetary/ time effects can be predicted. Risk management helps to complete the project within planned time, cost and defined scope without compromising quality.

Although there is general awareness about risk management techniques in Pakistan's construction industry, however there is a lack of real understanding of the concept. Cost, time and scope are usually expressed in monetary terms and in the absence of agreed frame works of risk management, project managers tend to rank one of the parameter on the lighter side that may lead to project cost overrun and project delays. In Pakistan different governmental/ private organizations prepare and manage schedule of rates for project cost estimation. These schedules of rates are used by entire construction industries of Pakistan. Military Engineering Services (MES) Schedule of Rates, Public Works Department (PWD) Schedule of Rates, Punjab Finance Market Rates System (MRS), Pakistan Institute of Cost and Contract (PICC) composite rates and National Highway Authority (NHA) composite rates are mostly followed.

1.2 Problem Statement

Currently construction industry of Pakistan generally follows schedule of rates issued by MES, PWD, Punjab finance department, PICC and NHA for preparation of project cost estimates. Contingency reserves are designed as fixed percentage of the estimated cost to cater for uncertainties in market rates of construction items. Current methodology used in construction industry of Pakistan for preparation of project cost estimates using fixed percentage (generally 5-10%) contingency reserve has proved ineffective over the years. Our entire history of construction industry shows the majority of the projects had issue of cost overrun and delays. With recent advances in risk management techniques project risks can be identified at an earlier stage and their monetary impacts and responses can be predicted.

The current situation demands development of an enhanced frame work for project cost estimation that enables to:

a. Predict precise future project cost scenarios.
b. Helps project team to design rational contingency reserves.
c. Analyze those factors which contribute majorly in cost overrun and project delay.

1.3 Research Objectives

The prediction of project cost for different scenarios is an important step in successful execution of any project. In order to address this key issue and other associated factors, the objective set forth for present research are:-

a. To study and analyze the variation in construction items' prices and formulate distribution parameters for prediction of future project cost scenarios.
b. To develop risk management framework (RMF) for road and building construction projects considering cost and time parameters.
c. To test the validity and reliability of the developed RMF using real data.

1.4 Overview of Study Approach

To accomplish the research objectives, a detailed methodology was devised (Figure 1.1) and the following research tasks were outlined:-

a. Detailed literature review for the identification of risk factors which leads to project cost overrun and project delays.
b. Selection of a typical building and road project.
c. Development of 'Project Cost Estimation Model' on excel.
d. Collection of departmental schedule of rates i.e. MES, PWD, Punjab Finance Department and NHA.
e. Identification of project cost risk factors.
f. Collection of construction item's rates data for last ten years.
g. Collection of data for efficiencies of labour and machines from the field with the help of questionnaire survey.
h. Incorporation of risk factors in project cost estimate model.
i. Development of 'Probabilistic Project Cost Model'.
j. Development of 'Time Boxing Project Cost Model' by incorporating major price variations factors into 'Probabilistic Project Cost Model'.
k. Analysis of results using simulation techniques.

1.5 Thesis Organization

This research is organized into five chapters. The introduction, problem statement and study objectives are discussed in Chapter 1. Chapter 2 provides a literature review on project cost estimation techniques, contingency techniques, simulations and related topics. In Chapter 3 the methodology used for the preparation of risk management frame work is discussed. Chapter 4 covers the analyses and results. Lastly, the research summary, findings, and recommendations are presented in Chapter 5.

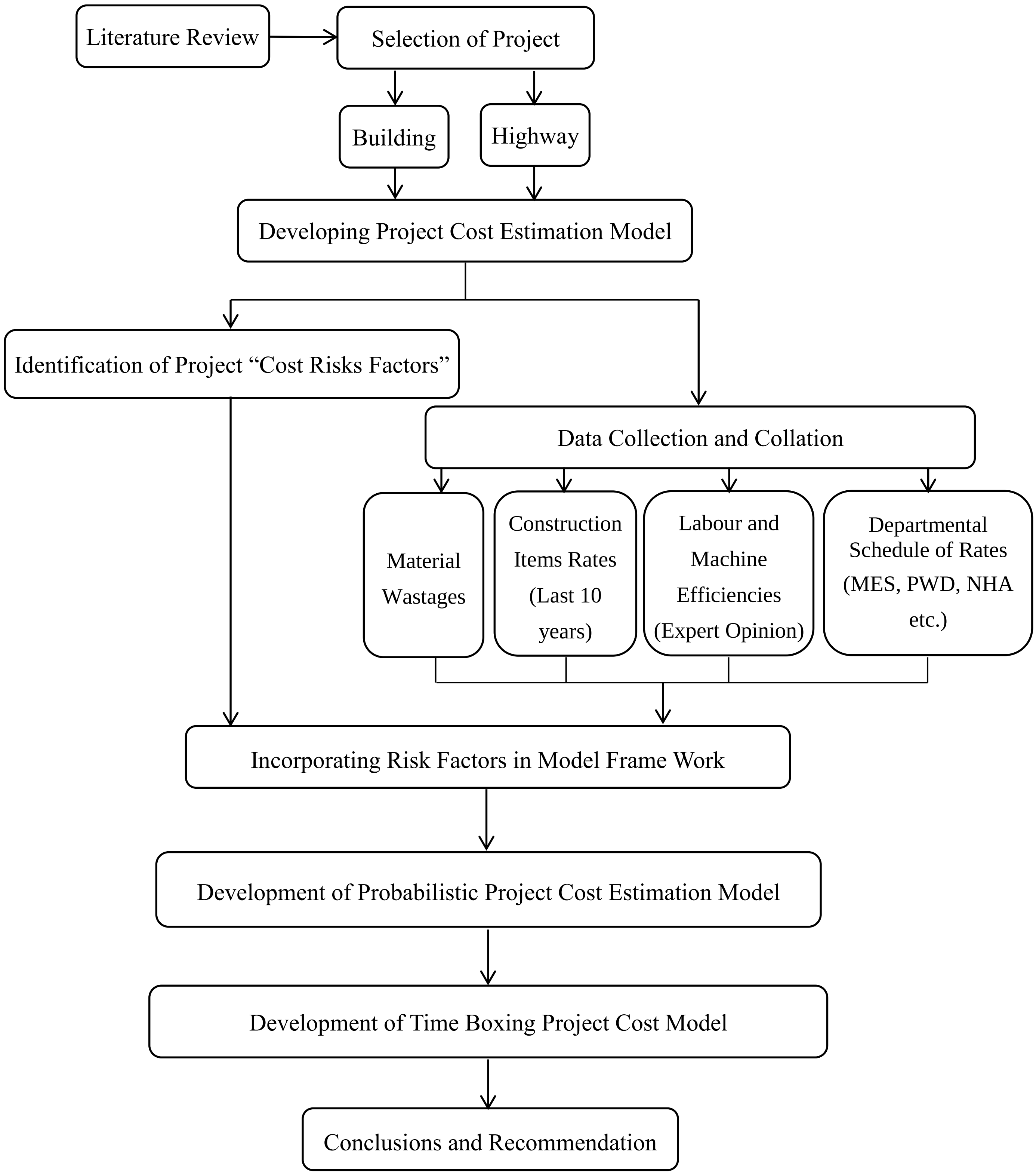


Figure 1.1 Overview of Study Approach

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter summarizes following topics project cost estimation techniques, cost contingency techniques, importance of sensitivity analysis, difference between traditional approach and analytical approach for project cost contingency, simulations, concept of time line series and labour/ machine efficiencies. This chapter first examines the project cost estimation techniques and contingency techniques. Bottom-up technique and traditional contingency approach are the most commonly used but developed countries are adopting advanced techniques and software for project cost estimation and contingencies.

Risk may be defined as “An uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective” [PMI, 2000]. According to Association for Project Management (APM) it is “An uncertain event or set of circumstances that, should it occur, will have an effect on the achievement of the project’s objectives” [APM, 1997]. Project Management Institute (PMI) defines Risk Management as a proactive approach to dealing with uncertainties rather than a reactive approach. According to PMI guide book [2004] risk management consists of 6 processes; (1) risk management planning, (2) risk identification, (3) qualitative risk analysis (4) quantitative risk analysis (5) risk response planning, and (6) risk monitoring and control. Literature review revealed that sensitivity analysis is one of the most effective techniques for project risk management. It highlights the parameters which are influencing the product behaviour and with the help of sensitivity analysis factors affecting the project cost can be identified and their remedial responses can be designed. This chapter also explains difference between traditional approach and analytical methods in case of project costing. Traditional methods are mostly empirical based on some experiences and thumb rules whereas; analytical methods are based on formulas and relative probabilistic terms.

Simulations and their importance have been discussed for clarifying their relation with risk management, which can be used for making effective project cost estimates. Concept of time line series is the most important part of this literature collection. This concept defines the factors which affects the variation and trends of rates for the construction items. Lastly the literature review highlights labour and machine efficiencies alongwith factors which affect them. Project cost and duration is directly dependant on the efficiencies of labour as well as machines.

2.2 Cost Estimation Techniques

Cost estimation is one of the most important steps in the project planning and execution. It establishes the baseline of the project cost at various phases of the project execution. Some of the commonly used techniques for project cost estimation are as follows:

2.2.1 Bottom-Up Technique

The bottom-up method is considered to be the most precise method for preparation of project estimates. Estimates prepared by using this method are also known as micro estimates. During the planning period and project commencement, this method is used to determine budget and complete estimates. This technique uses the estimate of individual work items and summing them to get a total project cost. Work Breakdown Structure (WBS) is being developed during the planning phase of the project. Estimates are calculated for all activities at the lowest level of the WBS and then these are added to get the complete project estimates. This method requires experts to perform the estimation. One of the drawbacks of bottom-up method is that it consumes more time than other techniques [Larson and Gray, 2011].

2.2.2 Top-Down Technique

The estimates prepared by using this method are also known as macro estimates. These are made by the top level management, who has experience, knowledge and information to define the project duration and project cost for the processes used to complete the project. In order to define magnitude estimate at the beginning of any project, this method is applied. The method uses the actual time durations and costs from prior projects as a basis for reforming the project cost for the new project [Larson and Gray, 2011].

2.2.3 Analogy Technique

The analogy method of estimation is based on a comparison of the new system with a prior one. It depends upon the known cost of an item used in earlier project as the basis for the cost of a same item in a new project. Even if two projects would not be identical, an estimate using this technique would be prepared by considering their likenesses and differences in design and performance. Known Cost will be amended depending upon the differences in relative complexities of operational characteristics, design and performance. In analogous method actual cost of the similar previous project is taken as a baseline and then adjustments are made for known differences, of project size, scope, duration, etc., in the cost for the current project. One of the examples of analogy technique is “square-foot estimates” [John, 1997].

2.2.4 Parametric Technique

Parametric estimates and analogy technique go hand to hand; however the complexity of the equation used in parametric estimates is far more [Dagostino and Peterson, 2011]. This technique is used to validate bottom up estimates and to obtain final estimates. This method is useful when the given information is partial. Historical data is required for applying parametric estimating technique based on similar projects. Parametric estimates use equations that define Correlations between cost drivers and system parameters (design, performance parameters etc.) by using statistical analysis on gathered data. The cost equations and cost estimate relationships are derived with this analysis that can be applied individually or grouped into complex models [John, 1997].

2.2.5 Trend Analysis Technique

A contractor efficiency index is determined by the help of comparison between original contract costs of the project against actual costs on work executed to that date. This derived efficiency index is used to define the cost estimate of works not yet accomplished [John, 1997].

2.2.6 Expert Opinion Technique

Expert judgment methodology is in coincidence with objective estimation techniques. It provides information about the working environment of the organization and also the information from previous comparable projects by using knowledge gained from past project management experiences. This method is used when other techniques cannot be applied due to unavailability of reasonable data. In this method numerous experts are consulted frequently until an agreed estimated cost is established [John, 1997].

2.2.7 Specialized Softwares

In 2003 the American Society of Professional Estimators (ASPE) reported that 47 % of construction companies used specialized estimating softwares. These specialized softwares increase the productivity of the estimator. These estimating software packages use a spread sheet layout used for cost estimation and combine it with the data base. These layouts displays the cost associated with each bid item. These items are selected from the database, which contains standard costs, productivity rates and labour rates etc. The disadvantage of these softwares is that they are expensive and requires substantial commitment to set up and maintain them [Dagostino and Peterson, 2011].

2.3 Techniques for Project Cost Contingencies

Contingency is defined as "the amount of money or time needed above the estimate to reduce the risk of overruns of project objectives to a level acceptable to the organization" [PMI, 2000]. Contingencies are used to cover unknown unforeseen risks that are not possible to adequately evaluate at the time the project cost estimates are prepared. Popular techniques being followed around the world for establishing contingency reserves for the projects are as following;

2.3.1 Traditional Percentage

In Traditional technique contingencies are calculated as fix percentage addition on the base cost estimate, based on past experience and historical data. Traditionally cost contingencies are deterministic; as it gives point cost estimates for each component based on their most probable value [Mak et al., 1998]. The fix percentage addition methodology is based on arbitrary method and may consider project characteristics like project type and project scope [Lorance and Wendling, 2001]. The traditional percentage technique is reasonable for simple projects under stable and favourable conditions but it is unsatisfactory for complex and huge projects [Newton, 1992]. As some parts of the project reflect greater uncertainties than others therefore, different contingency percentages should be calculated for each main cost element. This method is considered more rational and reliable than the applying a fix percentage to whole project cost because it allows close examination of each cost element [Ahmad, 1992; Moselhi, 1997]. The fix percentage method is arbitrary (subjective) and difficult and hard to justify [Thompson and Perry, 1992]. This technique is the main reason for cost overrun of many projects as it is an unscientific approach [Hartman, 2000].

2.3.2 Method of Moments

In this technique uncertainty present in each cost item is reflected by using probability distribution for an estimate. Depending upon a desired confidence level, contingency is derived from the each selected probability distribution. Each cost item has its mean value and standard deviation based on its distribution. Therefore, the mean values and standard deviation for all items are summed up to get the overall mean value and variance for the total project cost. Based on the central limit theorem this total project cost is assumed to follow a normal distribution but only if the cost items are independent. After that the contingency can be evaluated from the probability distribution, of the overall project cost, by using the standard probability tables for normal distribution depending upon a desired confidence level [Baccarini, 2005].

2.3.3 Monte Carlo Simulation

Monte Carlo Simulation (MCS) is a quantitative method for risk analysis. MCS provides a framework of setting the contingency value for total cost of the project. The output of Monte Carlo Simulation is a probability distribution defining the uncertainty that exists. Multiple trial runs are done, with help of simulation tool, using random variables to get the probable outcome defining the contingency required [Baccarini, 2005].

2.3.4 Regression Analysis

Regression model techniques have been used for cost estimation since 1970s [Kim et al., 2004]. Behaviour of contingency is explain and predicted by using linear regression, which reflects the linear relationship between a dependent variable and independent variables. Estimating the contingency reserves for construction cost overruns requires the identification of risk factors and relationship between them. A statistical analysis (multiple regression analysis) is used for evaluating project cost overruns and associated contingency funds, by setting these identified risks as predictors to produce a predictive model. Multiple regression analysis is usually represented in the form:

$$Y = A + \beta_1 X_1 + \beta_2 X_2 + \ldots\beta_n X_n$$

Where Y is the dependant variable and X_1, X_2 are independent variables. β_1, β_2 etc. are the constants estimated by regression analysis. Once the values of the independent variables are inserted, the regression equation can then be used to estimate the value of a dependent variable. [Baccarini, 2005; Jason et al., 2006].

2.4 Importance of Sensitivity Analysis in Risk Management

Complex physical systems are investigated by using computer modelled simulations. These models contain structured parameters, and if small changes in the parameter value take place, the numerical results can be highly sensitive. [PMB, 2013]. Sensitivity analysis is modelling tool for risk management that is used in assigning value to each risks. In risk analysis technique, project risks are analysed for their impact on the project goals. One of the most useful graphic tools for assessing risk sensitivity or effect on overall uncertainty of the risk model is "tornado diagram". Keeping in view the impact of various risk elements on a project can assist management with setting priorities to achieve the end result quickly. The results of a sensitivity analysis can easily be predicted by management through the use of a tornado diagram. Tornado diagram gives graphical results showing the correlation between uncertainties of inputs in model and the distribution of the outputs and it highlights the factors which are contributing in overall project risk. Project management can use sensitivity analysis to prioritize the major project risk factors affecting the project objectives and by this more effort can be concentrated to lessen the impacts of those risks. Lesser risk potential allows projects to flow in a smoother way with fewer unseen delays. The risk analysis is complicated technique due to complex modelling and it requires subjective data for conducting the analysis. Though, regardless of the complexity, benefits being extremely valuable which out weight the complications of the process [USDOT, 2006].

2.5 Traditional and Analytical Method of Risk Analysis for Project Cost Contingency

Traditional techniques for risk analysis are procedures which are established by using empirical knowledge which focus mainly on estimating project cost contingencies.

In this technique, risk factors are allocated to several project components based on past findings of relative risk of several project components. Project contingency is extracted by multiplying the estimated cost of individual component by its particular risk factors. This technique is considered as simplest technique and it generates cost contingency estimates. Though, the project team information is only considered in few risk factors. Traditional techniques do not encourage responses of the risk outputs of the definite project risks as they are based on empirical and historical nature of risk assessment. Similarly, the identification of definite project risk drivers is not supported by this technique as well. Also project schedule risk cannot be evaluated by using this methodology. Analytical methods are also known as second-moment methods and they follow probability techniques to evaluate the expected value and variance of the outputs. Formulas are used in these methods that associate the expected value and standard deviation of each input to the expected value and standard deviation of the output variables. These techniques are more suitable when the output is a simpler sum or product of the several input values. Analytical methods are relatively way easier and simpler to comprehend as they need only an estimate of the individual variable expected value and variance. They permit specific information risk to be assimilated into the variance values and provide a realistic cost contingency estimate [USDOT, 2006].

2.6 Risk Analysis with Simulations

Simulation uses mathematical modelling techniques to help managers artificially experience a situation and thereby identify the potential risks and opportunities associated with it. The advantage of simulation over the largely manual techniques is its ability to handle huge quantities of information and to take into account the interdependence between different risk variables. That is how one risk can create another and how a particular combination of circumstances can impact upon a project variable. Computers are essential to undertake this process where the computer acts as an experimental laboratory where the project can be "run" over-and-over again using different combinations of input assumptions [Loosemore et al., 2006].

Computerized probabilistic calculations that use random number in multiple trial runs to get the probable outcome from probability distributions are called Monte Carlo method. The main purpose of the simulation is to identify the cause and effect of various risks on project parameters (for e.g. the project duration or total project cost). Monte Carlo method has advantage over common analytical methods that it can evaluate the effect of risk on cost and duration for complicated models. MCS through sensitivity measures determine the effect of particular risk on the project cost and duration. Though, Monte Carlo techniques require relevant information and appropriate training for their successful application. User should be aware of the probability distribution inputs require for applying Monte Carlo method i.e. expected value, variance, and distribution shape. Monte Carlo techniques are widely used for risk analysis of project because they provide comprehensive knowledge about risk effects on the project cost and duration [Molenaar et al., 2010].

2.7 Time Line Series

Hill and Lewicki [2007] explain that analysis of time line series depicts techniques for studying time series data for extracting statistics and characteristics of given data. Time series sequence can be explained in two main components (1) trend, and (2) seasonality. The trend reflects a common structured linear or nonlinear element that deviates over time and does not occur again within the given time defined by our data. The two major aims of time series analysis are:

a. Figuring out the nature of the phenomenon reflected by the sequence of observations.
b. Forecasting.

There are no such methods to pinpoint trend elements in the data of time series. Though, as long as the trend is constantly increasing or decreasing its analysis can be done easily. When the time line series data has considerable errors than first of all data is normalized for trend identification by following smoothing process. Smoothing always involves averaging of given data such that the non-systematic elements of each observation cancel out each other. After smoothing, that data is fitted i.e. best fit curve and to apply. Time series data with monotonous nature (consistently increasing or decreasing) can be approximated by a linear function but if there are some monotonous non-linearity elements in the data than first of all that data should be transformed to remove non-linearity.

2.8 Machines Productivity

According to Peurifoy and Schexnayder [2003] over 1,145,000 businesses utilize heavy equipment while engaged in contract construction. The ability to win contracts and earn profit is determined of a construction contractor by two vital aspects (1) people (2) machines. To be economically competitive, equipment spread must be competitive both mechanically and technologically. Old machines, which require costly repairs, cannot compete successfully with new equipment having lower repair costs and higher efficiency.

The cost of equipment is considered to be 10 to 30% of total project cost. Proper planning, procurement installation, selection, operation, maintenance and equipment policy play its vital role in equipment efficiency for successful project completion. The main task of the Equipment manager is to decrease downtime and attain optimum equipment proficiency at lowest cost. Thus equipment management integrates and continuously interacts with human, technical, financial and production system in order to achieve top efficiency and cost effectiveness [Sharma, 1988]. Table of standard machine efficiencies are placed at Appendix ‘A’.

2.9 Labours Productivity

To express the relationship between outputs and inputs term “productivity” is used [Borcherding and Liou, 1986]. “The definition of labor productivity is the amount of goods and services produced by a productive factor (manpower) in the unit time” [Drewin, 1982]. Kazaz et al., [2008] describes factors affecting on construction workforce productivity as follows; (1) work discipline, (2) health and safety conditions, (3) work satisfaction, (4) relation with workmates (5) cultural differences (6) on-time payment, (7) incentive payments and financial rewards, (8) working at similar activities, (9) design complexity, (10) weather conditions (11) overtime, (12) Quality of site management, (13) Supervision etc. and all these factors were distributed under four major groups as (1) socio-psychological factors, (2) organizational factors, (3) economic factors, and (4) physical factors. Standard efficiencies given by Dutta B. N [2007] are placed at Appendix ‘B’.

2.10 Chapter Summary and Conclusion

Preparation of project cost estimate is one an important phases for any project. Different kind of techniques are used worldwide for the cost estimation out of which bottom-up technique is considered the most detailed estimation approach but in developed countries trend for the use of specialized project cost estimation softwares is increasing day by day. For project cost contingency use of traditional percentage approach as contingency reserves is becoming unpopular as this technique is subjective and difficult to validate [Thompson and Perry, 1992]. Instead “method of moments” and use of “Monte Carlo Simulations” for accessing project cost contingencies are becoming popular.

Sensitivity analysis is one of the effective techniques of risk management which can be used for risk analysis of project cost. Factors varying or influencing the project cost can be identified with the help of sensitivity analysis. Use of computer simulations is an effective tool for risk analysis and risk management. Sensitivity analysis with the help of computer simulations can be performed in more effective way for identification of factors affecting the project cost.

Time line series explains about the methods used to analyze time series data, in order to extract meaningful statistics of the data. It has two basic components (1) trend and (2) seasonality. By understanding the concept of time line series behavior of construction items price trends can be analyzed.

Project cost directly depends on the efficiencies of labour and machines during the project execution phase. Considering plausible efficiencies during the preparation of cost estimates is very much important as they affect the project cost. Therefore understanding of labour and machine efficiencies and factors, which may vary the efficiencies, is very important for accurate cost estimates as well as for efficient and effective project management.

CHAPTER 3. STUDY METHODOLOGY

3.1 Introduction

This chapter discusses the modified approach for generating project cost estimates. The designed methodology covers those risk factors which are usually ignored by the professionals, even being aware.. Thus a probabilistic project cost can be predicted, by this methodology, including the effects of cost risk factors and future price variation factors over time.

Risk Management Framework (RMF), explained here has been designed in steps and by going through different phases. A typical project cost estimation model was developed in the beginning. Afterwards general methodology was adopted for identifying the project cost risk factors. Field data and standard values available in literature were used for risk analyses. Identified cost risk factors were incorporated to 'Project Cost Estimation Model' with the help of collected data, which was modified into 'Probabilistic Project Cost Model'. The final phase of this RMF was "Time Boxing Model" in which uncertainties related to future price variations were incorporated to obtain project cost for future scenario.

3.2 Selection of Project Types

The main objective for this research was to design a risk management framework for project cost estimate. To prepare the project cost estimates two typical types of projects were selected, one from 'Building Industry' and other from 'Highway Industry'. Thus two different project cost estimates were to be developed from the selected projects i.e. each for the building and highway project. Following were the broad design specification for the selected projects:

a. Highways Model
   (1) Road length = 10 km (two lanes)
   (2) Width = 7.3m (24 ft.)
   (3) Shoulder = 2.5m (8ft.)

b. Building Model

(1) Double storey 10 Marla House

(2) Plot size = 30ft. x 75ft.

(3) Total Covered area = 2864 sq. ft.

Main reason for considering '10 Marla House' as building project and '10 km of Road' as highway project for modeling because of their wide applicability, as these are commonly executed in Pakistan. Due consideration was given to the fact that the RMF should be applicable to any type of construction project.

A typical cross-section of road for highway model is shown in Figure 3.1 and Plan used for building model is shown in Figure 3.2.

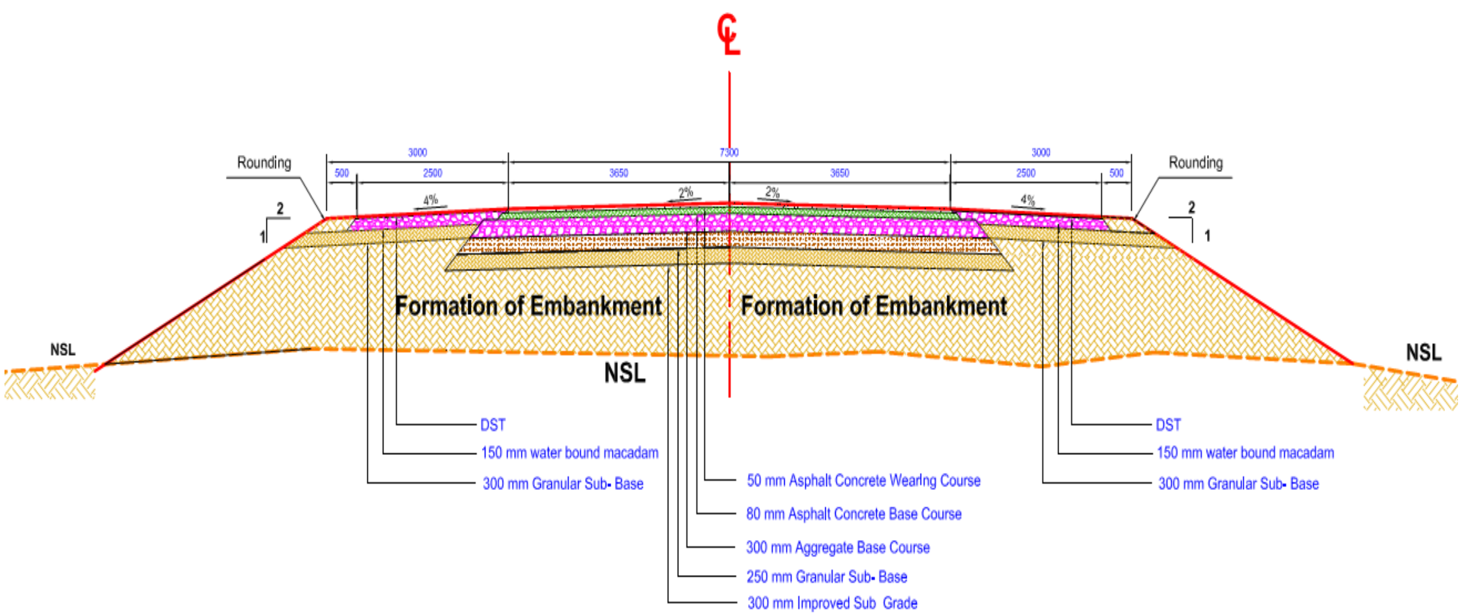


Figure 3.1 Typical Road X-Section for Highway Project

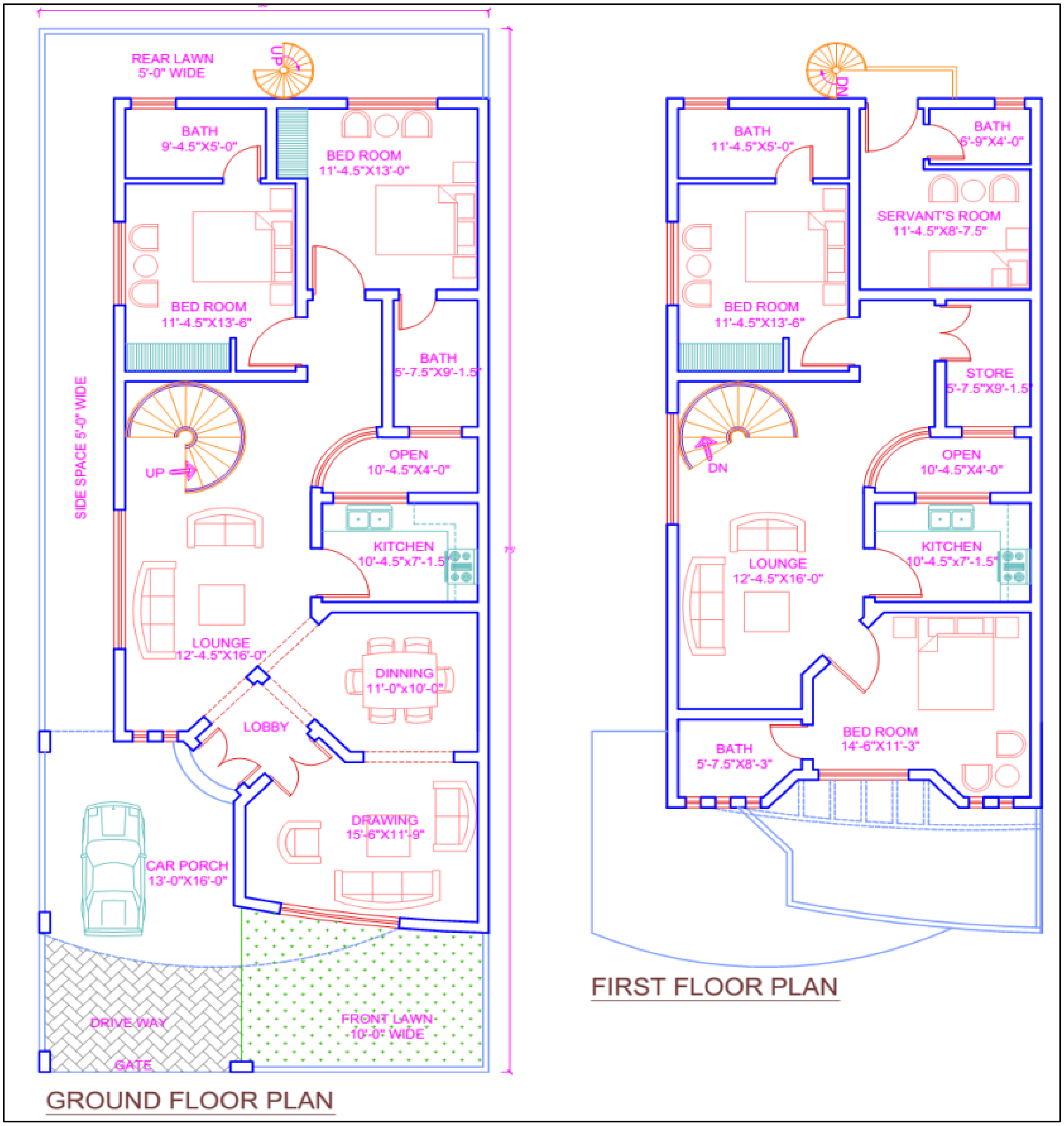


Figure 3.2 Plan of Ten Marla House for Building Project

3.3 Developing Project Cost Estimation Model

As discussed in the previous section, two types of projects were selected, one from building and other from highways. Cost estimates were to be developed for both of the projects separately, with the help of design specifications collected. Models were developed on Microsoft Excel. These models were typical and simple form of project cost estimates, which are commonly prepared by estimators. Steps followed for the developing of project cost estimation model were:

a. Step#1-Preparation of Quantity Sheets (Take-Off Sheet): Quantity sheet was generated as per design specifications of selected projects (10 Marla house and 10 Km of road). Quantities were calculated without considering wastages which are normally taken as approximately 5-7% for construction items.

b. Step#2-Preparation of Rate Analysis Sheets: Based on literature review and departmental rate analysis procedures (PWD, NHA etc.), rate analysis sheets were generated for each project activity.

c. Step#3-Preparation of Rate Index Sheet: An excel sheet was generated describing all the construction items (materials, labour and machines), which were considered during the preparation of rate analysis for each activity of ‘Bill of Quantities’ (BOQs). Rates of each item were set in ‘Rate Index Sheet’, which automatically update items’ rates in all ‘Rate Analysis Sheets’.

d. Step#3-Preparation of Bill of Quantities (BOQs): BOQs were generated as per calculated quantities using standards which are being followed by construction industry of Pakistan and different government departments.

e. Step#4-Interlinking Quantity Sheet, Rate Analysis Sheets and BOQs: All excel sheets (quantity sheet, rate analysis sheets for project activities and BOQs) were interlinked to produce project cost estimation model. Excel sheets were interlinked in following sequence:

(1) ‘Quantity Sheet’ was interlinked with ‘BOQs’ i.e. quantities for activities mentioned in ‘BOQs’, were actual reflection of numerical quantities calculated in ‘Quantity Sheet’.

(2) ‘Rate Index Sheet’ was interlinked with ‘Rate Analysis Sheets’ of each activity i.e. Items’ rates, in ‘Rate Analysis sheets’, were reflection of rates set as input in ‘Rate Index Sheet’.

(3) 'Rate Analysis sheets' were interlinked with 'BOQs' i.e. rates for activities mentioned in 'BOQs' were reflections of rate being calculated with 'Rate Analysis Sheets' for each activity separately.

After quantities and rates for each activity were interlinked, BOQs sheet was modified into 'Project Estimation Sheet' i.e. 'Basic Project Cost Estimation Model'. Thus project cost estimation model was developed by the help of MS-Excel. Flow chart showing the interlinking sequence for developed sheets for project cost estimation model is shown in Figure 3.3. Excel View for developed project cost estimation model is shown in Figure 3.4.

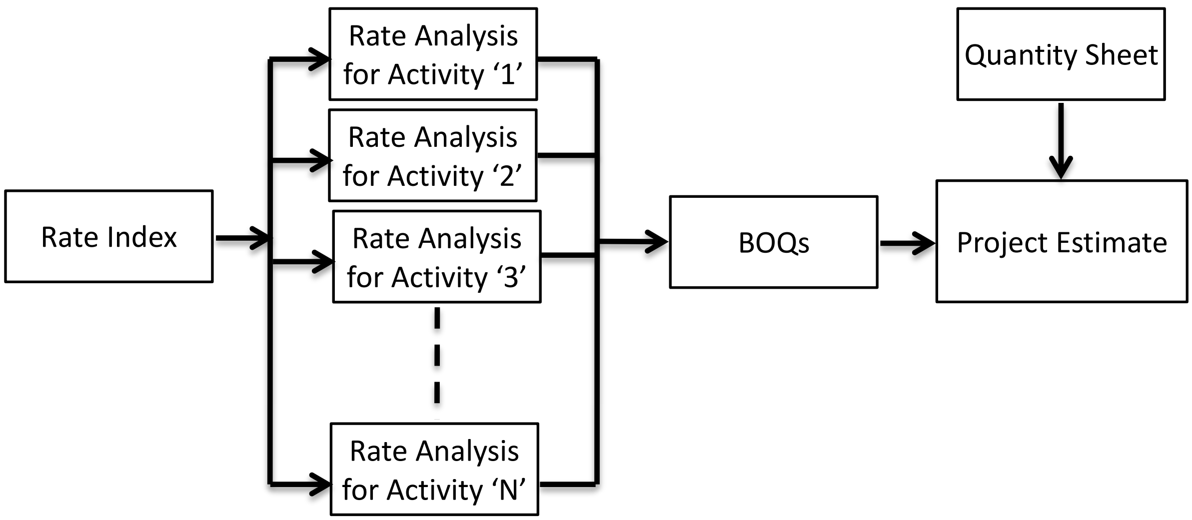


Figure 3.3 Flow Chart of Project Cost Estimation Model

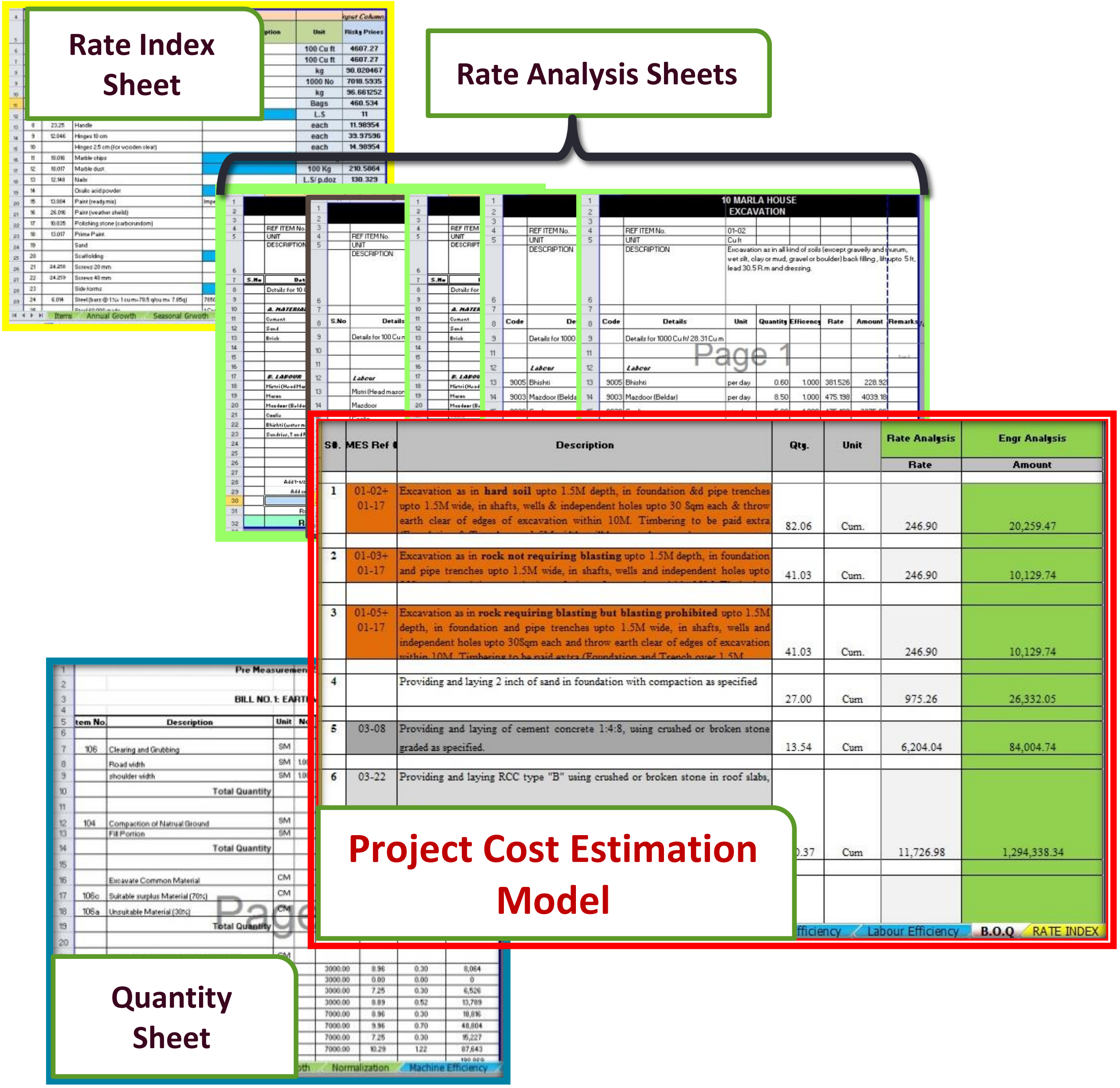


Figure 3.4 Excel View for Project Cost Estimation Model

3.4 Identification of Project Cost Risks

After development of project cost estimation models, cost risks (uncertainties) were identified which may cause project cost overrun and variance in project duration. With the help of detailed literature review and expert opinion following cost risk factors were identified; (1) labour efficiencies, (2) machine efficiencies, (3) construction material wastages, and (4) construction items' rates. Project cost risk factors are shown in Figure 3.5.

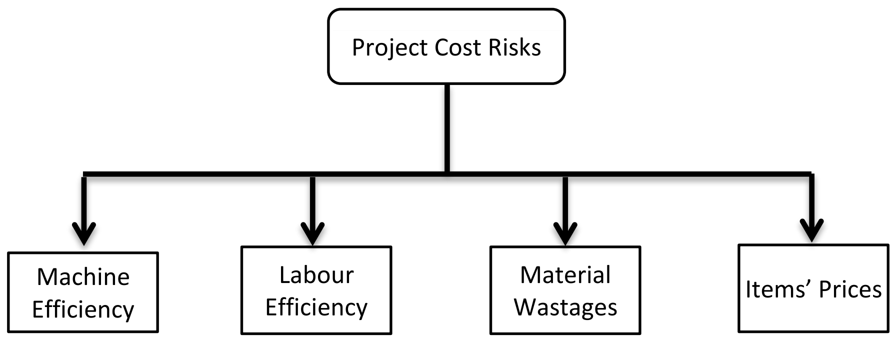


Figure 3.5 Project Cost Risk Factors

3.5 Data Collection and Collation for Cost Risk Factors

3.5.1 Labour and Machine Efficiencies

An empirical study based on the findings of the questionnaire survey was adopted. From literature review, the parameters were collected upon which the efficiency of different workmanship and machines can be defined. Separate questionnaires were prepared for building and highway project. The questionnaires were printed and distributed as well as published electronically. Distribution was made between academia, clients, consultants and contractors.

(1) Human Resource (HR) Efficiency Questionnaire

For HR efficiency survey a questionnaire was prepared containing 24 questions about different construction activities related to (1) labour, (2) mason, (3) plumber, (4) polisher, (5) carpenter, (6) steel fixer, (7) electrician, (8) painter, and (9) white washer. Total 120 responses were collected and summary of responses collected is shown in the Table 3.1. A copy of HR Questionnaire used is placed at Appendix ‘D’. Percentage distribution of responses from different fields is as follows:-

a. Academia - 12%

b. Clients - 11%

c. Consultants - 35%

d. Contractors - 42%

(2) Machine Efficiency Questionnaire

For machines efficiency survey a questionnaire was prepared comprising of 18 questions about the construction activities related to (1) grader 150 hp. for sub-grade, (2) grader 150 hp. for sub-base, (3) grader 150 hp. for base, (4) front end loader 2.30 cum, (5) dumper 10 T, (6) bull-dozer 200 hp. for spreading, (7) bull-dozer 200 hp. for cutting, (8) bull-dozer 200 hp. for clearing, (9) tandem vibratory roller, (10) pneumatic tyre roller (P.T.R) 18 T, (11) bitumen distributor tow type 2000 litre., (12) asphalt plant 80 T, (13) asphalt paver 4.75 m wide, (14) excavator 68 hp., (15) concrete batching plant 30 cum, (16) concrete transit mixer 4.5 cum, (17) concrete static mixer 1cum, and (18) road marking machine. Total 93 responses were collected and summary of responses collected is shown in the Table 3.2. A copy of machines efficiency questionnaire used is placed at Appendix ‘C’. Percentage distribution of responses from different fields is as follows:-

a. Academia - 18%

b. Clients - 21%

c. Consultants - 5%

d. Contractors - 56%

Table 3.1 Summary of HR Efficiencies-Survey Based

S No	Details	Quantity	Units
Mason output per day			
1	Bricks laid	769	No.
2	Concreting on roof	144	Sq. ft.
3	Concreting on floor	235	Sq. ft.
4	Plastering with cement (12 mm or ½”)	87	Sq. ft.
5	R.C.C work in beams and slab	108	Cu. ft.
6	6 mm Mosaic floor work over 2 cm thick cement concrete	44	Sq. ft.
7	2.5 cm thick cement concrete Laying of D.P.C	103	Sq. ft.
Labour output per day			
8	Mixing concrete	84	Cu. ft.
9	Deliver bricks up to a distance of 50’	2886	No.
10	Breaking of brick ballast (25mm)	26	Cu. ft.
11	Earthwork in excavation, ordinary soil	94	Cu. ft.
12	Earthwork in excavation, rock	31	Cu. ft.
13	Sand filling 2inch in foundations, width= 4 ft wide	144	Cu. ft.
Steel Fixer output per day			
14	Reinforcement work for R.C.C (cwt of steel): 1 cwt =50.8023 KG	1.3	cwt.
15	Holdfast per day	26	No.
White Washer output per day			
16	3 coats white washing	570	Sq. ft.
Painter output per day			
17	One coat paint	245	Sq. ft.
18	Paint two coats on wood	38	Sq. ft.
Carpenter output per day			
19	No. of door timber frames completed per day(1.6 sq.ft per frame)	0-2	Days
20	No. of days required to complete one door shutter (2.66 sq.ft per shutter)	0-2	Days
21	Shuttering (erection and dismantle)	32	Cu. ft.
22	Amount of work done by a Polisher per in mosaic flooring	6	Sq. ft.
23	Days taken by a Plumber to complete the plumbing work of 10 Marla house.	17	Days
24	Days taken by an Electrician to complete the electric work of 10 Marla house.	18	Days

Table 3.2 Summary of Machine Efficiencies-Survey Based

S No	Type of Machine	Survey Efficiency /hr	Unit
1	GRADER. 150 HP (Sub-Grade)	213	m
2	GRADER. 150 HP (Sub-Base)	170	m
3	GRADER. 150 HP (Base)	128	m
4	FRONT END LOADER 2.30 CUM	85	Cu. m
5	DUMPER 10 T.	5	Cu. m
6	BULL-DOZER 200 HP (For Spreading)	383	m
7	BULL-DOZER 200 HP (For Cutting)	170	m
8	BULL-DOZER 200 HP (For Clearing)	298	m
9	TANDEM VIBRATORY ROLLER	43	m
10	PNEUMATIC TYRE ROLLER (P.T.R) 18 T.	60	m
11	BITUMEN DIST. TOW TYPE 2000 LTR	1488	Sq. m
12	ASPHALT PLANT 80 T	22	Cu. m
13	ASPHALT PAVER 4.75 M WIDE	22	m
14	EXCAVATOR (TRACK TYPE) 68 HP	51	Cu. m
15	CONCRETE BATCHING PLANT 30 CUM	17	Cu. m
16	CONCRETE TRANSIT MIXER 4.5 CUM	4	Cu. m
17	CONCRETE STATIC MIXER 1CUM	6.5	Cu. m
18	ROAD MARKING MACHINE	17	m

3.5.2 Construction Items' Rates

One of the major cost risk factor is uncertainty in construction items' prices. For analysis of uncertainties/ variation of construction item's rates, past 10 years data on materials, labours and machines were obtained from Pakistan Bureau of Statistics, and Punjab Finance Department.

a. Pakistan Bureau of Statistics

Items' prices data for sixteen different construction items for year 2004 to 2013 was collected from Pakistan Bureau of Statistics. The items for which price data was collected are as follow: (1) bricks, (2) blocks, (3) aggregate (bajri), (4) sand, (5) cement, (6) timber log (sheesham), (7) iron bars 1/2" round, (8) buxly paint, (9) carpenter per day, (10) mason per day, (11) labour per day, (12) plumber per day, (13) electrician per day, (14) electrician per point, (15) petrol super per liter, and (16) high speed diesel per liter.

b. Punjab Finance Department

Punjab Finance Department offers Market Rate System (MRS) and construction items' rates free of cost, on their official website but that are updated bi-annually. Punjab Finance Department offers constructions rates of approximately 2960 different construction items, 90 different types of construction machinery and 130 different types of labourers.

As the said department offered such data for more than a decade, publicly, that has been utilized by various organizations. Hence to acquire that past data different department, contractors, quantity surveyors and organizations were approached.

3.5.3 Departmental Schedule of Rates

RMF was to be compared with standard practices for preparation cost estimates, which are being followed in Pakistan construction industry. For the said purpose following schedule of rates were collected from various departments:

a. MES Schedule of Rates - 2009 (revised in 2010)
b. PWD Schedule of Rates - 2012
c. Punjab Finance Department MRS Feb-Jul 13
d. NHA Composite Rates - 2011

3.6 Development of Risk Management Framework (RMF)

Basic Project cost estimation models were developed for building project and highway project. After project cost risks were identified and detailed data was gathered against each identified cost risk. Next step was development of Risk Management Framework (RMF) in which all the identified cost risks could be adjusted and realistic project cost estimates could be predicted for future scenarios. RMF was developed after following two phases; (1) development of probabilistic project cost model, and (2) development of time boxing project cost model.

Basic project cost estimation model was adjusted against the effects of identified project cost risks with the help of factors obtained after analysis of collected data. These factors, after being incorporated in the basic project cost estimation, modified the model into "Probabilistic Project Cost Model". The cost risks which were fixed in "Probabilistic Cost Estimation Model" are; (1) labour efficiencies, (2) machine efficiencies, (3) material wastages, and (4) items prices. This 'Probabilistic Cost Estimation Model' had the ability to predict project cost free from cost risks with the help of simulations but only for present scenario (depending upon the duration for which item rates data would be provided) and this model was unable to predict future scenario. “Probabilistic Project Cost Model” was incorporated with price variations factors and this modified the model into “Time Boxing Project Cost Model”. This was the final phase for the development of Risk Management Framework (RMF). This model has ability to predict future project cost including the effects of cost risk factors as well as price variations factors on project cost. Figure 3.6 shows the flow diagram showing complete working of “Time Boxing Project Cost Estimation Model” which was the final phase of Risk Management Framework (RMF).

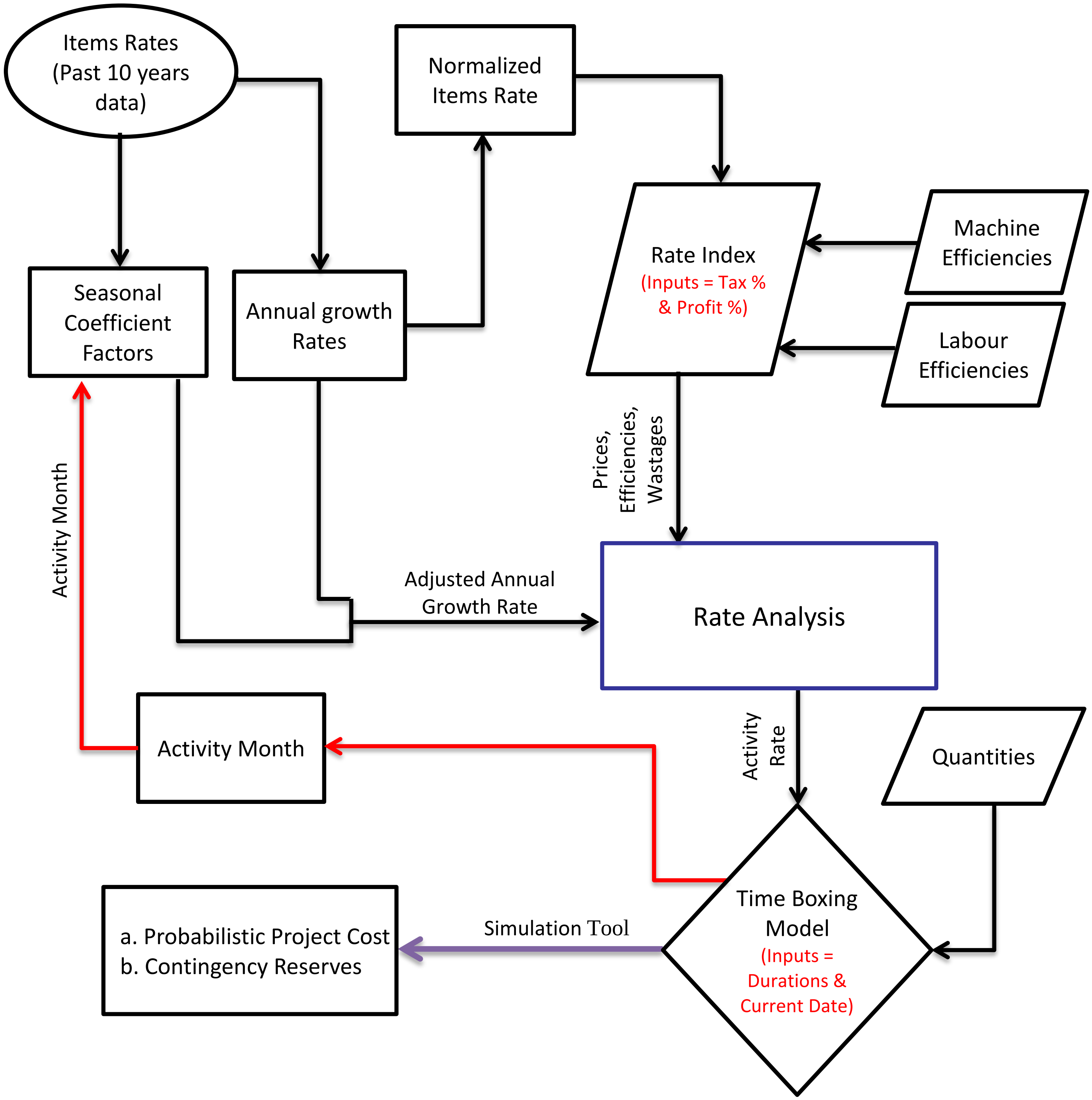


Figure 3.6 Risk Management Framework

3.7 Development of Probabilistic Project Cost Model

Basic project cost model was modified into ‘Probabilistic Project Cost Model’ by fixing identified cost risk factors help of gathered data. ‘Probabilistic project Cost Model’ was developed for building project and highway project. Cost risks factors were incorporated in the model as follows:

(1) Labour and Machine Efficiencies

Using simulation tool probabilistic mean (numerical) values and standard deviations were obtained for the labour and machine efficiencies from the responses collected with the help of field survey for each activity. Decrease in efficiency increases the project cost and vice versa. These labours and machines probabilistic mean values of efficiencies were introduced in the model (rate analysis sheets) in such a way that their effects on the cost can be predicted only when simulations would be run. In model incorporated (fixed) efficiencies of each labour or machine item set as 100% i.e. ‘1’ as it would not affect the estimate of project but when simulation would be run, efficiency for each would increases or decreases as per its standard deviation and mean value. Thus affecting the results by increasing the project cost as the efficiencies would be decreased and decreasing the project cost as efficiencies would be increased.

(2) Material Wastages

Literature review revealed that wastages are mostly considered as 3%, 5% and 7% for different items [Dutta, 2007]. For analysing the effect of material wastages, distributions were introduced with materials quantities in the Rate analysis sheets in such a way that their variation effects on the cost can be predicted when simulations would be run. Following distributions were used for different material items;

a. More sensitive materials RiskTriang (0.01,0.05,0.07)

b. General material items RiskTriang (0.01,0.035,0.07)

c. Materials taken as lump sum RiskTriang (1.1,1.35,1.7)

Distribution types for any case are selected according to parameters/ data available. In this case there are three parameters available upper limit, mode and lower limit which are parameters for triangular distribution and triangular distribution gives better numerical variance between set points that is why this has been used for material wastages. As already discussed material quantities for BOQs were calculated without considering wastages. So in this part wastage quantity for each material was made part of its cost depending upon its wastage factor (distribution) in the model (rate analysis).

Wastages were introduced in such a way that variance for wastage for each item would affect the project cost during simulation run.

(3) Construction Items' Rates

Past data for Construction items' prices was collected from Pakistan Bureau of Statistics and Punjab Finance Department. Period of this collected data was from Jan, 2004 to July, 2013. Prices for each construction item, according to project, were arranged on the excel sheet from year 2004 to 2013 month wise. Annual growth rates were calculated for each individual item for each year. Probabilistic mean of annual growth rates, for each item, was taken by using simulation tool. Figure 3.7 shows the annual growth rates for construction items' prices of each year. For analysing the effect of variation in items prices concept of "normalization" was introduced.

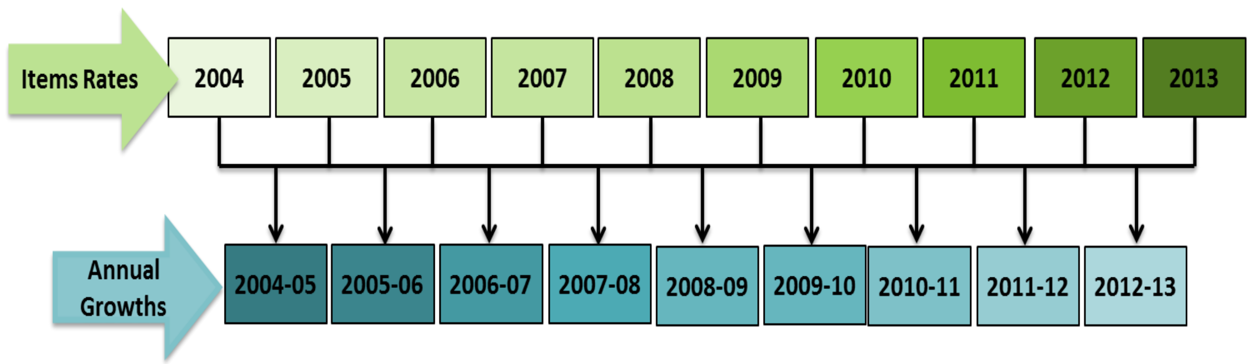


Figure 3.7 Annual Growth Rates from year 2004 to 2013

a. Concept of "Normalization

Price data for each construction items was arranged on excel sheet, month wise from Jan, 2004 to Jul, 2013. The purpose was to analyse uncertain variations in construction items' prices but in this state this data was not in form to be analysed for the price variations. The reason was that a price of item in 2004 cannot be related with price of that item in 2013. First we need to determine the effect of 2004 prices in 2013 by bring all the prices data to same level, either bringing all 10 year prices equivalent (down) to constant 2004 or bringing items' prices of past years up to constant 2013. Like this all prices would be on same level and can be analysed for uncertainties present. For this model item prices were normalized for constant 2013; as the objective was to predict the future project scenario cost compared with current scenario (2013).

In Normalization all 10 years rates were brought approximately at the same level by adding annual growth rates of successor years. Figure 3.8 shows aggregate prices from year 2004 to 2013. Probabilistic mean of each item without normalization would be in-accurate as probabilistic mean and standard deviation would be impracticable for analyses.

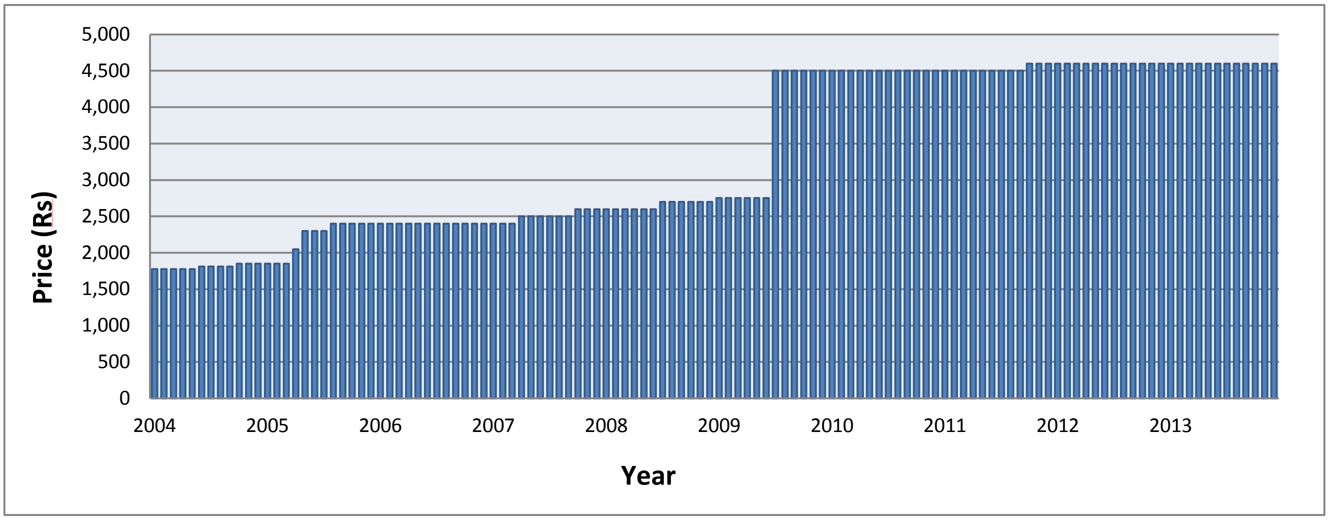


Figure 3.8 Aggregate Prices (per 100 Cu. Ft.) from 2004-2013

Concept of normalization says theoretically all the data points should become at the same level when their successor annual growth rates would be added. Figure 3.9 shows the theoretical concept for normalized construction items' prices.

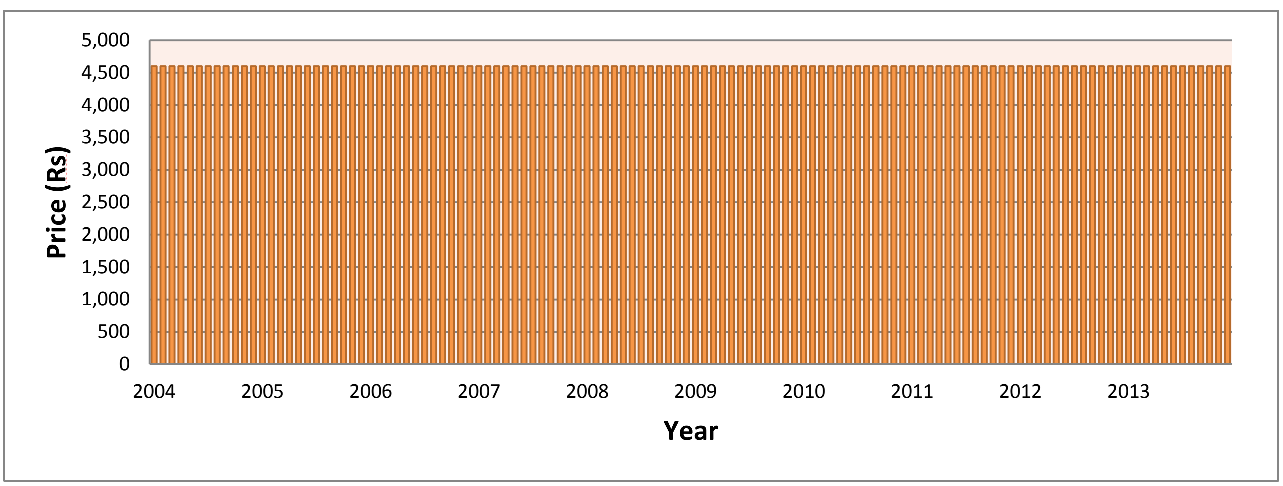


Figure 3.9 Theoretical Normalized Aggregate Prices (per 100 Cu. Ft.) from 2004-2013

When the normalization technique was applied on the 10 years item prices, for constant 2013, it was observed that they have different price values from year 2004 to 2013. Level difference that was observed between prices was that uncertain variance which was other than annual growth rates. Probabilistic mean of prices from Jan, 2004 to Jul, 2013 was taken by simulation tool, so these uncertain values could be predicted when simulation runs. Figure 3.10 shows the actual normalized aggregate prices from year 2004 to 2013.

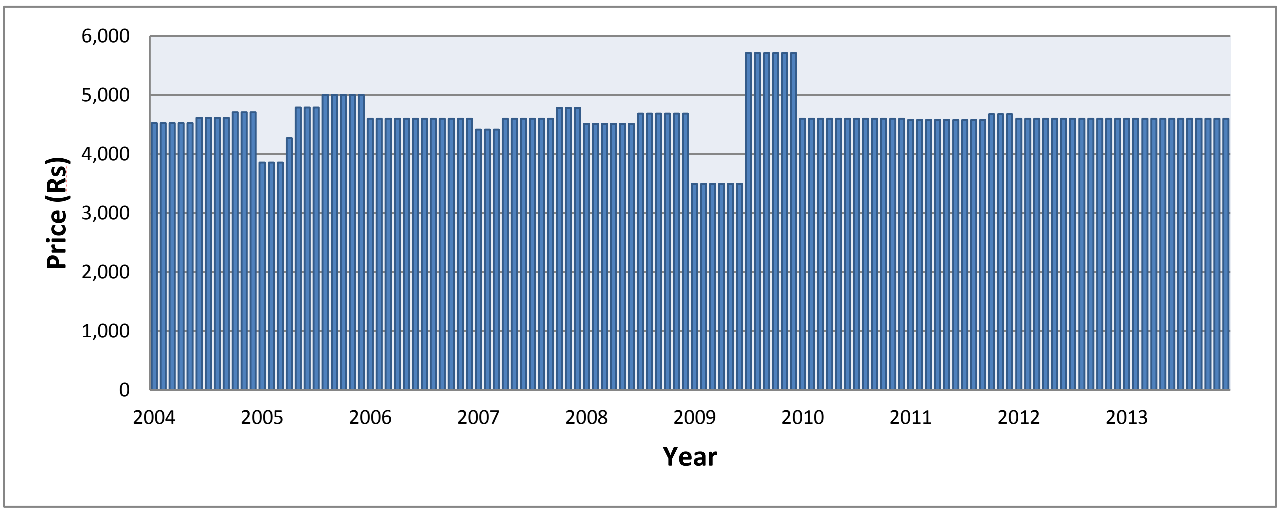


Figure 3.10 Normalized Aggregate Rates (per 100 Cu. Ft.) from 2004-2013

General formula for normalization will be as follows:

$$Normalized\ value[n] = Item\ Rate\ [1 + AG(n+1)] * [1 + AG(n+2)] * [1 + AG(n+3)] * \ldots\ldots\ldots\ldots . * [1 + AG(n+m)]$$

Where,

AG = Annual growth rate

n = Year in which data required normalization

m = number of years ahead n

3.7.1 Final Shape of Probabilistic Project Cost Model

Model was finalized in which, project cost risks; (1) labour and machine efficiencies, (2) construction material wastages, and (3) variation of construction items' prices were fixed and their effects are catered for the final project cost. Figure 3.11 shows the excel view for fixed cost risks (uncertainties) in the model.

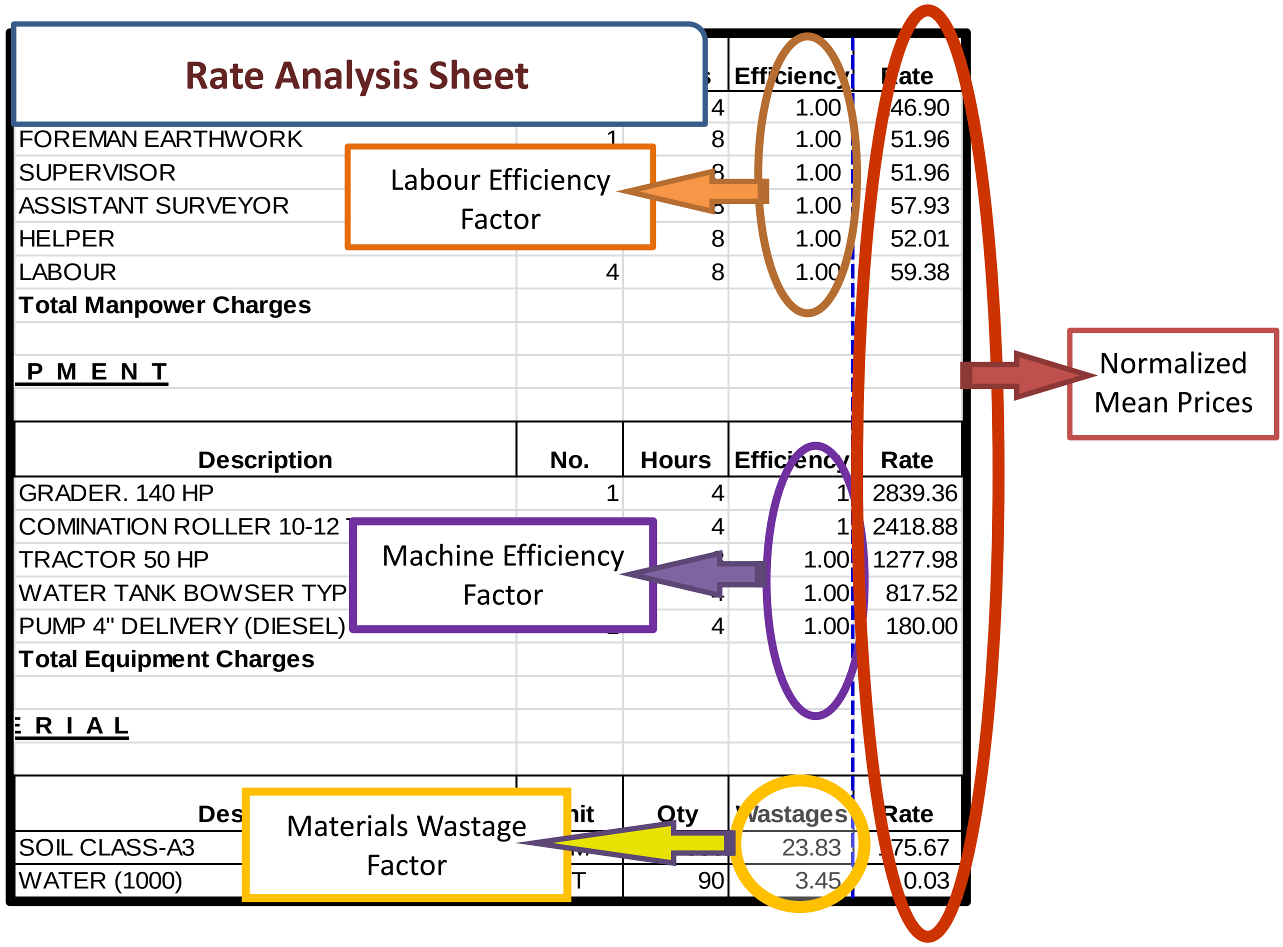


Figure 3.11 Excel View – Incorporating Cost Risks Factors in Model

'Probabilistic Project Cost Model' could predict probabilistic final project cost, considering the effects of project cost risks, by help of simulation tool but there was one short coming of this model as it could not predict cost for future scenarios. Model needed to be modified so that cost for future scenarios could also be predicted. Therefore 'Probabilistic Project Cost Model' was further modified to 'Time Boxing Project Cost Model'.

3.8 Development of Time Boxing Project Cost Model

'Probabilistic Project Cost Model' was unable to predict future cost which was one of the objectives of this study. Therefore model was modified to 'Time Boxing Project Cost Model', which would cater cost risks as well as predict future cost of the projects by formulating the parameters, for forecasting the increase in the rates of construction items (materials, labour and machines). Thus final cost for the project could be predicted for any future year.

As per section 2.7 Time series sequence can be explained in two main components (1) trend and (2) seasonality [Hill and Lewicki, 2007]. Therefore 'Time Boxing Project Cost Model' was incorporated with major price variations factors which affects the future prices (1) annual growth rate, (2) seasonal variation, and (3) uncertainty in project activities durations. These future price variation factors were incorporated in model as follows:

(1) Construction Items Prices' Annual Growth rate (r)

Annual growth rate is simply the annual increase in price of any item. It is taken in percentages with reference from last year price. It may be same or may be different for coming years. Probabilistic annual growth rate mean for each construction item was taken from past year annual growth rates with the help of simulation tool. Probabilistic mean of annual growth rates would be represented by symbol 'r'.

(2) Construction Items Prices' Seasonal Coefficient (S_o)

Seasonal variation is the monthly change in rate of prices for any particular item. It may be an increase or a decrease in a price. Seasonal variation for each month was integrated in model as "Seasonal Co-efficient". 'Seasonal Co-efficient' for models was calculated using following steps:

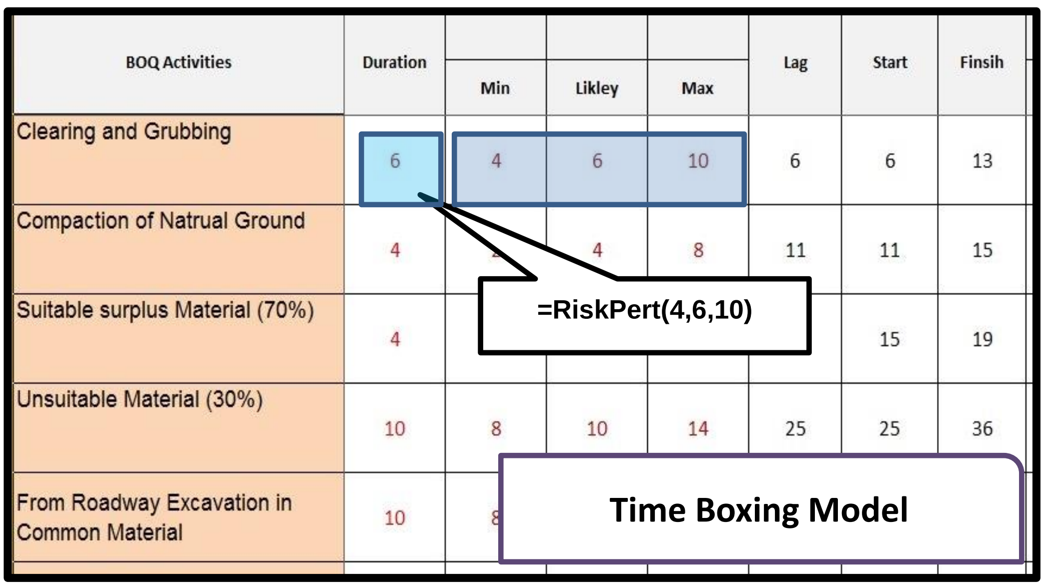
a. Dividing construction items each month price by average rate (value) of that year.
b. This gives a seasonal factor, which shows the behaviour of prices for each month for that year i.e. behaviour of item price increase or decrease could be analysed for each month.
c. Factors for specific month for e.g. 'January' were arranged together for 10 years.
d. Probabilistic mean of factors for month January was calculated with the help of simulation tool. Calculated seasonal factor is termed as 'Seasonal Co-efficient' and represented by symbol 'S_o' in present study.
e. This 'Probabilistic Seasonal Coefficient' for January would show the behaviour of price variation (increase or decrease) for month of January of that specific item.

f. ‘Seasonal Coefficients’ for rest of the months (February to December) were calculated for each specific construction item.

(3) <u>Fixing Uncertainty in Project Activities Durations</u>

Uncertainty in durations for each project activity was fixed by introducing ‘Pert distribution’. Parameters for pert distributions are minimum value, most likely value and maximum value. Pert technique helps to predict uncertainty in durations for activities and with this effects of increasing activity durations on the project cost can also be predicted. More the activity is prolonged than planned duration more will be the increase in Project/ activity cost. Pert distributions were incorporated in the model following way (Figure 3.12):

Duration=RiskPert (minimum days, most likely days, maximum days)



BOQ Activities	Duration	Min	Likley	Max	Lag	Start	Finsih
Clearing and Grubbing	6	4	6	10	6	6	13
Compaction of Natrual Ground	4		4	8	11	11	15
Suitable surplus Material (70%)	4					15	19
Unsuitable Material (30%)	10	8	10	14	25	25	36
From Roadway Excavation in Common Material	10						

Figure 3.12 Pert Distributions for Uncertainties in Durations

3.8.1 Integration of Annual and Seasonal Co-Efficient for Future Prediction

'Annual growth rate Factor' and 'Seasonal Co-efficient' were integrated in the model for each activity. These factors formulate the future price of item, which adds up to give probabilistic project cost. Future probabilistic increase in prices for any item for the model is done by following equation;

$$Adjusted\ Future\ Price\ =\ (1+ra)^{n/365}$$

Where,

r = Probabilistic annual growth rate

S_o = Probabilistic seasonal coefficient

ra = Adjusted annual growth rate = r x S_o

n = Number of days after which activity would be commenced = N + Lag

N= Number of days after which project is required to be predicted

Lag = Number of days from the project start to the end of activity

Adjusted annual growth rate is the product of 'Probabilistic Annual growth rate' and 'Seasonal Coefficient'. By this price of items varies depending upon the month for the specific year. Thus final adjusted value obtained by this equation is shown below. Figure 3.13 shows the application of this formula in excel view:

$$(Quantity\ or\ Hours) * \ Efficiency * \ Rate * \ (1+ra)^{n/365}\ =\ Adjusted\ Future\ Value$$

3.8.2 Final Shape of Time Boxing Project Cost Model

Major price variations factors which affect the future prices were fixed and incorporated in the 'Time Boxing Model' to give the final shape to RMF. Final project cost for any future scenario can be predicted with 'Time Boxing Model' by considering all the cost risk factors and price variation factors. Future price variation factors are annual growth rate, seasonal variation, uncertainty in project activities durations. This model was prepared for building project as well as highways project.

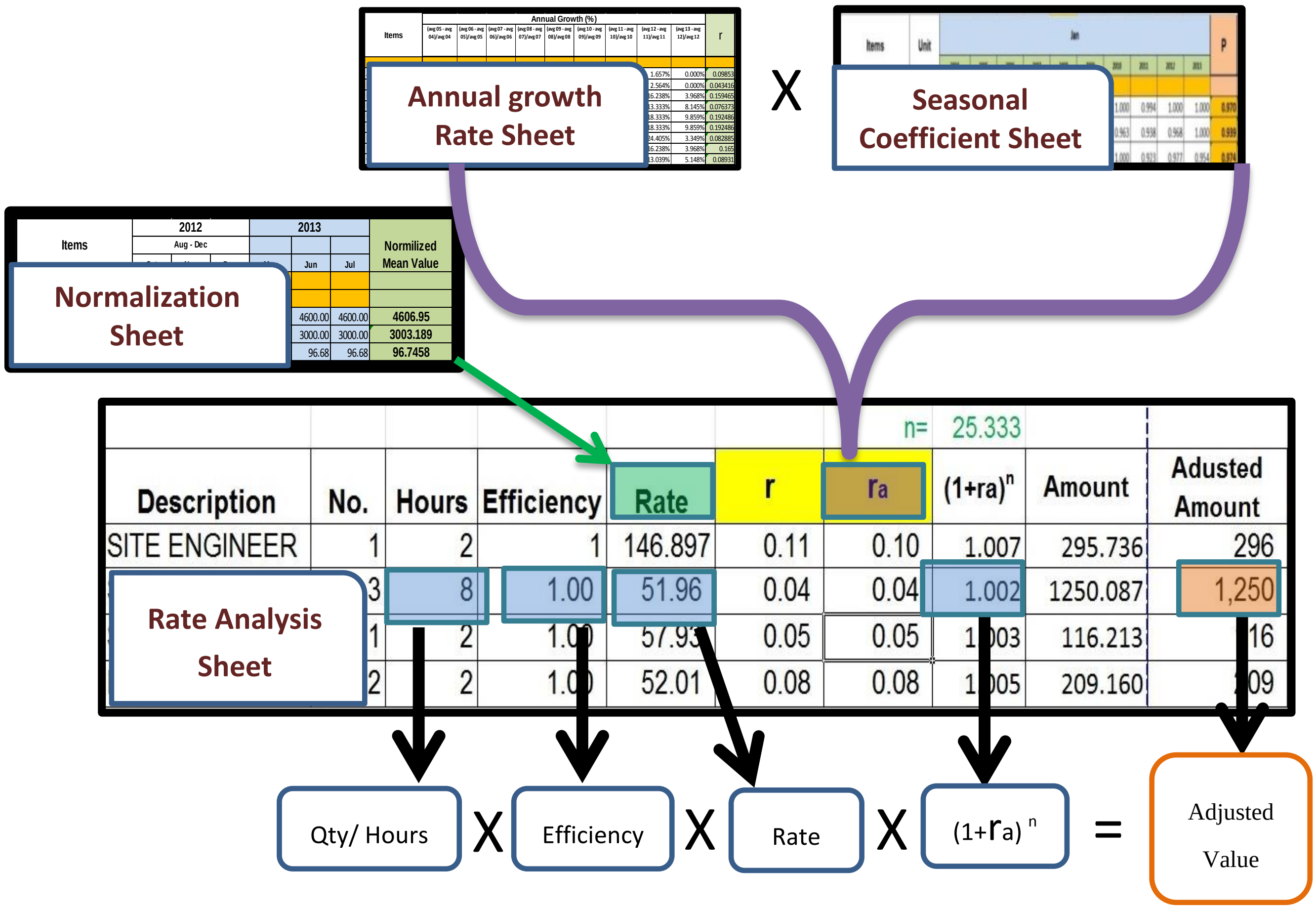


Figure 3.13 Excel View-Formula for Adjusted Value in Time Boxing Project Cost Model

3.9 Chapter Summary

Two types of projects were selected one from building infrastructure (10 Marla house) and other from highway infrastructure (10km, two lane road). Projects details including designs specifications were collected and 'Project Cost Estimation Model' was developed, in initial phase, for both of the projects with help of MS-Excel.

Project cost risks were identified with the help of detailed literature review and expert opinion. Identified cost risks were; (1) labour efficiencies, (2) machine efficiencies, (3) construction material wastages, and (4) construction items' rates. Data relevant to these cost risks were collected by the help of literature review, field survey, past data and standards adopted for risk parameters.

Using gathered data, identified project cost risks were fixed, using risks factors, and integrating them in the initially prepared 'Project Cost Estimation Model', which modified into ‘Probabilistic Project Cost Estimation Model’. This model was able to predict estimated cost of the project by considering all the cost risk factors for present scenario only (duration up to which construction item prices would be provided) but was unable to forecast project cost. Therefore ‘Probabilistic Project Cost Model’ needed modifications for future price variation factors. Following factors were identified which affects the future cost for any project; (1) construction items’ prices annual growth rate, (2) construction items’ prices seasonal variation, (3) uncertainty in project activities durations. Fixing these uncertainties in ‘Probabilistic project Cost Model’, modified it into ‘Time Boxing Project Cost Model’. This was the final shape for RMF by which future cost for any type of project can be predicted considering all the cost risks with the help of simulation tool. Thus ‘Time Boxing Project Cost Model’ was the final shape of the RMF.

CHAPTER 4. RESULTS AND ANALYSES

4.1 Introduction

This chapter deals with the analyses of the estimates produced by the newly developed ‘Time Boxing Project Cost Model”. The model has been tested for its optimum usage and durations (future years) up to which model results would be realistic. The main aim was to test the results by ‘Time Boxing Project Cost Model’ for their efficiency and effectiveness in comparison to traditional practices which are followed in Pakistan construction industry for preparation of project cost estimates. The results were also analysed to check in how many ways ‘Time Boxing Project Cost Model’ could be utilized and be made helpful for an estimator.

‘Time Boxing Project Cost Model’ has also been checked for prediction of project cost for several future scenarios randomly. Efficiency and effectiveness of ‘Time Boxing Project Cost Model’ has also been validated and verified by comparing model’s predicted costs with actual project cost for last 10 years. ‘Time Boxing Project Cost Model’ was also compared with different departmental schedule of rates (MES, PED, Punjab Finance Department and NHA) for cost estimation for determining their applicability and effectiveness. The model was also tested for the results of project costs, in case of the variable values for contractor’s profit. All the analyses were tested on both types of projects i.e. building and highways with the help of simulation tool. The detailed discussion on these analyses is given in following:

4.2 Future Cost Prediction using Time Boxing Project Cost Model

‘Time Boxing Project Cost Model’ was tested for future prediction of costs and contingencies for the building project and highways project. Aim for this analysis was to evaluate the effectiveness of results predicted by the model for future scenarios and to check how complex this model would be for an estimator. Once the ‘Time Boxing Model’ has been developed for any type of project, the model only requires three types of inputs from user:

a. Current Date (date for which model is updated for construction items' prices)
b. Future duration after which project is to be started (year, months and days)
c. Project activities' durations (maximum duration, most likely duration, minimum duration)

Models for the building and highway projects were tested by considering three scenarios (a) 1st July, 2013, (b) 14 February, 2014, and, (c) 14 February, 2015.

First building model (10 Marla house) was tested for above mentioned three scenarios. The current date for this model was 1st July, 2013 as model updated for construction items' prices upto July, 2013. Table 4.1 shows the results collected by the 'Time Boxing Model' for building project.

Table 4.1 Results of Time Boxing Model for Building Project

Time Boxing Model Project Cost Estimates (Building Project)			
Details	**1st July, 2013**	**14th Feb, 2014**	**14th Feb, 2015**
Probabilistic Cost	6,694,434	7,009,150	7,659,381
Cost Contingency	328,749	409,931	663,615
% Cost Contingency	4.91%	5.85%	8.66%

Highways project (10km road with two lanes) was also tested for the same three scenarios. Table 4.2 shows the results collected by the 'Time Boxing Model' for highways project.

Table 4.2 Results of Time Boxing Model for Highways Project

Time Boxing Model Project Cost Estimates (Highway Project)			
Details	**1st July, 2013**	**14th Feb, 2014**	**14th Feb, 2015**
Probabilistic Cost	413,266,173	444,072,470	505,158,869
Cost Contingency	22,843,393	28,955,081	51,969,851
% Cost Contingency	5.53%	6.52%	10.29%

It can be seen from the results that 'Time Boxing Model' predicted the probabilistic future cost for both projects alongwith amount of contingencies. These cost contingencies that are predicted by model are the variance (risks) in prices may or may not occur. Model predicts the project cost and contingency according to future year depending upon the cost risk factors and future price factors which are incorporated in the model. ‘Time Boxing Model’ during its operation stabilizes following risks:

a. Workmanship efficiencies
b. Machines efficiencies
c. Uncertainties of activities’ durations
d. Uncertainties of construction items’ prices

This model helps to predict future cost considering the effects of cost risk factors which may lead project cost to vary. Thus a stabilized cost can be estimated for future scenarios by considering methodology followed in ‘Time Boxing Project Cost Model’.

4.3 Validity of ‘Time Boxing Project Cost Model’

‘Time Boxing Project Cost Model’ was validated for effectiveness and efficiency of its results. To validate the model, predicted project costs for future years were compared with actual project costs in those years. Actual project costs were obtained for both the building project (10 Marla house) as well as highways project (10km road, two lanes) by the help of past gathered data for construction items’ prices. Actual project costs were obtained for each year from 2004 to 2013 for both projects. Using Microsoft-Project general timelines were prepared for projects (building and highway) for the distribution of activities. Standard timeline was set for each project for each year as; (1) timeline for 10 Marla house was designed for 05 months i.e. Jan to May (for each year from 2004 for 2013), and (2) timeline for 10km of highway road was designed for 06 months i.e. Jan to July (for each year from 2004 to 2013). Actual project costs were obtained by entering prices for each activity depending on its month of occurrence (planned month) and actual project costs were obtained for each year from 2004 to 2013 for building project as well as for highway project.

After obtaining actual project costs, ‘Time Boxing Model’ was tested for its validity. ‘Time Boxing Models’ were simulated by considering items’ prices at Jan, 2004 (set in the ‘Rate Index’ sheet) and project costs were predicted with help of simulation tool from year 2004 to 2013 for both building and highways project. Comparison of actual project costs and costs predicted by ‘Time Boxing Model’ for building project is show below in Table 4.3 and for highway project in Table 4.4:-

Table 4.3 Actual Costs and Model Estimated Cost for Building Project

Year	Model Estimated Cost	% Cost Contingency	Actual Cost	% Error
2004	3,678,313	2.841%	3,637,630	-1.12%
2005	3,909,008	4.935%	3,954,343	1.15%
2006	4,207,899	8.017%	4,371,197	3.74%
2007	4,579,702	11.854%	4,387,494	-4.38%
2008	5,053,485	16.154%	4,885,159	-3.45%
2009	5,670,980	25.314%	5,358,781	-5.83%
2010	5,934,201	18.639%	5,513,303	-7.63%
2011	6,334,199	18.214%	6,126,341	-3.39%
2012	6,791,658	18.101%	6,877,751	1.25%
2013	7,179,548	17.660%	7,191,907	0.17%

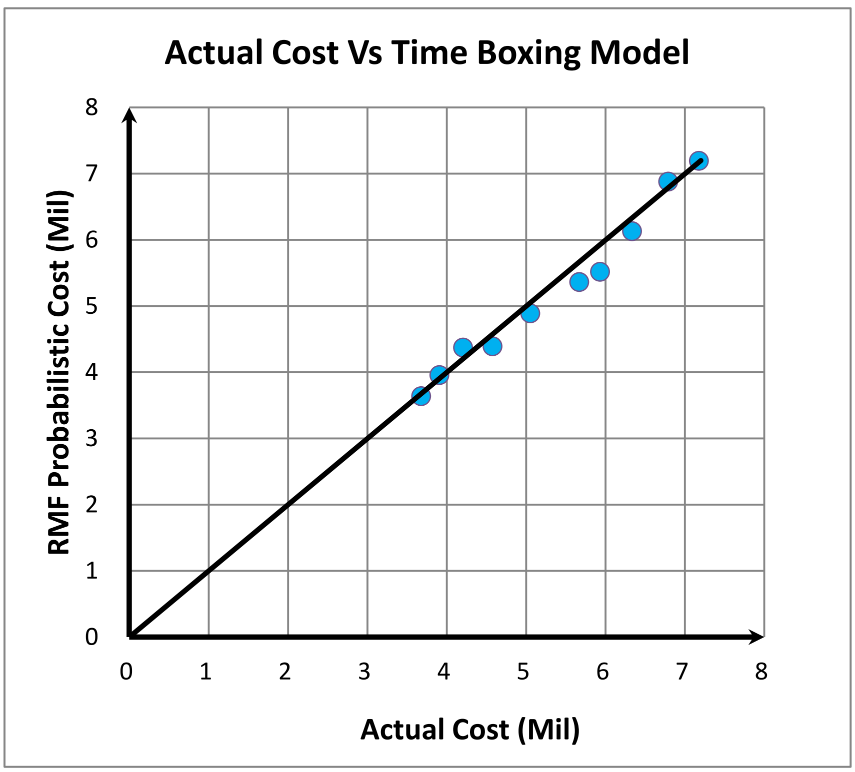


Figure 4.1 Comparisons between Actual Cost and Model Cost for Building Project

Table 4.4 Actual Costs and Model Estimated Cost for Highway Project

Year	Model Estimated Cost	% Cost Contingency	Actual Cost	% Error
2004	133,464,547	4.748%	131,849,169	-1.23%
2005	147,310,848	6.065%	137,498,000	-7.14%
2006	164,581,644	8.830%	168,488,319	2.32%
2007	186,889,176	12.359%	181,944,228	-2.72%
2008	216,939,440	16.905%	200,208,732	-8.36%
2009	254,702,139	23.052%	245,837,670	-3.61%
2010	280,443,600	18.243%	285,731,625	1.85%
2011	319,656,998	18.517%	313,045,858	-2.11%
2012	359,754,905	18.720%	377,330,976	4.66%
2013	410,690,055	19.116%	401,564,258	-2.27%

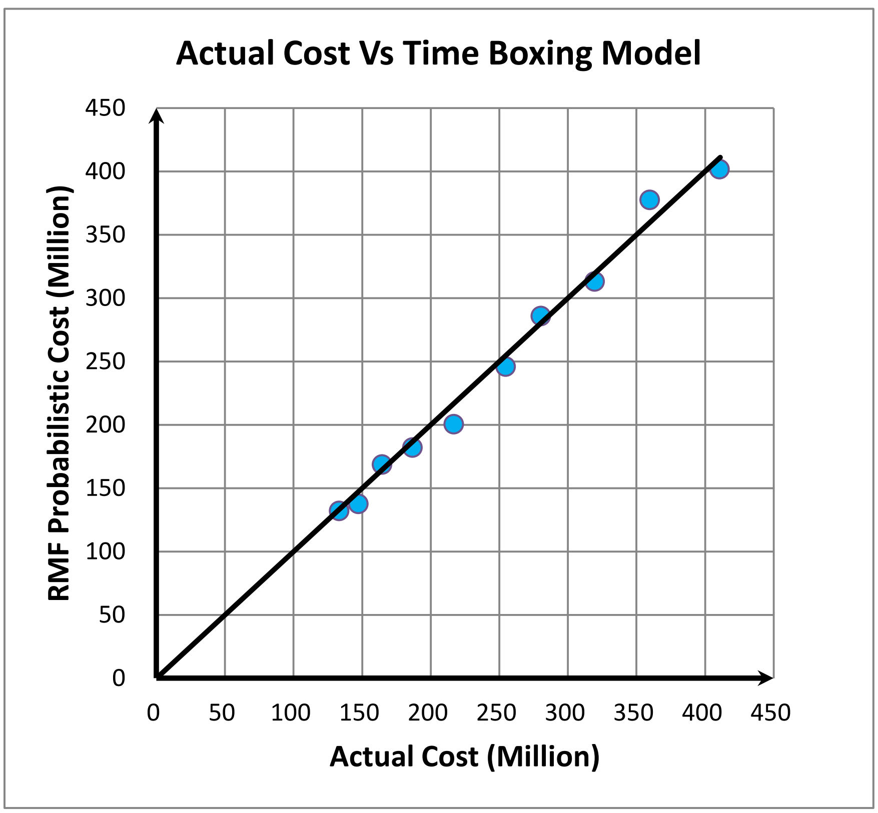


Figure 4.2 Comparisons between Actual Cost and Model Cost for Highway Project

Figure 4.1 and Figure 4.2 clearly show that the predicted costs by models were close to the actual costs and this also authenticates the model. ‘Time Boxing Model’ also predicts the contingency reserves which are actually the uncertainty in prices which might or might not occur. It can clearly be seen that the percentage contingency reserves are random for each year and nature of contingency percentage dependants upon the cost risk factors and price variations factors incorporated in the model ‘Time Boxing Model’ was also evaluated for its accuracy and effectiveness of results in comparison with actual project cost by obtaining MAPE (Mean Absolute Percentage Error). First percentage errors for model predicted cost in comparison with actual cost were computed for each year (2004 to 2013). Afterwards their MAPE were estimated as follows:

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}|PE_i|$$

Where, $PE_i = (A_i - P_i) / A_i$ is the percentage error for year i of the actual and predicted project rate. MAPE for building model was estimated as 1.95% and MAPE for Highways model was estimated as 1.86%, which clearly defines the validity of ‘Time Boxing Model’ and its methodology.

4.4 Comparison between Model Output and Departmental Schedule of Rates

Cost estimates predicted by ‘Time Boxing Model’ were also compared with cost estimates which are generated with the help of departmental Schedule of Rates. Following Schedule of Rates were collected:-

a. MES Schedule of Rates - 2009 (revised in 2010)

b. PWD Schedule of Rates - 2012

c. Punjab Finance Department MRS Rates Feb-Jul 13

d. NHA Schedule Composite Rates - 2011

Departmental rates and model rates were analysed for their rate analysis practices and for percentage difference of project costs when compared with each other for the same project. Comparison of model and departmental schedule of rates was done as follows; (a) first of all project estimated costs for both projects (building and highway) were calculated by using each departmental schedule of rates , by introducing rate of each BOQs activity as per departmental rate, (b) Different estimated costs were calculated for building project (10 Marla house) and highway (10km road, two lanes) project, by using schedule of rates of each department i.e. MES, PWD, NHA and Punjab Finance

Department. In this way for same project different estimated costs were calculated using different departments' schedule of rates. (c) On other hand 'Timing Boxing Model' was simulated by using normalized mean rates at July, 2013 in the model and results of the model were predicted for both same projects (building and highway).

Departmental schedule of rates are not updated every year so to counter the effects of escalations in prices, fixed percentage premiums are published by each department's headquarters for each year. These fixed premium percentages are required to be added to the estimated cost which is calculated by using schedule of rates. Percentages of premiums vary department to department.

In this analysis these premiums were ignored and cost for each project by each departmental schedule of rates was calculated without considering its premium as premiums are fixed percentages. One of the main purposes of this comparison was to compare the predicted model cost with each department schedule of rates but in their real state i.e. without considering premiums and other purpose was to compare departmental schedule of rates with each other for same projects. Cost predicted by 'Time Boxing Model' also contains the effects of cost risk factors. Comparisons of predicted model cost and estimated cost by departments' schedule of rates are as follows:

(1) <u>Building Model</u>

a. <u>Case 1</u>: Income tax (6%) not considered for the model

Table 4.5 Comparison between Departmental Schedule of Rates and Model without Tax

Details	**Time Boxing Model (July, 2013)**	**PWD 2012 Schedule**	**MES 2009 Schedule**	**Punjab Finance Rates (Feb-Jul 13)**
Cost (PKR)	6,711,482/-	6,571,579/-	5,235,218/-	6,757,404/-
%Difference		-2.13%	-28.20%	+0.68%

b. <u>Case 2</u>: Income tax (6%) was considered in the model

Table 4.6 Comparison between Departmental Schedule of Rates and Model with Tax

Details	**Time Boxing Model (July, 2013)**	**PWD 2012 Schedule**	**MES 2009 Schedule**	**Punjab Finance Rates (Feb-Jul 13)**
Cost (PKR)	7,074,463/-	6,571,579/-	5,235,218/-	6,757,404/-
%Difference		-7.65%	-35.13%	-4.69%

(2) Highways Model

a. Case 1: Income tax (6%) not considered for the model

Table 4.7 Comparison between Departmental Schedule of Rates and Model without Tax

Details	**Time Boxing Model (July, 2013)**	**NHA Composite Rates 2011**	**PWD Schedule 2012**	**MES Schedule 2009**
Cost (PKR)	391,915,313/-	390,299,421/-	319,347,724/-	315,687,741/-
%Difference		-0.58%	-22.93%	-24.36%

b. Case 2: Income tax (6%) was considered in the model

Table 4.8 Comparison between Departmental Schedule of Rates and Model with Tax

Details	**Time Boxing Model (July, 2013)**	**NHA Composite Rates 2011**	**PWD Schedule 2012**	**MES Schedule 2009**
Cost (PKR)	413,364,777/-	390,299,421/-	319,347,724/-	315,687,741/-
%Difference		-5.88%	-29.41%	-30.91%

An in depth study was carried out at literature review and documentation review stage for effect of advance income taxation on total cost of project. During rate analysis stage it was established that PWD and MES costing process don't consider 6-7% income tax for schedule rates. This very procedure is based on the very firm assumption that to pay tax on one's income is the responsibility of that individual/ organization. However the whole concept of advance income tax (fixed at 6-7% of total cost) is based on that regardless of profit or loss that tax will be contractor's risk and hence contractor eventually start adding tax amount in shape of padding in bids, resulting undermining the very essence of the schedule.

The model developed through this study has the capacity to validate/ check the adequacy/ practicality of any schedule of rates. Through this capacity "Schedule of rates check analysis" was carried out and it was found that if we don't consider income tax i.e. 6% for our analysis of rates, then model (building) gives 2.13% and model (highways) gives 22.93% more probabilistic costs than PWD Schedule of rates 2012. Also in comparison with MES schedule of rates 2009, model (building) gives 28.20% and model (highways) gives 24.36% more than costs given. However model (building) suggests 0.74% less cost than Punjab Finance MRS rates.

When the 6% income tax was considered in the model, it was concluded that PWD schedule of rates were (7.73% - 6%) less than actual simulated cost for building model and (29.41% - 6%) less than for highways model. whereas the situation was grave for MES schedule of rates when costing techniques gives (35.23% - 6%) less future cost for building model and (30.91% - 6%) less for highways model. However for NHA rates highways model gives 0.58% more cost without 6% tax and 5.88% more cost when 6% income tax is considered.

This analysis shows that PWD rates will become inefficient after sometime. However MES schedule of rates will become redundant early and whole concept of developing schedule of rates will be dissipated.

4.5 Comparison between Steady and Variable Profit for the Project by the Model

'Time Boxing Model' was also analysed for profit percentages for the model. An analysis was established between steady profit (10% usually) and variable profit (10%, 18% and 30%). The objective for this analysis was to assess the behaviour of estimates predicted by model if profit is set variable and. how it would affect the project cost w.r.t. to different years.

A firm needs profit to meet its financial needs and cover its risks. A construction firm takes risks when it tenders for a project and after winning the contract it expects its reward in the form of calculated profit which is expected to be higher than its known and unknown risks. The firm also has a risk that if in case they were not able to deliver the project in time they may lose money. Mega projects usually involve more risks and uncertainties. As it can be concluded this year profit percentage for e.g. 10% may not be an achievement or fruitful output for next year due to any risks or escalations for contractor. During the survey it was concluded that contractors mostly like to consider their profits between 10%, 18% and 30% depending upon the projects.

This model has an ability to predict project cost by considering variable profit percentages for any project. Simulation results were compared between two scenarios, one with steady profit and other with variable profit for both projects (building and highway). Steady profit was set as 10% (normal practice) and variable profit was set between 10%, 18% and 30% with help of simulation tool. As variable profits values are three limits, i.e. lower limit, mode and upper limit, therefore triangular distribution was selected for variable profit parameters. Inputs set in the model for this analysis were as follows:

a. Distribution set for the variable profit was. RiskTriang(0.1,0.18,0.3)
b. Normalized mean rates were set for July, 2013
c. Results were determined for current year , 1st year, 2nd year, 3rd year, 4th year, 5th year, 6th year, 7th year, 8th year, 9th year, 10th year.

Table 4.9 Comparison of Results between Steady Profit and Variable Profit for Building

Year	**Steady Profit (10%)**		**Variable Profit (10%, 18%, 30%)**	
	Mean Cost	**% Cost Contingency**	**Mean Cost**	**% Cost Contingency**
0	7,078,577	5.06%	7,605,345	5.85%
1	7,637,456	6.83%	8,198,310	7.65%
2	8,361,164	9.72%	8,956,501	10.38%
3	9,284,715	13.96%	9,944,907	14.54%
4	10,402,141	18.81%	11,158,261	18.92%
5	11,874,809	25.52%	12,793,967	25.34%
6	12,731,715	20.40%	13,695,675	20.80%
7	13,649,941	20.30%	14,677,174	20.33%
8	14,784,703	19.93%	15,774,265	19.88%
9	15,814,149	23.00%	16,979,052	19.27%
10	17,020,315	18.78%	18,055,055	18.40%

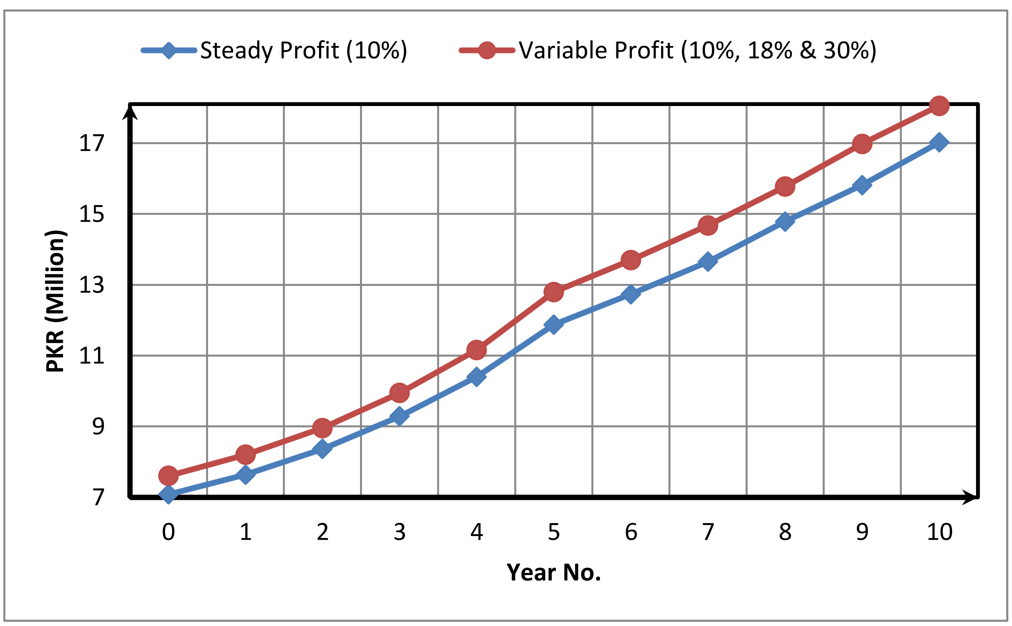


Figure 4.3 Graph for Results between Steady Profit and Variable Profit for Building

Table 4.10 Comparison of Results between Steady Profit and Variable Profit for Highway

Year	Steady Profit (10%)		Variable Profit (10%, 18%, 30%)	
	Mean Cost	% Cost Contingency	Mean Cost	% Cost Contingency
0	409,803,795	5.36%	442,161,781	6.15%
1	459,652,964	7.55%	496,778,834	8.41%
2	523,864,796	11.64%	564,440,157	11.97%
3	606,895,165	16.31%	654,916,786	16.34%
4	714,156,460	22.51%	770,840,037	22.61%
5	858,602,277	30.11%	919,281,770	33.49%
6	948,906,805	21.96%	1,019,698,570	23.09%
7	1,064,112,310	21.62%	1,146,273,603	22.09%
8	1,203,166,907	22.02%	1,314,668,544	22.04%
9	1,352,490,046	21.15%	1,469,688,078	22.20%
10	1,539,322,455	21.34%	1,644,502,931	21.65%

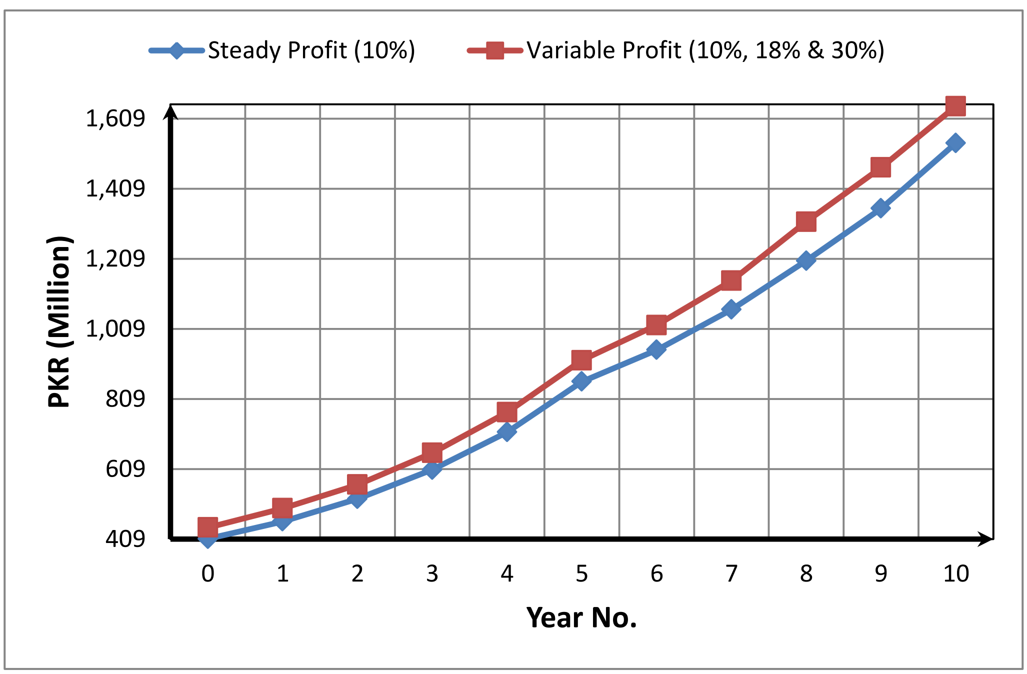


Figure 4.4 Graph for Results between Steady Profit and Variable Profit for Highway

It can be seen from the graphs (Figure 4.3 and Figure 4.4) that variable profits does not affect the behavior of predicted project costs by ‘Time Boxing Model’. Behavior of curves, one with steady profit (10%) and other with variable profit (10%, 18%, 30%), remains the same with passing years. Thus the assumption that variable profit might lead to aggressive project cost was wrong and ‘Time Boxing Model’ can be used for prediction of project cost considering variable profits as well.

4.6 Chapter Summary and Conclusion

‘Time Boxing Model’ was the last phase during the development of Risk Management Framework (RMF) for project cost estimation. In this model future price could be predicted by considering effects of cost risk factors and future price variance factors by using simulation tool. ‘Time Boxing Model’ was required to be tested, analyzed and validated for its efficiency and effectiveness. Therefore, first of all model was tested for prediction of diffrent future scenarios for building project as well as highway project. It was found that model predicted effective future projects costs alongwith considerable contingencies for each project. Afterwards ‘Time Boxing Model’ was also validated with comparison with actual project costs. Actual project costs (building and highways) were achieved with the help of past 10 years construction items’ prices data (Jan, 2004 to July, 2013). Actual project cost for both projects were achieved for 10 years from 2004 to 2013. On other hand project cost for 10 years (2004 to 2013) were predicted by ‘Time Boxing Model’ by using construction item prices in Jan, 2004 for both of projects (building and highway). Actual project costs for each year were compared with model’s predicted cost of that year and it was found that project costs predicted by model were close to actual costs, also Mean Absolute Percentage Error (MAPE) for both of the projects were very reasonable i.e. less than 2%.

Departmental schedule of rates were also analyzed with the model. Results were compared first time by considering taxes and second time by not considering taxes. It was concluded MES schedule of rates are becoming ineffective which need to be revised with time. Finally model was checked for its efficiency and effectiveness for the profit margins. Model outputs were compared for the estimated project cost for steady profit and variable profit. Contractors use to keep variable profits for their projects and adjust them in their bids as this gives them more room to cater future unknown risks. Model cost results were compared between steady profit (usually 10%) and variable profits (10%, 18% and 30%) for 10 years. It was analyzed that behavior of curves, of model outputs, was similar for steady profit and variable profit. So it was concluded that this model has ability to predict project costs and contingencies effectively when variable profits are to be considered and thus the assumption that variable profit might lead to aggressive project cost was wrong.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Synopsis of the Research

This research is mainly focused on development of cost estimation model for predicting future cost scenarios for a typical highway and building projects duly incorporating the effects of different cost risk factors. Major cost risk factors (material wastages, labor and machine efficiencies and individual construction item prices) that may vary the project cost were identified and were incorporated into Risk Management Framework. The developed framework enables to: (1) predict precise future project cost scenarios, (2) helps project team to design rational contingency reserves, and (3) analyze those factors which contribute majorly in cost overrun and project delay. Present study also analyzed the methodology that is being followed in Pakistan construction industry for preparation of project cost estimates and practice for keeping contingency reserves.

The study began with an extensive review of literature in which different techniques for project cost estimation and contingencies were critically analyzed. Two different types of projects, one each from building and highways industry along with their design specifications, were selected. Project cost estimates were prepared for the both projects based on the practices followed in Pakistan construction industry. The detailed literature review also helped in identifying project cost risks (factors) which commonly lead to project cost overrun and project delay. These risks factors are (1) labor efficiencies, (2) machine efficiencies, (3) material wastages, and (4) construction items' prices. In order to study the impact of identified cost risk factor on overall project cost data for construction items' rates (past 10 years), labor and machine efficiencies and material wastages were analyzed. Mean and standard deviation of data were incorporated into deterministic project estimate model to yield 'Probabilistic Project Cost Model'. In next step annual and seasonal variation in construction items' prices due to escalations and uncertainty in project activities duration were incorporated into 'Probabilistic Project Cost Model' to yield 'Time Boxing Project Cost Model'. The developed 'Time Boxing Project Cost Model' (designed for both building and highways projects) was validated by using the past 10 year's construction items' prices data. For both the building and highway projects model project costs were compared with the project cost estimated using cost data for individual construction items. The models were validated by calculating the mean absolute percent error (MAPE). MAPE value of .0195 and 0.0186 were obtained for building and highway models respectively. MAPE values closer to zero signify higher prediction accuracy of the developed model.

The results of "Time Boxing Project Cost Models", for building and highway, were also compared with project cost estimates obtained using common schedules of rates of: (1) MES, (2) PWD, (3) Punjab Finance Department, and (4) NHA. It was revealed that for building projects PWD Schedule of Rates and Punjab Finance Department MRS provides reliable project cost estimates. For highway projects NHA's composite rates are more reliable and may be used for highway project cost estimation. Developed models were also analyzed for both steady and variable project profit for cost prediction. It was found that developed 'Time Boxing Project Cost Models' has an ability to predict reliable future project cost even if the profits are kept variable.

5.2 Research Findings

The major findings from present study are:

a. A thorough review of the different schedules of rates being used in Pakistan for project cost estimation revealed that MES, PWD and NHA schedules of rates are inefficient as in most cases estimates lead to project cost overrun. It was revealed that these schedules of rates need regular revision in order to get reliable project cost estimates.

b. Detailed analysis of current project contingency reserves techniques revealed that current practice of keeping fixed percentage of project cost as contingency reserves is an ineffective practice as it fails to account for project duration. In order to avoid cost overrun agencies should preferably have contingency reserves that are also based on project duration.

c. Study results revealed "project timeline" is an important consideration for accurate estimation of project cost.

d. Use of simulation techniques for prediction of project costs with reasonable methodology is an effective approach for project cost estimation.

5.3 Recommendations

Based on analysis and discussions following recommendations are proffered:

a. MES and PWD project cost estimation methodologies need revision.

b. Any project cost estimate must give due consideration to future price escalations.

c. Project contingencies be established basing on the project durations.

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APPENDIX

Appendix A. Standard Machine Efficiencies

S NO	Type of Machine	Standard Efficiency / hr	Units
1	GRADER. 150 HP (Sub-Grade)	250	m
2	GRADER. 150 HP (Sub-Base)	200	m
3	GRADER. 150 HP (Base)	150	m
4	FRONT END LOADER 2.30 CUM	100	Cu. m
5	DUMPER 10 T.	5.5	Cu. m
6	BULL-DOZER 200 HP (For Spreading)	450	m
7	BULL-DOZER 200 HP (For Cutting)	200	m
8	BULL-DOZER 200 HP (For Clearing)	350	m
9	TANDEM VIBRATORY ROLLER	50	m
10	P.T.R 18 T.	70	m
11	BITUMEN DIST. TOW TYPE 2000 LTR	1750	Sq. m
12	ASPHALT PLANT 80 T	25	Cu. m
13	ASPHALT PAVER 4.75 M WIDE	25	Cu. m
14	EXCAVATOR (TRACK TYPE) 68 HP	60	Cu. m
15	CONCRETE BATCHING PLANT 30 CUM	20	Cu. m
16	CONCRETE TRANSIT MIXER 4.5 CUM	4.5	Cu. m
17	CONCRETE STATIC MIXER 1CUM	7.5	Cu. m
18	ROAD MARKING MACHINE (CR)	20	m

Appendix B. Standard Labour (Workmanship) Efficiencies

S No	Activity`	Labour	Standard	Unit
1	Bricks laid by a mason per day upto a height of 10'	Mason	900	No.
2	Concreting on roof by a mason	Mason	200	Cu. ft.
3	Concreting on floor by a mason	Mason	300	Cu. ft.
4	Plastering with cement per mason (12 mm or ½”)	Mason	90	Sq. ft.
5	R.C.C work in beams and slab per mason	Mason	125	Cu. ft.
6	Terrazo floor 6 mm thick Mosaic floor work over 2 cm thick cement concrete (1:2:4) per mason	Mason	50	Sq. ft.
7	2.5 cm thick cement concrete Laying of D.P.C (1:1.5:3)	Mason	125	Sq. ft.
8	Mixing concrete by a mazdoor (helper) per day	Labour	100	Cu. ft.
9	Bricks delivered by a mazdoor (helper) per day up to a distance of 50’	Labour	4000	No.
10	Breaking of brick ballast 25mm (1") gauge per labourer/ breaker per day	Labour	30	Cu. ft.
11	Earthwork in excavation in ordinary soil per mazdoor	Labour	100	cu ft
12	Earthwork in excavation in rock per mazdoor	Labour	35	Cu. ft.
13	Sand filling in plinth per mazdoor	Labour	140	Cu. ft.
14	Reinforcement work for R.C.C per blacksmith per day : 1 cwt =50.8023 KG	Blacksmith	2	cwt.
15	Fixing flat iron Holdfast per day per Blacksmith	Blacksmith	36	no
16	White Washing 3 coats per white washer	Painter	700	Sq. ft.
17	One coat paint per painter	Painter	250	Sq. ft.
18	Paint two coats on wood	Painter	35	Sq. ft.
19	No. of door timber frames completed per day(1.6 sq.ft per frame) per carpenter	Carpenter	3	no
20	No. of days required to complete one door shutter (2.66 sq.ft per shutter)	carpenter	4	no
21	Shuttering (erection and dismantle) (cu ft)	carpenter	35	Cu. ft.
22	Amount of work done by a Polisher per in mosaic floorig	Polisher	9	Sq. ft.
23	Days required for a Plumber to complete the plumbing work of 10 Marla house	Plumber	16	days
24	Days required by an Electrician to complete the electric work of 10 Marla house.	Electrician	20	days

Appendix C. Determination of Efficiencies of Machinery Used in Construction of Buildings and Roads

This survey is design to determine the efficiencies Machinery used for construction of buildings and Roads. It is requested to give your personal opinion about the probable outputs in relevance with their defined specifications based upon your personal experience.

Respondent Profile

Name of Respondent

Name of Firm/Organization/Company

Please indicate your qualification

- Doctorate (PhD)
- Master Degree (MS/M Phil)
- Bachelor Degree
- Diploma Holder
- Other:

Your company/ Organization belong to which sector

- Govt.
- Private
- University/College
- Other:

Please indicate your position in company/ Organization

- Project Manager
- Construction Manager
- Project Engineer / Architect / Planner
- Site Supervisor
- Professor / Lecturer

- Other

Please indicate your professional experience (in years)

- 0-5
- 6-10
- 11-15
- 16-20
- >20

In which type of construction do you involve?

you can select more than one

- Buildings
- Infrastructure and Road
- Bridges/ Flyovers
- Runways
- Dams/ hydal power / Canals
- Other

Machinery

Give the output/ efficiencies of machines in accordance with their defined (standards) outputs

1. For laying 15 cm thick layer of Sub-Grade, how much length (equal to the width of blade) a 150 HP Grader will grade in one hour?

- 150 m
- 250 m
- 350 m
- 450 m

2. For laying 15 cm thick layer of Sub-Base, how much length (equal to the width of blade) a 150 HP Grader will grade in one hour?

- 100 m
- 200 m

- 300 m
- 400 m

3. For laying 15 cm thick layer of Base, how much length (equal to the width of blade) a 150 HP Grader will grade in one hour?

- 50 m
- 150 m
- 250 m
- 350 m

4. How much material will be loaded by a Front End Loader of blade 2.3 m3 in one hour?

- 100 m3
- 150 m3
- 200 m3
- 250 m3

5. How much a 10T Dumper will transport ordinary soil in one go?

- 3.5 m3
- 4.5 m3
- 5.5 m3
- 6.5 m3

6. For laying 15 cm thick layer of Soil, how much length a 200 HP Bull-Dozer will spread in one hour?

- 150 m
- 250 m
- 350 m
- 450 m

7. For cutting 15 cm thick layer of Soil, how much length a 200 HP Bull-Dozer will cut in one hour?

- 100 m

- ○ 200 m
- ○ 300 m
- ○ 400 m

8. You have to Clear 15 cm thick layer of Soil, how much length a 200 HP Bull-Dozer will clear in one hour?

- ○ 150 m
- ○ 250 m
- ○ 350 m
- ○ 450 m

9. You have to compact 15 cm thick layer of Sub-Grade with 4.75 m width, how much stretch (equal to the width of drum) a Tandem Vibratory Roller will compact in one hour?

- ○ 50 m
- ○ 100 m
- ○ 150 m
- ○ 200 m

10. You have to Compact 8 cm thick layer of Asphalt Bearing Course with 4.75 m width, how much length (equal to the width of drum) a Pneumatic Tyre Roller will compact in one hour?

- ○ 70 m
- ○ 100 m
- ○ 130 m
- ○ 160 m

11. If the road length is 1 km and the width is 4.75 m, how much area will be covered by a bitumen distributer in one hour?

- ○ 1500 m2
- ○ 1750 m2
- ○ 2000 m2
- ○ 2250 m2

12. How much asphalt premix will be produced by 80T Asphalt Plant in one hour?

- 25 m3
- 30 m3
- 35 m3
- 40 m3

13. How much asphalt premix will be laid by an Asphalt Paver if road width is 4.75 m and thickness 8 cm in one hour?

- 25 m
- 35 m
- 45 m
- 55 m

14. An Excavator of 68 HP with 1 m3 bucket size will excavate how much quantity of soft soil in one hour?

- 40 m3
- 60 m3
- 80 m3
- 100 m3

15. How much Concrete will be produced by Concrete Batching Plant of capacity 30 m3 in one hour?

- 20 m3
- 30 m3
- 40 m3
- 50 m3

16. How much Concrete will be produced by Concrete Transit Mixer of capacity 4.5 m3 in one hour?

- 1.5 m3
- 2.5 m3
- 3.5 m3

- 4.5 m3

17. How much Concrete will be produced by Concrete Static Mixer of capacity 1 m3 in one hour?

- 5.5 m3
- 6.5 m3
- 7.5 m3
- 8.5 m3

18. How much length of road will be marked by Road Marking Machine (CR) in one hour having width of 4.75 m and length 1 km?

- 20 m
- 40 m
- 60 m
- 80 m

Appendix D. Effect Of Efficiency Of HR On Quantitative Analysis of Risk Management In Construction

Respondent Profile

1. Name of Respondent

____

2. Email address

____

3. You belong to which Stakeholder Company/ Organization:

- Owner/ Client
- Consultant
- Contracotr
- Academia / Researcher
- Other ____

4. Your company/ Organization belong to which sector :

- Govt
- Private
- Unviersity/College
- Other ____

Information About The Workmanship on Construction

1. Amount of work done by a **Mason** per day in:
   - Bricks laid
     a. 500-600
     b. 601-700
     c. 701-800
     d. 801-900
     e. Other_________________
   - Concreting on roof

a. 50-100 ft^2
b. 101-150 ft^2
c. 151-200 ft^2
d. 201-300 ft^2
e. Other________________

- Concreting on floor

a. 150-200 ft^2
b. 201-250 ft^2
c. 251-300 ft^2
d. 301-350 ft^2
e. Other________________

- Plastering with cement (sq ft) (12 mm or ½”)

a. 50 -70
b. 71-90
c. 91-110
d. 111-130
e. Other________________

- R.C.C work in beams and slab (cu ft)

a. 50-75
b. 76-100
c. 101-125
d. 126-150
e. Other_______________

- 6 mm Mosaic floor work over 2 cm thich cement concrete (sq ft)

a. 20-35
b. 36-50
c. 51-65
d. 66-80
e. Other________________

- 2.5 cm thick cement concrete Laying of D.P.C (sq ft)

a. 75-100

b. 101-125
c. 126-150
d. Other________________

2. Amount of work done by a **Labor (Mazdoor)** per day in:
   - Mixing concrete
     a. 70-80 ft^3
     b. 81-90 ft^3
     c. 91-100 ft^3
     d. 101-110 ft^3
     e. Other________________

   - Deliver bricks up to a distance of 50’
     a. 2500-3000
     b. 3001-3500
     c. 3501-4000
     d. 4001-4500
     e. Other________________

   - Breaking of brick ballast (25mm) (cu ft)
     a. 15-25
     b. 26-35
     c. 26-45
     d. 46-55
     e. Other________________

   - Earthwork in excavation, ordinary soil (cu ft)
     a. 70-85
     b. 86-100
     c. 101-115
     d. 116-130
     e. Other________________

   - Earthwork in excavation, rock (cu ft)
     a. 20-30
     b. 31-40
     c. 41-50
     d. 51-60
     e. Other________________

- Sand filling 2inch in foundations, width= 4 ft wide (Rft)
  a. 80-100
  b. 101-180
  c. 181-300
  d. 301-450
  e. Other_________________

- Refilling excavated earth in foundation (cu ft)
  a. 300-400
  b. 401-500
  c. 501-600
  d. 601-700
  e. Other_________________

3. Amount of work done by **Steel Fixer** per day in:
   - Reinforcement work for R.C.C (cwt of steel): 1 cwt =50.8023 KG
     a. 0.5
     b. 1
     c. 1.5
     d. 2
     e. Other_________________

   - Holdfast per day
     a. 20
     b. 25
     c. 30
     d. 36
     e. Other_________________

4. Amount of work done by a **White Washer** per day in:
   - 3 coats white washing (sq ft)
     a. 500-575
     b. 576-625
     c. 626-700
     d. 701-775
     e. Other_________________

5. Amount of work done by a **Painter** per day in:
    - One coat paint (sq ft)
        a. 200-250
        b. 251-300
        c. 301-350
        d. 351-400
        e. Other________________

    - Paint two coats on wood (sq ft)
        a. 15-25
        b. 26-35
        c. 36-45
        d. 46-55
        e. Other________________

6. Amount of work done by a **Carpenter** in:
    - No. of door timber frames completed per day(1.6 sq.ft per frame)
        a. 0-2
        b. 3-4
        c. 5-6
        d. Other________________

    - No. of days required to complete one door shutter (2.66 sq.ft per shutter)
        a. 0-2
        b. 3-4
        c. Other________________

    - Shuttering (erection and dismantle) (cu ft)
        a. 20-25
        b. 26-30
        c. 31-35
        d. 36-40
        e. Other________________

7. Amount of work done by a **Polisher** per in mosaic flooring (ft^2)
    a. 2
    b. 4
    c. 6

d. 8
e. Other________________

8. How much days it takes for a **Plumber** to complete the plumbing work of 10 Marla house.
   a. 7
   b. 14
   c. 21
   d. 28
   e. Other________________

9. How much days it takes for an **Electrician** to complete the electric work of 10 Marla house.
   a. 7
   b. 14
   c. 21
   d. 28
   e. Other________________