A Probabilistic Framework to Estimate Cost and Time Contingency for Building Projects in Pakistan

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Certified that the contents and form of thesis titled “A Probabilistic Framework to Estimate Cost and Time Contingency for Building Projects in Pakistan” submitted by Sana Rafiq have been found satisfactory for the requirement of the degree.

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Associate Professor (Dr. Anwaar Ahmed, PhD)

To my beloved parents, adored
siblings and respectful teachers

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TABLE OF CONTENTS

LIST OF TABLES

APPENDIX TABLE

LIST OF FIGURES

LIST OF ACRONYMS

BAC	Budget at Completion
ACC	Actual Cost at Completion
CRCF	Cost Risk Contingency Factor
TRCF	Time Risk Contingency Factor
BOQs	Bill Of Quantities
PEC	Pakistan Engineering Council
CPI	Cost Performance Index
CPI	Consumer Price Index
MRS	Market Rates System
PICC	Pakistan Institute of Cost and Contracts
PMB	Project Measurement Baseline
PMI	Project Management Institute
EVM	Earned Value Management
WBS	Work Breakdown Structure
MCS	Monte Carlo Simulation
HR	Human Resource
MAPE	Mean Absolute Percentage Error
SPI	Schedule Performance Index
PWD	Public Works Department
RMF	Risk Management Framework

ABSTRACT

Large numbers of risks are associated with construction industry because of its highly diversified and multifarious nature. To cater for these risks, contingency reserves are designed and added to the project`s budget and schedule. Different techniques are being used worldwide to calculate contingency reserves but unfortunately, Pakistan's construction industry continues to use the "traditional percentage methodology". In this technique a pre-set fixed amount, usually 5% - 10% of the project`s cost, is added to the base cost estimate without identifying and analyzing the risks. In case of time contingency, the situation is even more alarming. Time contingency is overlooked in majority of the projects and if considered, is usually based on subjective opinion of experts. This predetermined amount for uncertainty itself denotes the arbitrariness and becomes a reason of cost and time overrun in majority of these projects. Current study developed an enhanced framework that has circumvented this uncertainty of the system by using probabilistic quantitative risk techniques. This study thus proposes a probabilistic model for predicting total cost and duration of the project by translating the effect of risks in probabilistic scheduling and cost estimate. Rational contingency reserves for cost and time are also predicted by determining risk contingency factors. The framework developed in this research can be used by construction agency for reliable estimation of project`s cost, duration and contingency reserves, in planning phase of the project.

CHAPTER 1. INTRODUCTION

1.1 Background

During planning phase of any construction project, project managers finds it extremely challenging to reliably forecast project`s duration and budget at completion (BAC) for the uniqueness and uncertainty intrinsic to project activities (Ford, 2002; Thal, et al., 2010). Even for the project of similar nature, design and size, unique project characteristics lead to distinctive risk environment (Buertey, et al., 2012). If project risks are not properly managed, there is an increased likelihood of its adverse consequences on the project's overall objective (Jackson, 2012). Unmanaged and unmitigated risks are a major reason of cost and time overrun (Zavadskas et al., 2010). These risks are reckoned as an indication of poor project planning (Fortune and Cox, 2005).

Risk management techniques can be used at project planning phase for analysing different risk factors and for obtaining precise project estimates. Risk management if properly performed can help project managers to efficiently control and handle the cost and time uncertainties in the project (Lyons and Skitmore, 2004; Kutsch and Hall, 2010). Risk management uses contingency as a tool, to abate the consequence of risks on project's objective (PMI, 2013). Main reason of assigning contingency is to make sure that the project`s estimate developed is realistic and ample to cope for any variation in the cost and time, incurred by risks (Ford, 2002). Despite of earnest efforts worldwide to calculate contingency, cost and time overrun remains a challenging problem for construction projects (Touran, 2003; Barraza and Bueno, 2007; Love, et al., 2012)

Construction industry in Pakistan continues to suffer from cost and time overrun due to its failure to adopt risk management practices, especially on small projects. To avoid the systematic approach of identifying, analysing and quantifying the risks, project managers simply add 10% to the base estimate as cost contingency which is insufficient in majority of the projects (PEC, 2010). Traditional "percentage approach" used for cost contingency is based on expert opinion in which common risks are either overlooked or dealt arbitrarily (Mills, 2001). Subjectivity becomes the main issue of this method as understanding, experience and expertise of the professionals differ widely (Sonmez, et al., 2007). Situation is more alarming in case of time contingency as no valuable consideration is given to this aspect by construction industry in Pakistan. For few projects, for which time contingency is considered, an arbitrary number of days, based on judgement of scheduler, are added to the duration as time buffer or cushion. Use of irrational approaches is major cause of over budgeting and delay in the project schedule (Touran, 2003; Idrus, et al., 2011)

The main objective of this study is to develop a probabilistic framework, using risk management processes, to estimate cost and time contingency. The developed framework would contribute to the current practices of project estimation in planning phase and help predicting contingency more precisely for construction industry of Pakistan. The framework is demonstrated using data from housing construction projects. Cost and time contingency is estimated by comparing the probabilistic estimate (projects risk duly incorporated) with traditional estimates (ignoring common project risks).

1.2 Problem Statement

Currently construction industry has a very poor repute of failure to meet the required time deadline with the targeted estimated cost (Bartholomew, 1989). It has been observed that 75% of the projects are classified into cost overrun and under run categories and average time overrun for construction projects worldwide was 222% in 1995 which improved to 163% in 2001 (Baccarini, 2005). Failure of project manager to precisely predict the contingency required for the project is the major reason for cost overrun (Ben-David and Raz, 2001). General practice involves assigning a predetermined percentage (usually 5% - 10% of the estimated cost) to the budget as ‘Contingency Reserve’, which is an overly ingenuous approach (Dikmen, et al., 2008), based solely on experience and intuition. Also, a similar and simplified practice is being used by construction industry in Pakistan to predict the cost of similar natured projects by adding an arbitrary percentage to the total cost of the previous projects that have been executed or are under execution. But this fixed percentage has been unsuccessful over the years and is the major cause of cost overrun for many projects.

Furthermore, construction professionals and experts frequently quote timely deliverance of project as one of the principal challenge, but no considerable effort has been made to quantify the time risks (Mohamed, et al., 2009). Majority of the schedules in Pakistan are developed without considering time contingency. Time contingency added in few of the projects is totally based intuitions, which cannot be considered reliable and considered as the major cause for time overrun.

1.3 Research Objectives

The objective of this research is to develop a probabilistic framework using Monte Carlo technique that:

a. Calculate cost and time risk contingency factors using probable budgeting framework based on simulation.
b. Predicts reliable total project cost.
c. Predicts reliable total duration of the project.

1.4 Overview of Study Approach

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

a. Detailed literature review for contingency calculation of cost and time.
b. Selection of projects.
c. Development of traditional model for estimation of cost and time.
d. Comparison of traditional estimate with the actual data from completed projects
e. Identification and data collection of cost and time risks.
f. Incorporation of cost risk factors in cost estimation sheet.
g. Incorporation of time risk factors in scheduling.
h. Development of probabilistic model for estimation of cost and time.
i. Model validation.
j. Comparison between probabilistic and traditional estimates.
k. Determining cost and time contingency factors.

1.5 Thesis Organization

This research is organized into five chapters. Introduction, problem statement and study objectives are discussed in Chapter 1. Chapter 2 provides a literature review on project cost and time estimation techniques, risk treatments and contingency calculation techniques of cost and time. In Chapter 3 and 4 the methodology used for the preparation of traditional and probabilistic model is discussed and Chapter 5 covers the analyses and results of probabilistic model. Lastly, the research summary, findings, and recommendations are discussed in Chapter 5.

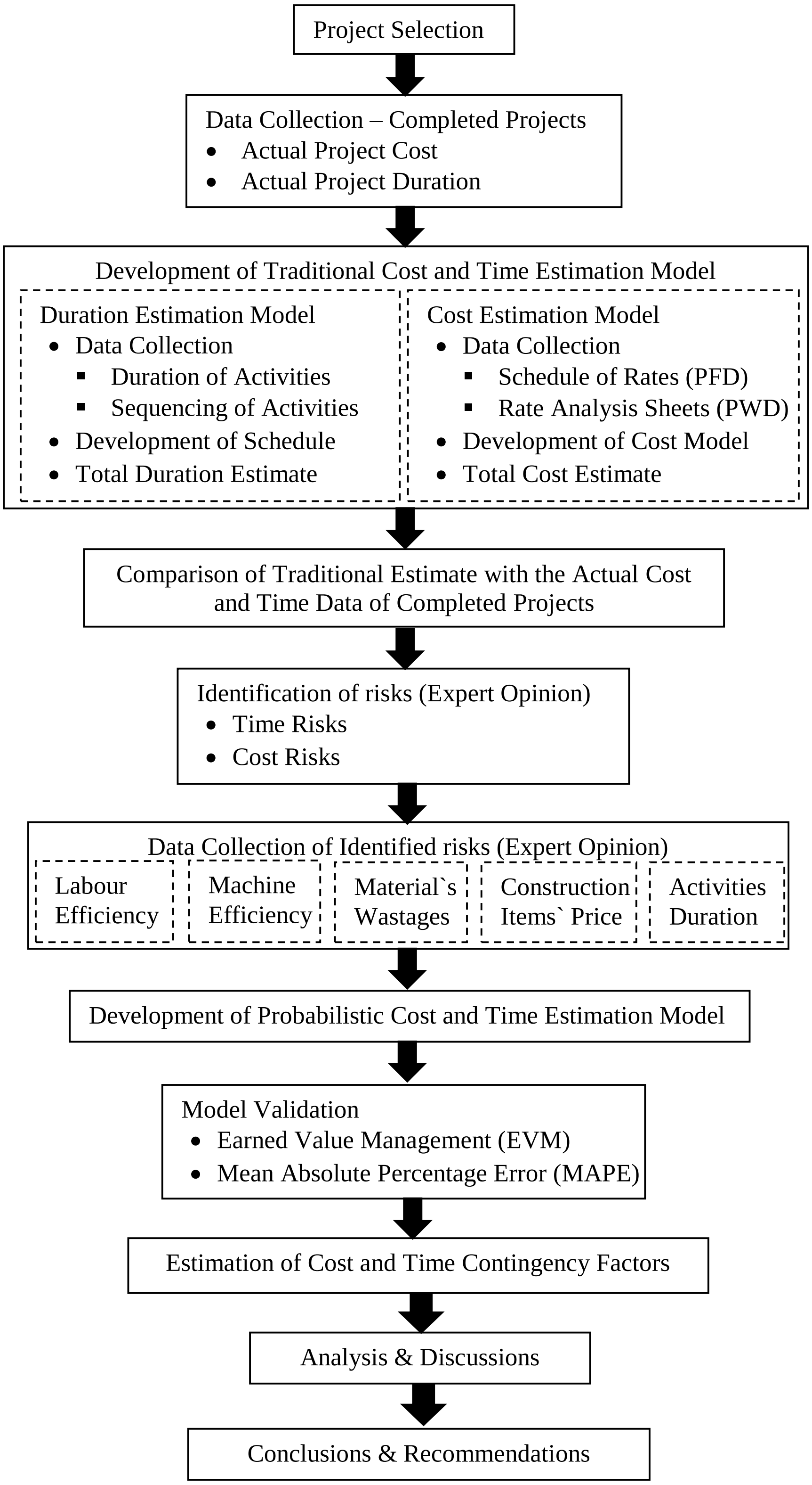


Figure 1.1 Research Methodology

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction

This chapter summarizes topics of risk management, risk treatment techniques and contingency calculation techniques for cost and time. Risk, as per PMI, is defined as "An uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective" (PMI, 2004). Risk Management is considered as a proactive approach to dealing with uncertainties rather than a reactive approach. Different treatments are being made to the risks identified, according to its impact on the project`s objective, which are discussed in detail in this chapter.

2.2 Risk Management

Cost overrun, though a very usual phenomenon in construction industry, is considered as the most intimidating experience for project managers (Fortune and Cox, 2005). It is the deviation of actual cost from estimated cost caused by risks (Love, et al., 2012). Project risk can be described as an uncertain incident that have a probability of its occurrence and may have a positive or negative effect on any of the project`s objective, if it occurs (PMI, 2004). Risks endanger the project manager to complete the project within the pre-defined scope on targeted time within the estimated budget (PMI, 2004). In case a project suffers from negative risks, activities may use more resources or take longer time than planned causing overruns in the project (PMI, 2004). There is general consensus that risks in the projects can be controlled by developing a rational project estimate by proper risk management techniques (Love, et al., 2012). Risk management covers the processes of identification and analysis of risks followed by creating strategy to mitigate, minimize or control the probability or/and impact of negative risks and enhancing the effect or/and probability of positive risks (PMI, 2004).

Risk management is a wearisome task for construction projects because of individuality of every project that distinguish it from even similar projects (Ford, 2002). Unique characteristics, design liability, contractual specifications, geological conditions, political scenarios and various other features make a project unique and one of its kind. Many researchers and project managers since early 1990s have investigated ambiguous project environment termed as ‘risk’, (Zavadskas, et al., 2010). The commonly used risk response strategy to control the effect of risks in construction industry is allocation of contingency reserves (PMI, 2004).

2.3 Risk Treatments

In risk management technique, risks are identified and depending upon its type and its probability and impact, four key potential risk treatments are considered:

a. Risk avoidance: Risk avoidance is to avoid the activity that would have risks associated with it. It is not a practical approach because positive risks associated with the project or the activity will also be lost. (Larson and Gray, 2011).

b. Risk reduction: Risk reduction is the risk optimization technique which includes the steps to minimize the probability and impact of the risk (Larson and Gray, 2011).

c. Risk sharing: Risk sharing is considers as the best technique of risk treatment. It is described as "sharing with another party the burden of loss or the benefit of gain occurred from a risk." This includes insurance or outsourcing the activity having the risks (Larson and Gray, 2011).

d. Risk acceptance: It is the most dangerous strategy of the risk treatment. It includes accepting the risk and budgeting for it. Risk acceptance is generally of two types (1) active acceptance in which no action is taken beyond documenting the decision, and (2) passive acceptance in which strategies are planned and being acted upon (Larson and Gray, 2011).

2.4 Risk treatment in Construction Industry

The most commonly used risk management strategy in construction industry is the active acceptance technique in the form of reserves. Two kinds of reserves are commonly used in the construction industry.

a. Contingency Reserves: Contingency reserve is used to handle “known-unknowns”. Unknowns depicts the risks and known represents the risks that can be identified. It is generally taken as a percentage of the budgeted cost or is calculated using risk management techniques (PMI, 2004).

b. Management Reserves: Management reserve is used to handle the “unknown-unknown” (unknown=unidentified, unknown=risks) Management reserve is a random figure and is taken according to the organization’s policy. It is not estimated (PMI, 2004).

2.5 Project Cost Contingencies

Contingency assessment problem has been analysed by many authors in recent past. Majority of research efforts remained focused on factors of risks that affect project`s cost and contingency and slight significance has been given to the methods and techniques to calculate contingency reserves for a project (Thal Jr., et al., 2010). Hollmann (2007) summarized the techniques used to calculate contingency into four general subgroups (1) subjective opinion of the experts, (2) pre-set limits, values and guidelines of a particular organization, (3) parametric analysis, which uses results from previous similar projects, and (4) probabilistic analysis. Contingency is being estimated using either one or combination of these four techniques.

Spooner (1974) is considered amongst the pioneer researchers who developed probabilistic project`s estimate. He collected subjective data and recommended using three point estimation techniques for proper assessment of risks. Ibbs and Crandall (1982) used utility theory and multi attributed objective function to create a statistical decision making model for risk analysis. The major limitation of using utility theory was the ambiguity in specifying the guide or the source of the utility function, especially on large projects. Al-Bahar (1988) introduced the concept of using Monte Carlo Simulation technique for risk analysis. Yeo (1990) presented an approach of two-tiered contingency allocation (engineering contingency and management allowance) for determining probable cost of the project. Ranasinghe (1994) modified this two tiered general framework to develop Contingency Allocation and Management Model (CALM) by allocating the uncertainties to discrete bill item costs. Hassanein and Cherlopalle (1999) forecasted the project`s estimate by addressing the uncertainties using fuzzy theory.

Chen and Hartman (2000) developed Artificial Neural Network (ANN) model for estimating the probable contingency required for the project. ANN learns from the previous project`s experience and predict for the new ones. Mak and Picken, (2000) developed a framework known as “Estimation under Risk Analysis (ERA)” for Hong Kong government to forecast project’s contingency. Proposed methodology is a modified version of “Multiple Estimating using Risk Analysis” (MERA) technique used by the Public Services Agency of UK. ERA identify, analyse and quantify project cost risks to determine project contingency. Hastak and Shaked (2000) worked on generalizing risk evaluation processes. Authors developed a model using 73 risks factors collected from various countries across the globe to create a risk evaluation model for international construction projects. In 2001, Bent developed a contingency chart, using scoring system, for determining cost contingency percentage. Molenaar (2005) evaluated risk factors for highway projects using data from Washington State Department using a programmatic approach. Barraza and Bueno (2007) estimated the cost contingency required for a project by simply summing up the contingency evaluated for main activities of the project. Sonmez, et al. (2007) utilized linear regression analysis to calculate contingency. Recent studies have mainly focused on estimating the contingency during the planning phase of the project. Generally a quantitative model is developed, that uses identified risk events or factors to forecast the contingency required for a particular project (Sonmez, et al., 2007; Cioffi and Khamooshi, 2009; Lhee, et al., 2009; Mohamed, et al., 2009). Touran (2003) recommends the use of probabilistic approach to develop a probable estimate and Barraza and Bueno (2007) considers Monte Carlo Simulation, the most customary and beneficial technique for probabilistic estimation.

One of the major limitations of these methods is that they require proper statistical knowledge from project managers and associated stakeholders. Most of the construction personnel fail to understand the concept as they lack the knowledge of the formalized technique (Smith and Bohn., 1999). Kangari and Riggs (1989) and Dikmen, et al. (2007) hence concluded that due to limited knowledge of the personnel in the construction field, traditional approaches based on experience, intuitions and expert knowledge cannot be avoided, in spite of these being imprecise, ambiguous and inaccurate. Therefore use of a subjective pre-set percentage with the total cost, as contingency reserve, is the commonly used technique which becomes a major reason of overruns in the industry (Touran, 2003; Thal, et al., 2010). As the awareness and responsibility of completing the projects without overruns is increasing, traditional percentage method is becoming less common (Vose, 2008).

2.6 Project Time Contingencies

Most past studies remained focused on cost contingency of the project but for a successful project, it is necessary to assign contingency to both cost and time (Touran, 2003). PMI defines time contingency as a cover to safeguard delays and oversights in the activities duration calculation (PMI, 2004). The schedule developed therefore, should be elastic enough to cope with the time risks without negatively affecting the total project duration (Mohamed, et al., 2009).

Different techniques have been suggested in literature to calculate and assign time contingency to the schedule (AbouRizk and Halpin, 1992; Sohail and Edum-Fotwe, 2000). Ballard and Howell (1995) proposed assigning a buffer to the project schedule, depending on the uncertainty involved in the project. Reliability criteria is another technique which states placing contingency with the succeeding activity enough to keep the activity reliable, depending on the risks associated with it (Park and Peña-Mora, 2004). Galindo (2000) proposed an integer linear programming model considering activities duration variability, probability and criticality indexes.

Despite the rational results given by the probabilistic scheduling, mostly managers in the construction industry prefer a subjective approach for calculating time contingency (Crandall and Woolery, 1982; Burger, 2003). In subjective approach, time contingency is often calculated as a fraction addition to the total duration of the project, without considering the uncertainty of the discrete activities. Because the schedule variability is dependent on the behaviour of the activities, time contingency should be estimated by taking into account the uncertainty and performance inconsistency of respective activity instead of basing on human judgment (Pollack and Liberatore, 2005; Barraza, 2010).

2.7 Chapter Summary and Conclusion

Preparation of project schedule and cost estimate is considered as one of the most vital but critical step for any project. For reliable estimation, cost and time contingency should be added to the estimate. For project contingency, traditional approach was widely used but is now becoming unpopular because of it being subjective and difficult to validate (Thompson and Perry, 1992). Instead "Monte Carlo Simulations" is used for calculating project contingency (Touran, 2003).

CHAPTER 3. TRADITIONAL PROJECT ESTIMATES

To estimate contingency of cost and time, the study used a comprehensive framework that is shown in Figure 1.1. Traditional and probabilistic estimation models of cost and time are developed and compared for the purpose. This chapter discusses, in detail, the methodology used to develop traditional model to predict final cost and total duration of the project. Traditional model uses the common practice observed in the industry for estimation. Precision of model was checked by using Earned Value Management (EVM) techniques and Mean Absolute Percentage Error (MAPE).

3.1 Selection of Project Types

Housing construction projects were selected for this study for their simplicity, ease in estimation and wide applicability in the construction industry of Pakistan. Housing projects were selected from different parts of Rawalpindi and Islamabad cities, which varied in size, design, finishes, time of construction and construction technique. Size of selected projects varied from 1125 sft (104 sqm) to 4500 sft (418 sqm) (Table – 1). Selected housing projects are the commonly build sizes in Pakistan and the percentage of the projects considered is an approximate representation of all constructed houses in two cities.

Table - 1 Sizes of Selected Housing Projects

Sr. #	**Size of Projects**		**Number of Project**	**Percentage of Projects**
	Sft	Sqm		
1	1125	104	52	36.1%
2	1575	146	12	8.3%
3	2250	209	43	29.9%
4	2700	251	09	6.25%
5	4500	418	28	19.4%

3.2 Data Collection – Constructed Houses

Actual duration and total cost at completion of completed 144 projects were collected. For the purpose, owners or contractors of all the projects were individually visited and interviewed. Details covering design and finishes of the house, total cost of the house excluding site payment and design fee, total time it took in the execution of the project and any uncertain events that occurred during execution phase were recorded.

3.3 Development of Traditional Model

Cost estimates were prepared for all the projects with the help of design specifications collected. These estimates were typical and were of the simplest form, which are commonly prepared by estimators in Pakistan. Figure 3.1 explains the detailed methodology for the development of Traditional model

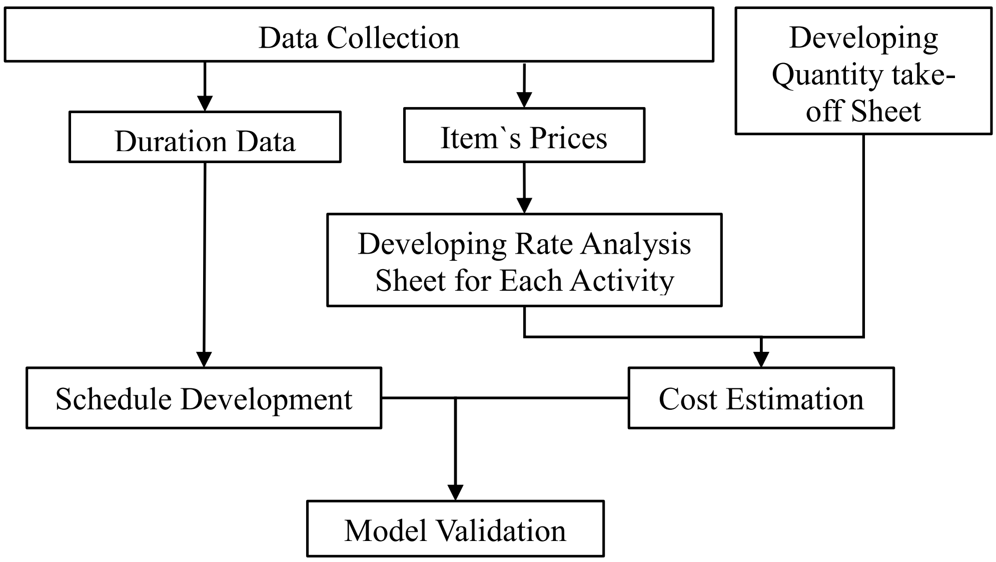


Figure 3.1 Traditional Model

a. Construction Item's Prices and Analysis of Rates: Construction item's prices for past eleven years were obtained from Punjab Finance Department (PFD). It offers market rates system and constructions rates of approximately 2960 different construction items, 90 different types of construction machinery and 130 different types of labor on their official website. Rates of 183 different construction items have been used in the model, which included 131 materials, 28 machinery and 24 different types of labor. Rate of analysis sheets were prepared using these item`s rates and departmental (PWD) analysis of rates (2012).

b. Duration Data: Data for duration of different activities was collected and used in the development of schedule. Expert opinion was used for data collection which 20 interviews were conducted. It included questions such as the number of hours required for different activities in 5 Marla, 10 Marla, and 1Kanal house construction. Arithmetic mean of the responses was taken to develop the schedule.

c. Preparation of Project Cost Estimate Sheets: MS Excel was used to prepare traditional cost estimate sheets. Steps followed for the development of the model were (1) preparation of quantity take-off sheets in which quantity sheet was generated as per design specifications of the selected 144 projects, (2) preparation of rate index sheet in which an excel sheet was generated having all the construction items' rates which was then used during the preparation of rate analysis sheet for each activity, (3) preparation of rate analysis sheets for each activity of the project based on PWD rate analysis procedures, and (4) preparation of project estimate by interlinking quantity sheet and rate analysis sheets.

d. Development of Schedule: Project Schedule was developed by sequencing the activities and developing relationship between these activities. Relationship between activities varied according to the dependency type which mostly included, start to finish relationship, but also finish to finish and start to start relationships were used with a lead or lag. The activities duration were taken from the expert opinion. The schedule is so developed that it automatically predicts the start and end date of activities, and hence final date of the project, using the working calendar just by the input of start date of the project.

3.4 Comparison of Actual Data with Traditional Estimate

Traditional estimate of the projects obtained using simple Microsoft Excel based model is compared with the actual data cost and time data collected for individual projects. Project Performance is measured using Earned Value Management (EVM) techniques, and Mean Absolute Percentage Error (MAPE). EVM techniques are considered as a beneficial and expressive tools used to status, report, and analyse project cost, schedule, and performance (Sumara and Goodpasture, 1996). Schedule Performance Index (SPI) is a schedule performance indicative tool and shows how proficiently project team has used its time whereas Cost Performance Index (CPI) indicates the efficiency of team in using its resources. The graphical representation of SPI of 144 projects is shown in Figure 3.2 with SPI on x-axis and the number of projects on y-axis. It was revealed that overall SPI varied from 0.67 to 0.86; however 85% projects had SPI less than 0.80. This implies that the schedule prepared was idealistic and was not able to cope for uncertain events.

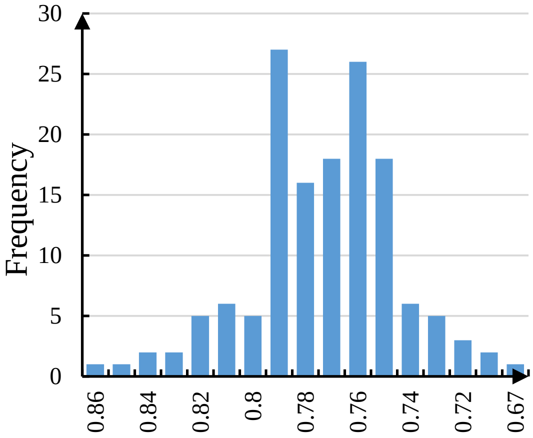


Figure 3.2 Schedule Performance Index of Traditional estimates

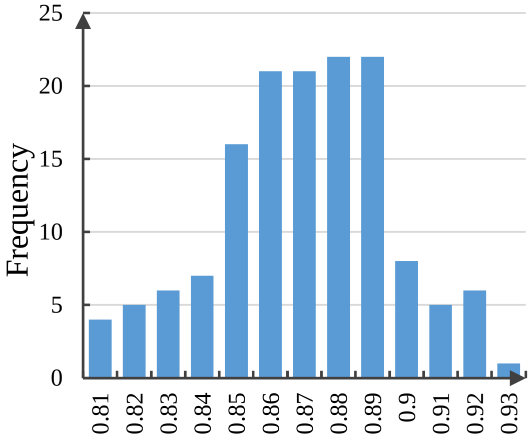


Figure 3.3 Cost Performance Index of Traditional estimates

The graphical representation of CPI of 144 projects is shown in Figure 3.3 with CPI on x-axis and number of projects on y-axis. It was revealed that overall CPI varied from 0.81 – 0.93; however 85% projects had CPI less than 0.90 indicating more than 10% error in the final cost calculated traditionally termed as traditional budget at completion (TBAC). Single percentage error can be calculated for all the projects by estimating MAPE which is given as follows:

$$\mathrm{MAPE} = \frac{1}{n} \sum_{i=1}^{n} |\mathrm{PE}|_i \qquad (1)$$

Where PEi = (Ai – Pi) / Ai is the percentage error for project i, which ranges from 1 to n. Ai is the actual value of the project and Pi is the final cost of the project estimated traditionally. MAPE for the projects is calculated as 9.03%. Results showed that estimate developed was not reliable and may result in cost overrun for the project. Literature review suggests that there are number of risks involved in the execution phase of the project and traditional approach is unable to incorporate its monetary effect on the budget in the planning phase (Thal Jr., et al., 2010). To cope with the risks, contingency is introduced to the project`s estimate by identifying the risks involved in the project and calculating its monetary effect (Barraza and Bueno, 2007).

CHAPTER 4. PROBABILISTIC PROJECT ESTIMATES

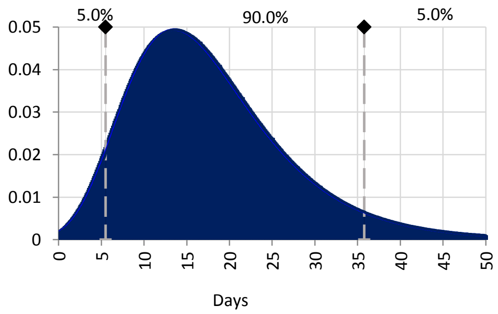
Traditional model was adjusted against the effects of risks to get the probable cost estimate. Risks involved in the construction of houses in Pakistan were identified and its detailed data was collected. Probabilistic estimation model adjusted these identified risks to predict realistic project cost and duration. Model development can be segmented into four phases as per the risk management processes during the planning phase: planning, identification, analysis, and response. Primarily, planning is done to define the projects that should be undertaken and approach taken to identify and evaluate the project risks. Secondly, risks are identified that may have their effect on project`s objective. Main emphasis of this research is on risks in execution phase of the project. Thirdly, probable consequences of the identified risks are evaluated using quantitative or qualitative risk analysis techniques. Fourthly, risk response strategy is designed to help alleviate the identified risks and to keep the project heading in the right direction. The probabilistic model developed will help to forecast probable and precise final budget and duration of construction project, in the planning phase of the project. Comparison of traditional and probabilistic estimates will help in developing Time Contingency Factors and Cost Contingency Factors. These factors indicate the contingency required with the base estimate to tailor the risks involved. A detailed description of each step is herein mentioned. This chapter discusses, in detail, the methodology used to develop probabilistic model to predict total duration and final cost in the planning phase of the project. Probabilistic approach covered all the possible risks of the project that are ignored while determining the up-front cost in traditional method. Precision of models were checked by using Earned Value Management techniques and its performance indices.

4.1 Identification of Project Risks

First and foremost step in risk management process is the identification of risks involved in the project (PMI, 2004). Following Zavadskas et al. (2010), project risks can be categorized into three classes (1) internal, (2) external, and (3) project. Main focus of this research is on project`s risks assuming an ideal case for all other scenarios. Other risks occurring in the planning phase of the project, such as contractual complexities, drawings formalities etc. that also have direct impact on project`s cost and time have been deliberately ignored. Through interviews of 25 construction industry professionals, 5 risk categories were identified that might have significant impact during project execution phase, on cost and schedule of project in Pakistan`s housing construction industry. The identified risk categories are (1) labour efficiencies, (2) machine efficiencies, (3) material wastages, (4) construction items' rates and (5) duration of different activities. The details of these risk categories are provided in ensuing paragraphs.

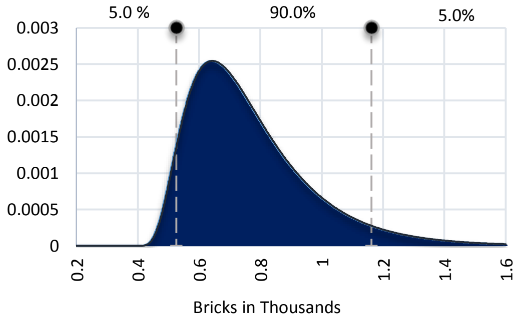
4.2 Data Collection and Collation for Risk Factors

a. Labor Efficiency: Labour efficiency is measured in terms of productivity. 'Productivity' is used to express the relationship between outputs and inputs terms. Labour productivity is defined as "the amount of goods and services produced by a productive factor (manpower) in the unit time" (Kazaz, et al., 2008). Labour cost about 30-35% of the total project`s cost and it is not uncommon to experience a loss of 30-40% in labour productivity (Rojas, 2008). This can increase the project`s cost to 9-14%. To determine the labour efficiency for housing construction industry of Pakistan, an empirical approach was adopted by developing a questionnaire comprising of 25 questions which were related to different labour categories including unskilled labourer, mason, plasterer, steel fixer, painter, carpenter, electrician and plumber. A total valid and complete 120 responses were collected. Using @RISK as the simulation tool, best distribution was fitted over the collected responses to get probabilistic mean and standard deviation of different activities. The efficiency for unskilled labourer and electrician with the best fitted probability distribution and probabilistic mean and standard deviation with a confidence level of 90% are shown in Figure 4.1. The effect of each risk factor was than incorporated into schedule and rate analysis sheets using probabilistic mean and standard deviation.



Extreme Value (13.67, 7.44)

(a)



Inv Gauss(417.01, 1721.38)

(b)

Figure 4.1 Probability Distribution (a) Days taken by an electrician for ducting and wiring of a 10 Marla house (b) Number of bricks (in thousands) laid by a mason in a day

b. Machine Efficiency: The equipment` cost is considered to be 10 to 30% of total cost of the project and if not properly managed, efficiency of the machinery is lost and it can increase the cost of the project considerably (Sharma, 1998). Subjective opinion was taken from professionals using questionnaire survey and machine efficiency in Pakistan was determined. Questionnaire for machine efficiency contained 10 questions for machines including loader, dumper, bull dozer, excavator concrete mixer and batching plant. 93 effective and comprehensive responses were collected and using @RISK as the simulation tool, best distribution was fitted over the collected responses to get probabilistic mean and standard deviation of different activities. Summary of responses collected is shown in the Table 2. This result is then translated in the schedule and rate analysis sheets to get probabilistic total estimate of the project.

Table - 2 Machine`s Efficiency Responses

Sr. #	Type of Machine	Survey Efficiency /hr	Unit
1	Front end loader 2.30 cum	85	Cu. m
2	Dumper 10 t.	5	Cu. m
3	Bull-dozer 200 hp (for spreading)	383	m
4	Bull-dozer 200 hp (for cutting)	170	m
5	Bull-dozer 200 hp (for clearing)	298	m
6	Excavator (track type) 68 hp	51	Cu. m
7	Concrete batching plant 30 cum	17	Cu. m
8	Concrete transit mixer 4.5 cum	4	Cu. m
9	Concrete static mixer 1cum	6.5	Cu. m

c. Material Wastages: During project execution phase materials wastage rate varies for different construction items and generally wastage rates are higher than the planned rates. Higher wastage rates results into more consumption of the material and thus resulting into increased cost of different activities. Expert opinion approach was used to establish the wastage rate for different material used. For this purpose 9 experts (contractors, owners and quantity surveyors) were interviewed and top 15 materials were identified, which were highly wasted in the building of a house. Using Likert scale ranging to scale the materials table - 3 shows the ranking and average weightage of these material from 0-5 (0 = not wasted, 1 = least wasted, 2= less wasted, 3 = normally wasted 4= highly wasted, 5 = very highly wasted). These top 15 material`s wastage rate was determined through subjective opinion of the professional and triangular distribution was fitted over the responses using maximum (Mx), minimum (Mn) and most likely value (ML). Reason of using triangular distribution was that with the same range and mode triangular distribution covers and accommodates broad range of uncertainty than any other distribution (Kim, 2015).

Table - 3 Construction Material's Wastages

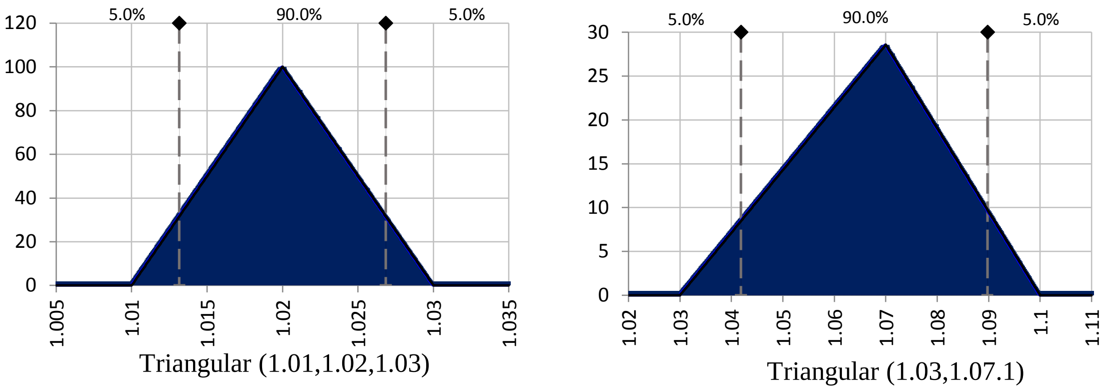
Material	Activity	Mean Weightage	Ranking	Wastage Rate
Aggregate	Preparation of concrete	2.9	1	13%
Sand	Preparation of concrete	2.9	1	13%
Nails	Installation of appliances and fixtures	2.7	3	12%
Mortar	Plastering	2.7	3	12%
Polythene	Insulation of roof	2.5	5	11%
Concrete	Reinforced cement concrete work	2.4	6	9%
Cement	Laying of bricks	2.4	6	7%
Steel	Reinforcement	2.3	8	6%
Timber	Formwork	2.2	9	5%
Tiles	Floor and wall tiling	2.2	9	5%
Wiring	Electrical work	2	11	4%
Paint	Painting/rendering	1.9	12	3%
Bricks	Brickwork	1.7	13	2%
Wood	Wood work	1.5	14	2%
PVC	Plumbing work	1.5	14	1%

Following Voes (2008) mean value and variance of the triangular distribution is expressed as:

$$\mathrm{Mean[Tri(Mx, Mn, ML)]} = \frac{Mx + Mn + ML}{3} \quad (2)$$

$$\mathrm{Variance[Tri(Mx, Mn, ML)]} = Mx^2 + Mn^2 + ML^2 - ((Mx \times ML) + (Mn \times ML) + (Mx \times Mn))/18 \quad (3)$$

Figure 4.2 shows the triangular distribution fitted to bricks and cement used for plastering. It shows that over 90% probability 2 % of bricks are wasted in brickwork with a standard deviation of almost 1.5% and 7% cement is wasted in plastering with a standard deviation of almost 4-5%. Mean and variance values obtained by fitting appropriate distribution were incorporated in the rate analysis sheet to get most probable cost estimate.



(a) (b)

Figure 4.2. Probability Distribution (a) Wastages of bricks in brickwork (b) Wastages of cement in plastering

d. <u>Items' Rates:</u> Fluctuation in construction item`s rates was regarded as the major reason of cost overrun by the experts during risks identification interviews. Traditionally cost estimates are prepared during planning phase of the project using item`s rates in that period of time, however, items rates undergo inflation with the passage of time. No price adjustment formula is used for small housing construction projects. Pakistan Engineering Council (PEC) price adjustment formula is only applicable for projects with over one year duration, since most of the housing projects have duration less than an year, therefore PEC price adjustment formula cannot be used. To cater for this risk, construction items' prices were collected from Punjab Finance Department for past eleven years from Jan, 2004 to Jan, 2015.

To study the effect of time on construction item rates, construction price index (CPI) were established for individual construction items on quarterly basis. CPI values were established by selecting a base item price and future CPI's were determined using base price. If, across two time periods t_b (time period of the base price) and t_i (time period for which CPI is to be determined), the same quantity of good or services was sold, but under different prices, then CPI is given as equation (4) (Deaton and Zaidi, 2002)

$$\text{CPI} = \frac{P_x t_i . Q_x t_i}{P_x t_b . Q_x t_b} \tag{4}$$

Where, P_x,t denotes the price of x in period t, Q_x denotes the quantity of x sold in period t. CPI calculated gave a trend to determine the future cost scenarios of the project i.e. to predict the cost of the materials and machinery used in planning phase of the project.

e. Duration Data: Total duration of the individual projects is calculated by adding the duration of activities that lie on the critical path. Subjective opinion of experts was taken for duration of these activities for small house construction through interviews. 20 interviews were conducted from field professionals which included project managers, schedulers and contractors. PERT distribution was fitted over the responses and probabilistic mean and standard deviation was calculated for activities` duration to develop probabilistic schedule by Monte Carlo simulation technique. PERT is defined by optimistic (O), most likely (ML), and pessimistic (P) values (PMI, 2013) using Equations 5 and 6 as follows:

$$\text{Mean[PERT(O, P, ML)]} = \frac{O + P + 4ML}{6} \tag{5}$$

$$\text{Variance[PERT(O, P, ML)]} = \frac{(O + P)}{36} \tag{6}$$

4.3 Probabilistic Scheduling

Probabilistic scheduling through simulation technique delivers more precise and accurate results, essential for making decisions (Barraza, 2010). To cater for time risks involved in the project, probabilistic schedule was developed. Schedule was prepared by sequencing the activities contingent to dependency types and relationship with the preceding activities. Uncertainty in duration of different activities was addressed by introducing "PERT Distribution". Labour and machine efficiency, with probability distribution, was decoded to duration of the activities to translate its effect on project schedule. By simulating the project using @RISK, probable project duration (PPD) was evaluated by considering different distributions over activities duration and efficiency of workmanship and machinery (Equation 7). PPD is obtained by summing the simulated probable duration of activities that lie on the critical path

$$\mathrm{PPD} = \sum_{i=1}^{n} \mathrm{PD_i} \quad \text{for } i = 1,2,3,\ldots,n \tag{7}$$

Where,

PD_i = Simulated probable duration of activities lying on critical path.

Simulated probable duration (PDi) is a function of duration (Di) of that activity, efficiency of labours and efficiency of machines used in that particular activity.

4.4 Probabilistic Cost Estimation

Total project cost (TPC) is predicted by summing the simulated probabilistic cost of each activity in the project (ACa) as per equation 8. These cost were determined from the rate analysis sheet prepared for each activity, incorporated with the cost risks.

$$\mathrm{TPC} = \sum_{a=1}^{z} \mathrm{AC_a} \quad \text{for } a = 1,2,3,\ldots,z \tag{8}$$

Where,

ACa = Cost of activities of the project in the project. Cost of each activity depends on the rate of all the labour worked and machinery and materials used in that particular activity. The rate is calculated by multiplying the quantity of labour, material or machinery used with rate of that particular item, growth rate and efficiency in case of material and labour and wastages in case of material. Growth factor is predicting by extrapolating the CPI values to measure the inflation that will occur, individually for all items. Developed probabilistic model allows analysis of a wider continuum of data by using @RISK as the simulation tool. Using 4000 iterations, simulations were run over uncertainties of the identified five risks categories in the model and probabilistic estimates were developed for every project.

4.5 Methodology Summary

Two types of models were developed using traditional and probabilistic approach. Total of 144 housing constructions projects were selected for each model. Traditional approach adopted the common practices used in Pakistan construction industry to determine the rates and develop the schedule. To develop the probabilistic model, project cost and time risks were identified through subjective opinion. Identified risks include; (1) construction material wastages, (2) labour efficiencies, (3) machine efficiencies, (4) construction items' rates, and (5) duration of activities. Data for these risks was collected and was then incorporated in the project`s schedule and rate analysis sheets to determine the probabilistic cost estimate and probabilistic schedule.

CHAPTER 5. RESULTS AND ANALYSIS

This chapter states the results and deals with the analysis of these result calculated from probabilistic model. The main aim was to assess the results and check the reliability of the traditional approach commonly practiced in Pakistan construction industry and then by incorporating the risk factors, competency and efficacy of probabilistic model was measured. This chapter also deals with the development of contingency factor graphs. These graphs determine the contingency factors of cost and time that are to be introduced with the traditional estimate to predict the most probable final cost and duration of the project. These risk factors tailor all cost and time risks involved in the housing construction industry of Pakistan.

5.1 Probabilistic Model

SPI of 144 projects were calculated, graphical representation of which is shown in Figure 5.1 with SPI on x-axis and number of projects on y-axis. The graph displays that SPI varied from 0.95 to approximately 1.00 of all the projects of which 80% of the projects have SPI more than 0.97. This suggests that by incorporating probability in the schedule, total duration of the project can be predicted with an error of just ±3.0%.

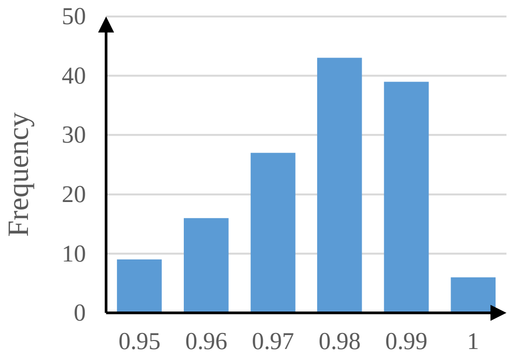


Figure 5.1 Schedule Performance Index of Probabilistic Estimates

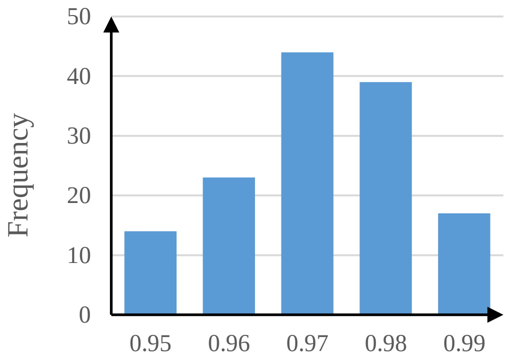
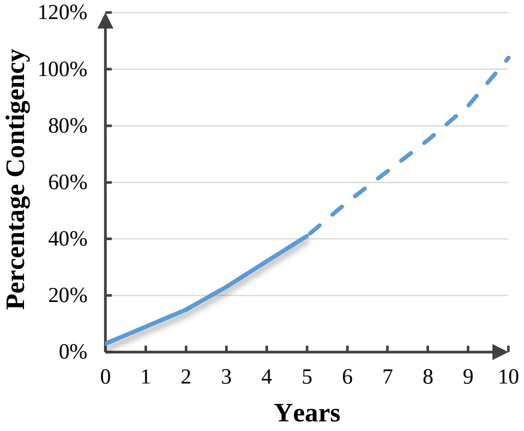


Figure 5.2 Cost Performance Index of Probabilistic Estimate

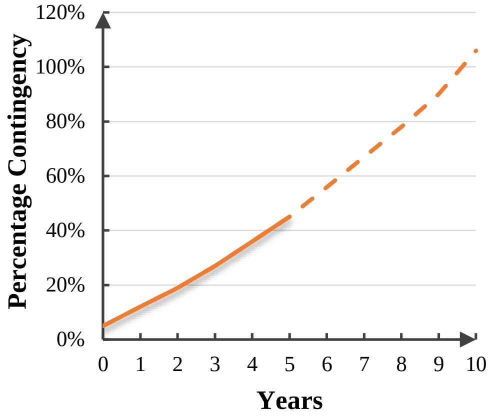
Similarly Cost Performance Index (CPI) was calculated and figure 5.2 shows its graphical representation with CPI on x-axis and frequency of projects on y-axis. Graph illustrate that CPI of all the projects varied from 0.95 – 0.99 of which 70% of the projects have CPI greater than 0.96 which indicates error of less than 4% in the calculated total cost termed as probabilistic budget at completion (PBAC). Single percentage error for all the projects is obtained by using MAPE (Mean Absolute Percentage Error). MAPE of the probabilistic projects is calculated as 1.6%. Precision of the estimates developed by using probabilistic technique was checked by two methods (1) SPI and CPI calculated of the PBAC; and (2) the mean absolute percentage error (MAPE) and its results showed that probabilistic model has the capability to predict project`s estimate, which included total budget and total duration of the project, efficiently and precisely.

5.2 Cost Contingency Factors

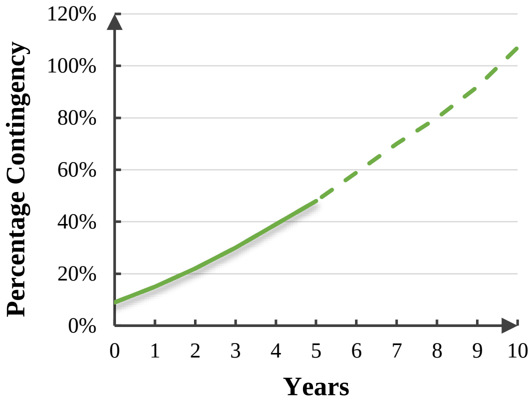
Cost contingency was estimated by the comparison of traditional and probabilistic project cost estimates. Probabilistic estimates had the effects of all the risks incorporated in it, ignored by the traditional estimate. Cost contingency is calculated by the difference between the two estimates to get the cost required to cope with the risks involved. Estimated contingency percentage obtained is added to the base cost estimate to get probable budget at completion (PBAC), without simulating or determining the risks and evaluating its effect before start of every project. Cost contingency factors have been estimated for different time lags between planning and year of actual construction. Cost contingency graphs for three different house sizes, for time lag from 0-5 years are shown in Figure 5.3 (contingency percentage on y-axis and year of construction, after planning, on x-axis). Figure 5.3 shows that as the time lag between planning and the actual execution increases, the cost contingency increases. It was also revealed that cost contingency is directly proportional to the size of the project. As the size of the building increases, the uncertainty associated with it also increases, thus greater amount of contingency is required. The findings of present research nullify the present practice of adding a pre-set percentage (usually 5% for every year) as cost contingency for every project of all the sizes.



(a) 1125 Sft House



(b) 2500 Sft House



(c) 4500 Sft House

Figure 5.3 Cost Contingency Graphs for Different Size Housing Projects

A comparison of the contingency calculated by traditional approach by adding a pre-set percentage value (5% contingency for every year) and probabilistic approach used in present research are presented in Table – 4.

Table - 4 Comparison of Probabilistic Contingency and Traditional Contingency

	Details	**Year - 0**	**Year - 1**	**Year - 2**	**Year - 3**	**Year - 4**	**Year - 5**
	Base Price	7.5	7.5	7.5	7.5	7.5	7.500
Traditional	% Contingency	5%	10%	15%	20%	25%	30%
	Contingency (Rs. in Millions)	.375	.750	1.125	1.500	1.875	2.2500
	Total Cost (Rs. in Millions)	7.875	8.250	8.625	9.000	9.375	9.750
Probabilistic (Present Study)	% Contingency	9%	15%	22%	30%	39%	48%
	Contingency(Rs. in Millions)	.675	1.125	1.650	2.250	2.925	3.6
	Total Cost (Rs. in Millions)	8.175	8.625	9.150	9.750	10.425	11.100
	Actual Cost	8.200	8.700	9.200	9.700	10.500	11.000
Percentage Error	Traditional	-3.98%	-5.22%	-6.28%	-7.18%	-10.79%	-11.26%
	Probabilistic	-0.30%	-0.86%	-0.54%	0.52%	-0.71%	0.91%

Statistics shows that the percentage error value of the traditional cost is fairly high as compared to the probabilistic. This percentage error value is the monetary effect of the risks which traditional approach was unable to interpret. The probabilistic estimate thus developed gave approximate results and will prevent the project to suffer from cost overrun.

5.3 Time Contingency Factor

Time contingency was also developed which addresses the uncertainty that may affect the schedule of a housing project. Time contingency was estimated by quantifying different the time risks to which a projected may be exposed and then incorporating their effect into project`s schedule. Time contingency is obtained by calculating the difference between the duration predicted traditionally and probabilistically. It is added to the project`s schedule to get most probable timeline of the project. Time contingency vary with the size of the project. Greater the size of the project, more will be the covered area, therefore, more will be the risk involved and hence, greater will be the contingency. Graphs were developed for determining time contingency (Figure 5.4) with contingency in days on y-axis and covered area of the building on x-axis. If these contingency days are converted into the percentage, it comes out to be between 17% - 20% of the total duration for housing project, which increases slightly with the increase in size of the project.

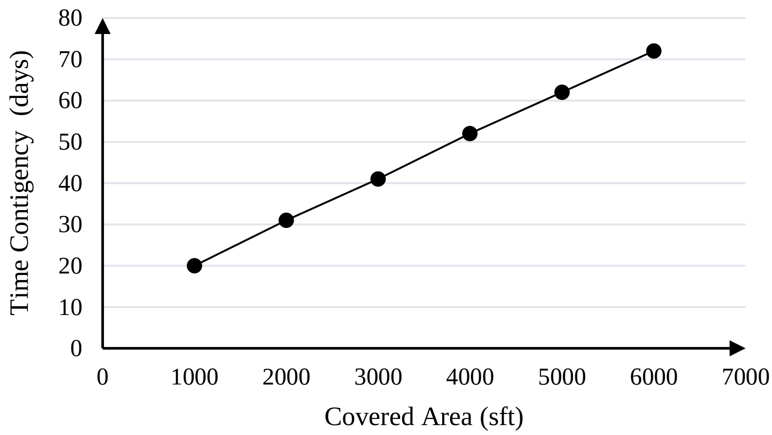


Figure 5.4. Time Contingency Graph

5.4 Chapter Summary and Conclusion

Traditional model was developed using traditional approach commonly practiced in construction industry of Pakistan. It was observed from its performance indices that all projects suffered from cost and time overrun with a varying degree. Literature review suggests that this cost overrun and delay is due to the risk involved in the projects. These risk were identified, quantified and their effect was then incorporated in traditional model to develop probabilistic model. Performance indices which includes SPI and CPI were calculated and their results portrayed that probabilistic model can accurately predict cost and time of the project.

To determine cost contingency for projects, contingency factors were developed. These factors are percentage numerals to be used with the estimated cost to determine the contingency required. They were calculated by comparing the PBAC of the project with TBAC. They were identified for 5, 10 and 20 Marla houses and were plotted on a graph, with risk factor on y-axis and time in years, after the planning date on x-axis. These graphs can forecast the contingency for up to 5 years after the start of planning of projects. Time contingency factors are also identified depending upon the covered area of the project. It is the number of days needed to be added as the time contingency with the schedule to cater for the time uncertainties on its way to completion. More the covered area more will be the value of risk factor.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Synopsis of the Research

This research is mainly focused on improvement of cost estimation and schedule development for housing building projects, duly incorporating the effects of different risks. Major risks that may vary the project cost and schedule were identified and were integrated into risk management framework model. The developed framework thus: (1) analyze those risks and incorporates their effect on budget and schedule, (2) predicts the reliable cost of a given construction project, (3) predicting probable timeline of the project (4) predict precise future project`s cost scenarios, (5) helps project team to design rational contingency reserves.

Present study began with an extensive review of literature in which different techniques for cost estimation, schedule development, risk treatment, and contingencies were critically analyzed. A total of 144 different types of housing projects along with their design specifications, were selected. Project cost estimates and schedule were prepared for the projects based on the practices followed in Pakistan construction industry and their performance was checked using EVM technique. The detailed literature review also helped in identifying project cost and time risks (factors) which commonly lead to project cost overrun and project delay. These risks factors were (1) labor efficiencies, (2) machine efficiencies, (3) material wastages, and (4) construction items' prices, and (5) activity duration.

In order to study the impact of identified risk factor on overall project; data for the risks identified were collected and analyzed. Mean and standard deviation of the data were incorporated into deterministic project model to yield 'Probabilistic Project Cost' and 'Probabilistic Schedule'. The developed model was then validated by comparing predicting project estimates with project`s actual data by calculating the mean absolute percent error (MAPE). Cost and time risk contingency factors were also determined by comparing the traditional estimate and actual data from completed projects. These factors were used to determine cost and time contingency required to cope with the risks involved..

6.2 Research Findings

The major findings from present study are:

a. Detailed analysis of current project contingency reserves techniques revealed that current practice of using fixed percentage of project cost as contingency reserves is an ineffective practice. In order to avoid cost overrun, organizations should preferably have contingency reserves based on the size of the project.
b. Time contingency should also be calculated by considering the risks involved in the project and used with schedule to avoid delays.
c. Use of simulation techniques for prediction of project cost and duration is an effective approach for project cost estimation.
d. Study results revealed that project timeline needs due consideration during project cost estimation. Duration of a project effect the project`s budget.

6.3 Recommendations

Based on analysis and discussions following recommendations are proffered:

a. Project cost and time estimate must give due consideration to the risks involved in the project.
b. Cost and time contingency reserves should be set aside duly considering the size, type of construction of the project, and project durations.

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APPENDICES

Appendix A. Questionnaire – Activities Duration

How many days are required for the completion of following activities in the mentioned size of the houses? Kindly notify the number of labours / skilled workers used for the completion of the activity in the mentioned duration.			
Activity		Duration	No. of Labours
1	Clearing and Grubbing - Levelling and Dressing the ground by cutting and filling earth up to 6" in depth		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
2	Excavation for Foundation in all kind of soil except gravelly and murum soil		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
3	Laying of Concrete in Foundation		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
4	Sand filling, after foundation, in excavation, till plinth		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
5	Assembling of Shuttering for Ordinary Slab 6" thick		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
6	Reinforcement for Ordinary slab 6" thick		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
7	Laying of Concrete for Ordinary Slab 6" thick		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
8	False Ceiling - Single Storey		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
9	Plastering - Internal and External		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
10	Piping for Water Supply and Sanitation		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
11	P.C.C Flooring 1:4:8 over 1:2:4		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		

Appendix A. Questionnaire – Activities Duration (Continued)

12	White Wash - Three Coats		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
13	Terrazzo Flooring - Single Storey - All Rooms		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
14	Tiling on Floor - Single Storey - All Rooms		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
15	Wooden Flooring - Single Storey - All Rooms		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
16	Wood Work including Wardrobe and Doors		
i.	5 Marla		
ii.	10 Marla		
iii.	1 Kanal		
17	Assembling for Shuttering for Lintel (5' wide)		
18	Reinforcement for Lintel (5' wide)		
19	Laying Of Concrete for Lintel (5' wide)		
20	Assembling of Shuttering for Stairs (Ground floor to First Floor - 22 steps - 5' Wide)		
21	Reinforcement for Stairs		
22	Laying of Concrete for Stairs		
23	Assembling of Shuttering for Stairs (Ground floor to First Floor - 22 steps - 5' Wide)		
24	Reinforcement for Stairs		
25	Laying of Concrete for Stairs		
26	Assembling of Shuttering for 7' wide Cantilever Slab		
27	Reinforcement for Cantilever Slab		
28	Laying of Concrete for Cantilever Slab		
29	Assembling of Shuttering for Columns, 9" x 9" , square, 5-6 in number		
30	Reinforcement of Columns		
31	Laying of Concrete for Columns.		
32	Aluminium Work for Windows with fixation of Glass - Average 7,8 windows		
33	Number of Bricks laid by a labour per day up to a height of 5'		
34	Number of Bricks laid by a labour per day above 5'		

Appendix B. Summary of Responses – Activities Duration

Activities	5 Marla	10 Marla	1 Kanal
Preparation of site / Site Cleaning	2.0	4.0	4.0
Excavation	2.0	5.0	6.0
Concrete in Foundation (P.C.C 1:4:8)	2.0	2.0	2.0
Brickwork in Foundation	6.0	13.0	18.0
D.P.C (1:2:4) in Foundation	1.0	1.0	1.0
Sand filling in Excavation	1.0	1.0	1.0
Brickwork in Ground Floor	11.0	19.0	22.0
Lintels - Ground Floor	5.0	12.0	14.0
Beams - Ground Floor	7.0	8.0	8.0
Stairs	25.0	35.0	40.0
Slab on Ground Floor	13.0	15.0	17.0
Brickwork in First Floor	11.0	18.0	22.0
Columns	10.0	12.0	14.0
Beams - First Floor	7.0	8.0	8.0
Lintels - First Floor	7.0	10.0	14.0
Slab on First Floor	13.0	15.0	17.0
Brickwork in Mumty	4.0	4.0	4.0
Lintels - Mumty	7.0	7.0	7.0
Beams - Mumty	7.0	8.0	8.0
Slab - Mumty	13.0	15.0	17.0
RCC Work	15.0	17.0	19.0
Overhead Water Tank	5.0	5.0	5.0
Iron Sheet Roofing	3.0	3.0	3.0
False Ceiling	10.0	14.0	17.0
Plastering	10.0	18.0	25.0
Piping	4.0	9.0	10.0
P.C.C Flooring - Ground Floor	3.0	5.0	6.0
P.C.C Flooring - First Floor	3.0	5.0	6.0
P.C.C Flooring - Mumty	3.0	5.0	6.0
Plumbing Faucet n Fittings	4.0	9.0	12.0
White Wash	10.0	12.0	15.0
Flooring	25.0	30.0	34.0
Skirting	13.0	13.0	13.0
Paint	10.0	12.0	14.0
Facing	7.0	7.0	7.0
Iron , Steel and Al Work	27.0	27.0	27.0
Wood Work	27.0	27.0	27.0
Fixtures	6.0	6.0	6.0
Plumbing Fixtures	6.0	6.0	6.0

Appendix C. Summary - Cost of Completed Housing Projects

Sr. #	Sizes of Project (marla)	Actual Cost in PRS.	Sr. #	Sizes of Project (marla)	Actual Cost in PRS.	Sr. #	Sizes of Project (marla)	Actual Cost in PRS.
1	5	6,000,000	49	5	6,800,000	97	5	6,800,000
2	5	6,000,000	50	5	7,000,000	98	10	9,500,000
3	5	6,200,000	51	5	7,000,000	99	10	9,500,000
4	5	6,200,000	52	5	7,000,000	100	10	9,500,000
5	5	6,200,000	53	5	7,000,000	101	10	9,500,000
6	5	6,300,000	54	5	7,000,000	102	10	9,500,000
7	5	6,300,000	55	5	7,000,000	103	10	9,500,000
8	5	6,300,000	56	5	7,000,000	104	10	9,500,000
9	5	6,300,000	57	7	7,800,000	105	10	9,500,000
10	5	6,300,000	58	7	7,800,000	106	10	9,800,000
11	5	6,300,000	59	7	7,800,000	107	10	9,800,000
12	5	6,300,000	60	7	8,000,000	108	10	10,000,000
13	5	6,500,000	61	7	8,000,000	109	10	10,000,000
14	5	6,500,000	62	7	8,000,000	110	10	10,000,000
15	5	6,500,000	63	7	8,000,000	111	10	10,000,000
16	5	6,500,000	64	7	8,000,000	112	10	10,000,000
17	5	6,500,000	65	7	8,000,000	113	10	10,000,000
18	5	6,500,000	66	7	8,000,000	114	10	10,000,000
19	5	6,500,000	67	7	8,000,000	115	10	10,000,000
20	5	6,500,000	68	7	8,000,000	117	12	10,500,000
21	5	6,500,000	69	10	8,500,000	118	12	10,500,000
22	5	6,500,000	70	10	8,500,000	119	12	10,500,000
23	5	6,500,000	71	10	8,500,000	120	12	10,500,000
24	5	6,600,000	72	10	8,500,000	121	12	11,000,000
25	5	6,600,000	73	10	8,500,000	122	12	11,000,000
26	5	6,600,000	74	10	8,500,000	123	20	12,000,000
27	5	6,600,000	75	10	8,500,000	124	20	12,000,000
28	5	6,600,000	76	10	8,500,000	125	20	12,000,000
29	5	6,600,000	77	10	8,500,000	126	20	12,000,000
30	5	6,600,000	78	10	9,000,000	127	10	9,500,000
31	5	6,600,000	79	10	9,000,000	128	10	9,500,000
32	5	6,800,000	80	10	9,000,000	129	12	11,000,000
33	5	6,800,000	81	10	9,000,000	130	12	11,000,000
34	5	6,800,000	82	10	9,000,000	131	12	11,000,000
35	5	6,800,000	83	10	9,000,000	132	20	11,000,000
36	5	6,800,000	84	10	9,000,000	133	20	11,000,000
37	5	6,800,000	85	10	9,000,000	134	20	11,000,000
38	5	6,800,000	86	10	9,000,000	135	20	11,000,000
39	5	6,800,000	87	10	9,000,000	136	20	11,000,000
40	5	6,800,000	88	10	9,200,000	137	20	11,000,000
41	5	6,800,000	89	10	9,200,000	138	20	11,000,000
42	5	6,800,000	90	10	9,200,000	139	20	11,000,000
43	5	6,800,000	91	10	9,200,000	140	20	11,000,000
44	5	6,800,000	92	10	9,000,000	141	20	11,000,000
45	5	6,800,000	93	10	9,200,000	142	20	11,000,000
46	5	6,800,000	94	10	9,200,000	143	20	11,000,000
47	5	6,800,000	95	10	9,200,000	144	20	11,000,000
48	5	6,800,000	96	10	9,200,000			

Appendix D. Questionnaire - Effect of Labor Efficiency on Project Estimate

1. Amount of work done by a Mason per day in:
    - Bricks laid
    - Concreting on roof
    - Concreting on floor
    - Plastering with cement (sq ft) (12 mm or ½”)
    - R.C.C work in beams and slab (cu ft)
    - 6 mm Mosaic floor work over 2 cm thich cement concrete (sq ft)
    - 2.5 cm thick cement concrete Laying of D.P.C (sq ft)
2. Amount of work done by a Labor (Mazdoor) per day in:
    - Mixing concrete
    - Deliver bricks up to a distance of 50’
    - Breaking of brick ballast (25mm) (cu ft)
    - Earthwork in excavation, ordinary soil (cu ft)
    - Earthwork in excavation, rock (cu ft)
    - Sand filling 2inch in foundations, width= 4 ft wide (Rft)
    - Refilling excavated earth in foundation (cu ft)
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
    - Holdfast per day
4. Amount of work done by a White Washer per day in:
    - 3 coats white washing (sq ft)
5. Amount of work done by a Painter per day in:
    - One coat paint (sq ft)
    - Paint two coats on wood (sq ft)
6. Amount of work done by a Carpenter in:
    - No. of door timber frames completed per day(1.6 sq.ft per frame)
    - No. of days required to complete one door shutter (2.66 sq.ft per shutter)
    - Shuttering (erection and dismantle) (cu ft)
7. Amount of work done by a Polisher per in mosaic flooring (sq. ft)
8. How much days it takes for a Plumber to complete the plumbing work of 10 Marla house.
9. How much days it takes for an Electrician to complete the electric work of 10 Marla house.

Appendix E. Questionnaire - Effect of Machine Efficiency on Project Estimate

1. How much material will be loaded by a Front End Loader of blade 2.3 m^3 in one hour?

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

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

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

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

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

7. How much Concrete will be produced by Concrete Batching Plant of capacity 30 m^3 in one hour?

8. How much Concrete will be produced by Concrete Transit Mixer of capacity 4.5 m^3 in one hour?

9. How much Concrete will be produced by Concrete Static Mixer of capacity 1 m^3 in one hour?

Appendix F. Labor`s Efficiency Responses

S No	Details	Quantity	Units/day
Mason output			
1	Bricks laid	769	No.
2	2.5 cm thick cement concrete Laying of D.P.C	103	Sq. ft.
3	Plastering with cement (12 mm or ½”)	87	Sq. ft.
4	6 mm Mosaic floor work	44	Sq. ft.
5	Concreting on roof	144	Sq. ft.
6	Concreting on floor	235	Sq. ft.
7	R.C.C work in beams and slab	108	Cu. ft.
Labor output			
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 foundation	144	Cu. ft.
Steel Fixer output			
14	Reinforcement work for R.C.C	1.3	cwt.
15	Holdfast per day	26	No.
White Washer / Painter output			
16	3 coats white washing	570	Sq. ft.
17	One coat paint	245	Sq. ft.
18	Paint two coats on wood	38	Sq. ft.
Carpenter output			
19	No. of door timber frames completed per day	0-2	Days
20	No. of days required to complete one door shutter	0-2	Days
21	Shuttering (erection and dismantle)	32	Cu. ft.
22	Amount of work done by a Polisher in flooring	6	Sq. ft.
Plumber output			
23	Days taken by a Plumber to complete the plumbing work of 10 Marla house.	17	Days
Electrician output			
24	Days taken by an Electrician to complete the electric work of 10 Marla house.	18	Days