ESTIMATED COST AT COMPLETION: INTEGRATING RISK INTO EARNED VALUE MANAGEMENT

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by

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thesis titled

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This thesis is dedicated to my Mother and Father.

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Abstract

Earned Value Management (EVM) developed in the 1960s is a technique used in monitoring the performance of ongoing projects. Performance Measurement Baseline (PMB) is setup at the start of the project and time and cost deviations in project performance are measured with reference to the PMB. Based on the current progress of the project, the estimated cost at completion is estimated.

Project Risk Management (PRM) deals with the risks that may alter the project's objectives which are mainly cost, time, quality and scope. Construction industry has lots of uncertainties so PRM has been identified as one of the most crucial techniques to accomplish project objectives.

EVM only focuses on the project schedule (Schedule Performance Index) and cost (Cost Performance Index), and does not address other important aspects such as quality, safety, risk, customer satisfaction, etc. Introducing performance indices to measure other key aspects of the project will give the stakeholders a better monitoring and decision making capability.

In order to estimate better EAC using EVM, a framework is developed that interconnects these various performance indices and uses their results to estimate project EAC. Also, critical success factors (CSFs) are identified for construction projects and a framework for their monitoring is established. Forecasting a better EAC during the construction period is achieved and validated using case studies.

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LIST OF ABBREVIATIONS

BAC	**Budgeted At Completion**
CAC	**Cost At Completion**
CPI	**Cost Performance Index**
EAC	**Estimate At Completion**
ETC	**Estimate To Complete**
EVM	**Earned Value Management**
KPI	**Key Performance Indicators**
PI	**Performance Indicators**
PMI	**Project Management Institute**
PRM	**Project Risk Management**
QPI	**Quality Performance Index**
RM	**Risk Management**
RPI	**Risk Performance Index**
SPI	**Schedule Performance Index**
WBS	**Work Breakdown Structure**

Chapter 1

1. INTRODUCTION

1.1. PREAMBLE

Increase in quality of decisions will eventually increase the performance of the project resulting into success. Therefore it is necessary to improve decision making. Thus the basic goal of project management is to refine the quality of decisions by revealing the original extent of risk involved and presenting the facts and figures to the decision makers (Diamantas et al., 2011).

As Project Risk Management (PRM) and Earned Value Management (EVM) have similar goals, i.e. providing information to the decision makers to increase the quality of the decisions, there is a strong need and incentive in streamlining their results. However there is a research gap between the two methods; results obtained from both the methods are used separately due to which they lose their efficiency. Some research work has been conducted on combining the two approaches (for example Barraza et al., 2000; Hilson, 2004; APM, 2008). This research constitutes a different approach for integration of these two methods i.e. adding risk factor when calculating estimate at completion for more realistic results.

PRM and EVM are executed as separate processes so there is quite a need to integrate both of them to make sure the data is used properly which is acquired from each of the methods for achieving project success. Quantification of various risks in terms of cost during different stages of the project is very important as well as challenging task and due to non-availability of any specific method to integrate it with the widely used method of EVM, there is a need to integrate both the methods so better estimate at completion can be estimated. The costs of various risks incurred during the project life results in the cost overruns, time overruns, and disputes causing problems for the stakeholders. (Hilson, 2004)

The research will focus on data collection, modelling and integrating earned value management with risk management to calculate better estimate at completion.

1.2. PROBLEM STATEMENT

This study deals with the integration of PRM and EVM to fill the gap between the two approaches so that project managers are in better position to take decisions hence improving the project performance. One of the most common problems faced in construction industry is cost and time overrun which clearly indicates a gap in planning, monitoring and controlling methods. One of the reasons why many projects are either under budgeted or over budgeted is the lack of knowledge about the project with the project manager. Using the results from the research we will be able to forecast better estimate at completion which will be covering risk factors and other project costs, which in turn will provide information for better project monitoring and control.

EVM mostly focuses on schedule and cost aspects of the project and does not consider other important constraints of the project like quality, scope, safety, risk, etc. A project can be in time and under budget but may be facing quality issues or scope requirements are not being fulfilled but EVM will be depicting that the project is going well which actually is facing problems. We need to involve other key performance indices as well in our monitoring tool so that we can depict clearer and broader aspects of the project along with cost and schedule, so to overcome this problem we need a new performance index along with Cost Performance Index (CPI) and Schedule Performance Index (SPI).

1.3. RESEARCH OBJECTIVES

The objectives of our study are:

- To identify performance indicators affecting the cost at completion.
- To analyse the data and develop a model for Risk Performance Index (RPI) incorporating these PIs.
- To develop an empirical relation incorporating the RPI and EVM for estimating better cost at completion.

1.4. RESEARCH QUESTION

What information project managers need in order to estimate with confidence the cost at completion during project execution?

How the risk performance influences the cost at completion?

1.5. SIGNIFICANCE OF STUDY

The study is of important nature due to possible effect at accommodating different risks in terms of costs and integrating them with EVM to estimate a better EAC during different stages of construction. The developed model will be accommodating various risk factors related to construction quality, safety, stakeholder satisfaction and other important risks that projects usually face during the construction period. This research can be used later on for forecasting better EAC for construction projects and to monitor and ovoid cost over runs so that stakeholders can take better decisions.

1.6. THESIS OVERVIEW

This thesis has been organized into five chapters.

Chapter 1 is ‘Introduction.’ It includes introduction to the research, problem statement, scope of the study and study objectives. It provides a general overview to the research.

Chapter 2 is ‘Literature Review.’ It explains the previous studies done concerning the research providing essential information related to EVM, RM and PIs concerning quality, safety and stakeholder satisfaction.

Chapter 3 is ‘Methodology’ of research. It explains how the research is conducted to obtain our research design.

Chapter 4 is ‘Data Analysis, Results and Discussion’ it covers the analysis of data after being collected, modeling and results according to our research objectives. It also discusses in detail how our objectives are achieved from using our analyzed data. It explains how our collected and analyzed data is interpreted to produce the results which interpret achievement of our objectives.

Finally, Chapter 5 is ‘Conclusions and Recommendations.’ Final conclusions and recommendations have been summarized in this chapter.

2. LITERATURE REVIEW

2.1. BACKGROUND

This chapter discusses the past work done related to the research being carried out. It entails a discussion on the EVM, PRM, KPIs and EAC. Also, linking the literature related to integration of earned value management and risk management.

2.2. EARNED VALUE MANAGEMENT (EVM)

"*The performance measurement to report the status of a project in terms of both cost and time at a given data date"* (Popescu and Charoenngam, 1995).

EVM was developed in 1960s as a financial management tool by U.S. Department of Defense (DOD) which integrated project cost and schedule control for monitoring of defense projects. This method is based on combing the project's cost and schedule in a single measurement system and is one of the most widely method for monitoring and forecasting project cost and schedule performance (Mubarak, 2015).

EVM is based on the technique of quantifying the technical performance of a running project and combining it with time and cost. It is a dynamic tool that allows unbiased monitoring of the project status which is compared with the baseline plan, variances are tracked and final cost is forecasted which is based on the past performance of the project (Narbaev and De Marco, 2013).

EVM is based on two steps, first is setting up a PMB and second is inspecting the project performance with reference to PMB (De Marco and Narabaev, 2013).

The basic steps involved in EVM to monitor and control project performance at any point according to Mubarak (2010) are determining the actual work done and how much was the planned work to be done. Calculating the amount you have spent and the amount earned. Determining the schedule and budget variances till the data date. Inspect the root causes for major variances and deciding possible remedies. On the basis of these variations forecast the cost and schedule figures by the end of the project.

Figure 2.1 Typical S-curve

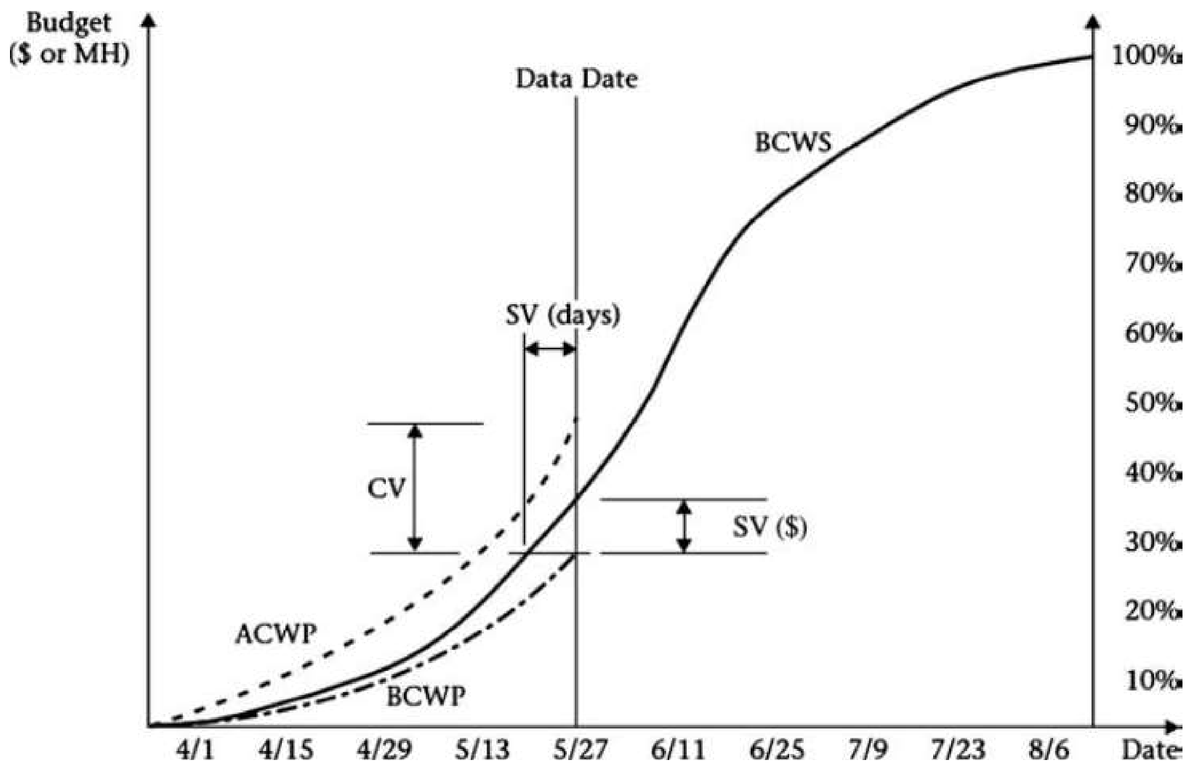


Figure 2.1shows the S-curve comparison between the Budgeted Cost Work Schedule (BCWS) or the planned value, Budgeted Cost Work Performed (BCWP) or earned value and Actual Cost Work Performed (ACWP) or the actual value depicting the graphical representation of Cost and Schedule Variance.

EVM is used to predict cost Estimate at Completion (EAC) based on the current progress and performance. The actual status of the project is compared with a plan and deviations are tracked from the project baseline and the final cost at completion and time is forecasted (Narbaev and De Marco, 2013).

According to Fleming and Koppelman (2006), Kim and Reinschimdt (2010), Tracy (2005) and Zwikael et al. (2000) the technique has three primary limitations in forecasting EAC:

- Using past cost performance only for forecasting
- Undependable forecasted figured at the start of the project
- No count of forecasting statistics

The three basic methods to calculate EAC are following:

2.2.1. Traditional Index based EAC:

Use of EVM techniques and can be modified further by assigning complementary weights to CPI and SPI for better result prediction (Narbaev and De Marco, 2011).

2.2.2. EAC with Statistical Tools:

Using statistical tools we can prevail over the restrictions of the traditional methods and have the advantage of addressing quality of project, estimates based on probabilities, risk consequences and undefined scope of work by increasing the confidence level we achieve accurate forecasting at even 10% completion (Lipke et al., 2009)

2.2.3. Simulation based EAC

Simulation based method is an alternative approach for both traditional and statistical methods. This method is of great use for forecasting EAC at the start of the project (Mizell and Malone, 2007).

2.3. PROJECT RISK MANAGEMENT (PRM)

"*Project risk has been defined as an uncertain event or condition that, if it occurs, has a positive (opportunities) or a negative (threats) effect on at least one project objective such as time, cost, scope, or quality"*(PMI, 2013, p.309).

PRM deals with the risks that may alter the project's objectives which are mainly cost, time, quality and scope. According to Project Management Book of Knowledge (PMBOK) PRM consists of steps which are planning, identification, analysis, responses and monitoring and control on a project.

There is a lot of uncertainty in construction projects and PRM has been identified as a crucial technique to accomplish project's objective that are cost, time, quality, safety, etc. PRM is an iterative process and is only helpful when it is carried out during the whole construction project's lifecycle i.e. from the planning stage to the completion (Banaitieneand Banaitis, 2012).

There are two types of risk analysis, namely qualitative risk analysis and quantitative risk analysis.

2.3.1. Qualitative Risk Analysis

Qualitative risk analysis is a risk assessment technique which is based on finding the probability of the occurrence of the risk event and its impact on the project. Each risk has probability and Impact. The likelihood that a risk event will take place is called its probability and impact is the significance of consequences of that risk event. Impact usually affects the project aspects that include schedule, scope, resources, quality, performance, cost, deliverables, and performance (Dumbravă and Iacob, 2013).

According to Heldman (2010) some of the techniques used to perform qualitative risk analysis include brainstorming, interviewing, use of historical data, strength weakness opportunity and threats analysis and risk rating scales.

2.3.2. Quantitative Risk Analysis

Quantitative risk analysis is a risk assessment tool which quantifies the risk of major hazards. The parameters the risk are defined and modelled using specialty software. Some of the techniques used for quantitative risk analysis are fault trees, HAZOP's, FMEA's, etc. (Vose, 2008).

Risk is described as probability of exposure to gain or loss multiplied by its quantity. Risk events can have a maximum probability of 100 percent to be a certain event or at least probability of 0 percent to be totally uncertain (Iqbal et al., 2015).To a certain level, each activity we do has some risk present in it. There are many kinds of risk e.g. business, safety, social, political, investment, ecological, military, etc. The more risk an activity has, the more cost it would incur if a wrong decision is made in its regard (Jannadi and Almishari, 2003).

Risk cause projects money and time and due to that very reason, stakeholders especially clients and contractors have suffered a lot (Zavadskas et al., 2010; Hameed and Woo, 2007). PRM is an important tool in construction industry, based on its results decisions are made. Construction inherits more risks due to nature of its projects and the level of risks that stakeholders are exposed to (Iqbal et al., 2015).

2.4. EARNED VALUE MANAGEMENT AND RISK MANAGEMENT

Barraza et al. (2000) stated that although many highly developed probabilistic planning methods have been developed but still no method is available for project's performance measurement which integrates cost, duration and progress data while taking into account risks in that activity. To overcome this disadvantage Barraza et al. (2000, 2004) developed technique for probabilistic monitoring and forecasting of project performance.

The approach suggested by APM (2008) was based on interfacing the two methods rather than integrating them. The difference between APM's approach and that of Barraza et al. (2000) and Hillson (2004) is that the PMB will use percentile of the project Probability Density Function (PDF) rather than expected value method, using which contingency reserve can be estimated. The PDF for both the time and cost is calculated using Monte Carlo Simulation (MCS).

EVM and PRM are effective tools that provide us the understanding of the factors that are affecting the performance of the project but there is unavailability of framework that interconnects the results obtained from both tools. As same problems are being addressed by both these tools and are providing information about the actions which should be taken so it can be very useful if the results obtained from both the tools are combined. If the performance management baseline consists of a well equated risk factor, we will be able to estimate better contingency reserve and foresee the uncertainties in the project which in terms means that a better cost at completion can be estimated (Hilson, 2004).

If time and cost risk analysis is performed and the identified risks are then quantified i.e. they are taken in terms of cost and these costs are then summed up with the estimated project baseline in terms of contingency so that we can use that new baseline for monitoring project's status and estimating projects cost at completion, we will be having better and more accurate results which will be portraying the project risks as well. These results can only be obtained when we have the results from both the tools i.e. RM and EVM in same units which is cost i.e. dollars etc. (Hilson, 2004).

Risk and EV Management share common frameworks. EVM requires a Work Breakdown Structure (WBS) which contains timescales, costs, budgets and product definitions, when this WBS is combined with an OBS we get a proper structure for identification of risks to setup objectives, to determine ownership and developing and managing mitigation plans. Before the contract awarding phase, a well performed risk based analysis of the drafted PMB will depict more reasonable contingency amount and will also provide better knowledge about the risks involved in the project therefore we can estimate more accurate cost at completion (Risk Decision, 2003).

2.5. KEY PERFORMACE INDICATORS (KPIs)

Cox et al. (2003) found out that in terms of effectiveness, efficiency and quality of work, KPIs play a key role to relate the actual and scheduled performance. KPIs can be stated as collection of measurable data, which can be qualitative or quantitative, that can provide us an insight to the performance of any construction project.

Kim (2010) has identified seven KPIs on which performance should be measured and these KPI's comprise of duration, cost, quality, customer satisfaction, design change, project performance, health and safety. Furthermore Kim also defined Risk Performance Index (RPI) which mainly constitutes of schedule risk performance index and cost risk performance index.

Lee et al. (2013) identified KPIs for assessing quality of expressway construction. He used these KPIs to develop Quality Performance Index (QPI). The KPIs identified were divided into two major groups; durability and functionality. By conducting a pilot survey weight for each of these identified items were obtained and used in the development of QPI formula.

Yasamis et al. (2002) divided construction quality into project and corporate level. Project level deals with quality plans, quality assurance and quality control whereas the corporate level deals with the total quality management systems of the organization. The KPIs of project level were divided into two groups, product and service product i.e. the constructed facility and service i.e. the contract planning.

Mostly contractors measure construction safety by Occupational Safety and Health Administration (OSHA), Recordable Injury Rate (RIR), Days Away Restricted work or Transfer (DART) injury rate; or the Experience Modification Rating (EMR) on worker's compensation after losses have occurred and budget evaluation have been made. Furthermore performance indicators were divided into leading and lagging indicators where leading indicators can be used to predict the safety levels in future and lagging indicators give information about the incidents already occurred (Grabowski et al., 2007).

Leading and lagging indicators differ by their focus group as leading indicators are mainly focused at individual or a group level and lagging indicators are wide ranging and focus on company level actions. Lagging indicators are rarely focused on individual conduct where as the leading indicators are more pinpointed towards individuals or small units (Grabowski et al., 2007).

Hinze et al. (2013) divided leading indicators into two main heads passive and active indicators. Passive indicators provide an indication of likelihood of safety performance within a company or on a project. These indicators can be predictive on large scale only as they are not much effective on predicting over a short term time span. Active indicators are the type of indicators which change over a short period of time.

2.6. LIST OF INDENTIFIED PERFORMANCE INDICATORS

Performance Indicators (PIs) identified from extensive literature review.

Table 2.1 List of PIs

Serial No.	**Performance Indicators (PIs)**	**References**
	Stakeholder Satisfaction	
1	Client Satisfaction	(Jastaniah, 1997 ; Egan, 1998 ;Yasamis et al.,2001; Chan, 2001; Kagioglou et al., 2001; Takim and Akintoye, 2002;Xiao and Proverbs, 2002;Bassioni et al., 2004; Ling and Peh, 2005;Swan and Kyng, 2005; Nudurupati et al., 2007; Kaluarachchi and Jones, 2007;Kim and Huynh, 2008; Horta et al., 2009; Dawood, 2010;Ogunlana, 2010; Radujković et al., 2010; Suk et al., 2011; Hegazy, 2012;Famakin and Ogunsemi, 2012; Wai et al., 2012; Jin et al., 2013; Pandremmenou et al., 2013; Zhai et al., 2013; Alumbugu et al., 2015; Carvalho and

		Rabechini Junior, 2015)
2	Conflicts / Disputes/ Claims	(Jastaniah, 1997 ;Takim and Akintoye, 2002; Sohail and Baldwin, 2004; ; Lam et al., 2008; Yeung et al., 2007, 2009 ;Ogunlana, 2010; Radujković et al., 2010; Suk et al., 2011)
3	Change Orders	(DETR, 2000; Kaluarachchi and Jones, 2007; Radujković et al., 2010; Suk et al., 2011; Cha and Kim, 2011;Lamptey and Fayek, 2012; Malek Akhlagh et al., 2013; Alumbugu et al., 2015)
	Quality	
4	Rework / Defects	(Egan, 1998 ;Kagioglou et al., 2001; Kagioglou et al., 2001; Xiao and Proverbs, 2002;Takim and Akintoye, 2002; Cox et al., 2003; Bassioni et al., 2004; Sohail and Baldwin, 2004; Ling et al., 2004; Ling and Peh, 2005;Swan and Kyng, 2005; Kaluarachchi and Jones, 2007; Skibniewski and Ghosh, 2009; Ogunlana, 2010; Radujković et al., 2010; Dawood, 2010;Suk et al., 2011; Lamptey and Fayek, 2012; Hegazy, 2012;Ali et al., 2013; Alumbugu et al., 2015)
5	Quality systems	(Woodward, 1997; Yasamis, F. et al.,2001;Xiao and Proverbs, 2002;Kim and Huynh, 2008;Almahmoud et al.,2012)
6	Materials quality	(Woodward, 1997; Anderson and Russell, 2001; Cox et al., 2003;Kim and Huynh, 2008)
7	Meeting specifications	(Ogunlana, 2010; Almahmoud et al.,2012; ; Carvalho and Rabechini Junior, 2015)
8	Wastage	(Ling and Peh, 2005; Kaluarachchi and Jones, 2007; Cha and Kim ,2011)
9	Non Conformance Rate	(Costa et al.,2006; Cha and Kim ,2011)
10	Personnel quality training	(Costa et al.,2006; Yasamis, F. et al.,2001)
11	Batcher and Crusher Plant Management	(Ling et al., 2004; Lee et al., 2013)
12	Pavement thickness	(Anderson and Russell, 2001; Lee et al., 2013)

13	Compressive strength of concrete	(Anderson and Russell, 2001; Lee et al., 2013)
14	Operational quality planning	(Yasamis, F. et al.,2001)
15	Contractor’s technical expertise	(Ling et al., 2004)
16	The design process	(Woodward, 1997)
17	Quality inspection	(Yasamis, F. et al.,2001)
18	Check listing	(Yasamis, F. et al.,2001)
19	Quality Control charts	(Yasamis, F. et al.,2001)
20	Strategic quality management	(Yasamis, F. et al.,2001)
21	Corporate quality culture	(Yasamis, F. et al.,2001)
22	Project assembly on site (construction)	(Woodward, 1997)
23	Flexural strength	(Anderson and Russell, 2001)
24	W/C ratio	(Anderson and Russell, 2001)
25	Asphalt Content	(Anderson and Russell, 2001)
26	Compaction Density	(Anderson and Russell, 2001)
27	Air void spacing coefficient	(Lee et al., 2013)
28	Asphalt pavement performance	(Lee et al., 2013)
29	Bridge and pavement roughness	(Lee et al., 2013)
30	Cracking rate of abutment wall culvert	(Lee et al., 2013)
31	Expansion joints performance	(Lee et al., 2013)
32	Expediting Operability/safety/value reviews	(Yasamis, F. et al.,2001)
33	Constructability review and Audits	(Yasamis, F. et al.,2001)
34	Flowcharting, Cause and effect diagramming	(Yasamis, F. et al.,2001)
35	Quality Metrics development	(Yasamis, F. et al.,2001)

	Safety	
36	Accident frequency ratio	(Chan et al., 2002; Cox et al., 2003; Beatham et al., 2004; Fang et al., 2004; Chan and Chan 2004; Ramirez et al., 2004; Ling and Peh, 2005; Lee et al., 2005; Costa et al., 2006; Nudurupati et al., 2007; El-Mashaleh et al., 2007; Yeung et al.,2007, 2009; Lam et al., 2008; Cha and Kim, 2011; Janackovic et al., 2013)
37	Safety training	(Cooper and Cotton, 2000;Toole, 2002; Fang et al., 2004; Tam, et al., 2004; Fang et al.,2006; Cha and Kim ,2011;Janackovic et al., 2013)
38	Toolbox meetings	(Fang et al., 2004; El-Mashaleh, et al., 2010; Hinze et al.,2013; Janackovic et al., 2013)
39	Jobsite pre-task planning	(Fang et al., 2004; Hinze et al.,2013;Janackovic et al., 2013;)
40	Number of management personnel with standard certification.	(Fang et al., 2004; Hinze et al.,2013;Janackovic et al., 2013)
41	Safety equipment and Maintenance	(Toole, 2002; Tam, et al.,2004)
42	Percentage of new workers on site	Fang et al., 2004;
43	Involvement of contractor top management	(Fang et al., 2004)
44	Subcontractor's selection on the basis of satisfying specific safety criteria	(Hinze et al.,2013)
45	Approved site specific safety program	(Hinze et al.,2013)
46	Involvement of contractor top management	(Hinze et al.,2013)
47	Random drug tests	(Hinze et al.,2013)
48	Number of close calls reported	(Hinze et al.,2013)
49	Safety audits	(Hinze et al.,2013)
50	Owner promoting job site safety	(Hinze et al.,2013)
51	Evaluation of worker observation records to determine the need for job site changes in the job safety program	(Hinze et al.,2013)
	Others	
52	Land Acquisition	(Radujković et al., 2010)

53	Supplier relationship	(Yasamis, F. et al.,2001)
54	Communication of information	(Yasamis, F. et al.,2001)
55	Project management activities	(Woodward, 1997)

2.7. ESTIMATE AT COMPLETION (EAC)

Projects during their execution phase may deviate from their original planned cost therefore the project team forecasts the EAC which differs from the BAC and is based entirely on the current performance of the project (PMI, 2013).

Although many studies have been conducted on forecasting EAC which use the standard EAC formulas and other models, there has been no guideline regarding which formula or model gives most accurate results. It is left with analysts and project managers to decide which EAC formula to use (Christensen et, al, 1992).

As per PMI (2013) the three of the most common EAC forecasting techniques for Estimate To Complete (ETC) are given below

1. **EAC forecast for ETC work performed at the budgeted rate**

This method uses the actual cost till data date and predicts that the rest of the project will be executed at the planned rate.

$$EAC = AC + (BAC - EV) \qquad \text{Equation 2.1}$$

2. **EAC forecast for ETC work performed at the present CPI**

This method considers the current CPI of the project and assumes that rest of the project will complete at current rate.

$$EAC = BAC / CPI \qquad \text{Equation 2.2}$$

3. **EAC forecast for ETC work considering both SPI and CPI factors**

This forecasting equation considers both the SPI and CPI of the project and is mostly useful when the schedule of the project is an impacting factor. Variations can also be done to this method by assigning complimentary weight to each index as per the project manager's decision, and the sum of these weightings must be equal to 1.

$$EAC = AC + [(BAC - EV) / (CPI \times SPI)] \qquad \text{Equation 2.3}$$

3. METHODOLOGY

3.1. INTRODUCTION

The findings of literature review provide an overview of EVM, PRM, contingency management, integration of risk management with earned value management and PIs. Methodology of this thesis is given in detail in this chapter.

Methodology will help us define a way to achieve the objectives of this research as stated in Chapter 1. This research was done in six distinct phases as stated under the heading of “Research Design”.

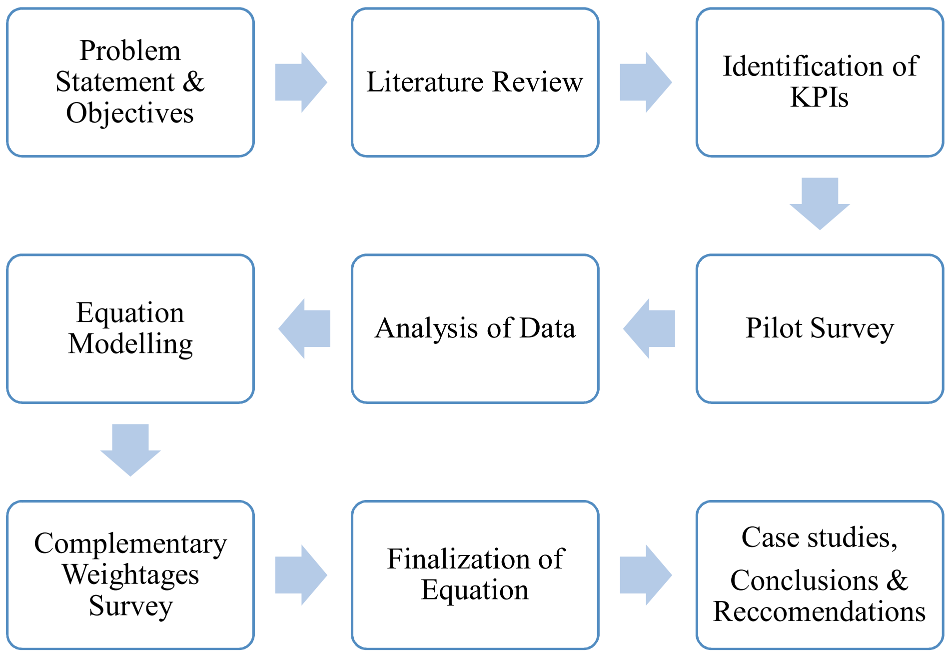
3.2. RESEARCH DESIGN

In first phase, after development of research proposal, extensive literature review was done to understand the basics of EVM, PRM, contingency management and KPIs. Google Scholar was mainly used as search tool for different scholarly papers and writings.

In second phase, a pilot survey was conducted to rank the identified KPIs. Ranking these KPIs helped in limiting the scope and complexity of the research to current academic level and need. In the third phase, weightings of the PIs obtained from the pilot survey were used to form an equation for RPI. Using the RPI equation, equation for EAC was generated.

In the fourth phase, survey was conducted to get the complementary weightings assigned to each index in EAC equation. The inputs from the survey were used to finalize the EAC equation. MS Excel was used to model the equation. In fifth phase, input data for our model was collected from various construction projects and results were obtained from the model. In the last phase, conclusions and recommendations were given.

Figure 3.1 Flowchart



3.3. COLLECTION OF PERFORMANCE INDICATORS

The performance indicators were collected from scholarly papers regarding KPIs of construction quality, safety and stakeholder satisfaction. Over 136 writings were collected and 57 were found relevant giving a relevance index of 41.9%. A total of 55 factors were identified as a result. These 55 factors were divided into four groups namely quality, safety, stakeholder satisfaction and others.

3.4. PILOT SURVEY

To rank and find weightings of the identified Performance Indicators (PIs) a pilot survey was conducted. Respondents were asked to rank the PIs on a rating scale of -3 to +3 where -3 represents maximum negative effect (increasing the cost of the project), +3 represents maximum positive effect (not increasing the cost of the project) and 0 represents no effect. The questionnaire forms were dispatched online via emails, social and professional websites. In total 39 respondents filled in the questionnaire form from different countries of the world. Statistical analysis tests including Anderson Darling normality test, Cronbach's Alpha test for reliability of data and to find correlation between the frequencies of identified factors in literature and pilot survey Spearman's Rho test was applied. Using Equation 3.1 Relative Importance Index (RII) of the factors within their respective groups was evaluated.

$$RII = \frac{\sum W}{A \, x \, N} \quad (0 \leq RII \leq 1) \qquad \textit{Equation 3.1}$$

Where 'W' is the weight given to each factor by the respondents, 'A' is the highest weight i.e. 3 in this case and 'N' is the total number of respondents. Muhwezi et al. (2014) considered factors having RII less than .599 insignificant but to incorporate impact of more factors in the equation, factors having RII less than 0.50 were considered insignificant. A total of 16 factors having RII > 0.5 were considered for the study.

3.5. DEVELOPMENT OF EQUATION FOR RISK PERFORMANCE INDEX

The identified PIs were divided into groups so the equation to calculate the Risk Performance Index (RPI) will constitute the factors within these identified groups. The value of a particular group is the summation of the individual weight of a variable multiplied with the perspective PI value which is provided by the user, based on the performance of the project (ranging from 0-1). The value of RPI is calculated by adding these individual group values multiplied with their respective group weightings. Equation 3.2 illustrates the generalized form of the RPI equation.

$$RPI = \omega_1[\sum_{i=1}^{n} \alpha_i K_i] + \omega_2 \left[\sum_{\substack{i=1 \\ j=n+1}}^{m} \beta_i K_j\right] + \omega_3 \left[\sum_{\substack{i=1 \\ k=m+1}}^{p} \gamma_i K_k\right] + \omega_4 \left[\sum_{\substack{i=1 \\ l=p+1}}^{q} \rho_i K_l\right] + \cdots \infty$$

$$(0 \leq RPI \leq 1) \; \textit{Equation 3.2}$$

Where ω_1,ω_2, ω_3, ω_4 are the group weightings, 'K_i','K_j','K_k', 'K_l' are perspective value of PIs at that point in project execution ranging from 0 to 1 and α_i, β_i, γ_i, ρ_i are the internal weightages of the respective variables.

3.5.1. Incorporation of quality performance indicators in equation

After finding the RII of the results obtained from the pilot survey, five PIs in the quality group had RII > 0.50 so they were considered significant to be incorporated in the equation. Rework / defects (K_1) was relatively the highest ranked PI so to input its effect in the equation, 0 to 1 input range was selected where 1 represents no rework /defect, a value can be inserted between 0 and 1 as per the actual status of rework/ defects on project site. Similarly If quality systems (K_2) were made as per the specific project specification requirements for all tasks input will be 1, for no such system input will be zero and for partial availability of these systems for the construction site user can input value between 0 and 1 as per the project site status. Periodic quality trainings (K_3) being held for the concerned personnel input 1 else 0, the input by the user will have 34% weight age while 33% of its input will be from the value of (K_4) and 33% of the weight age from (K_1). Similarly for Nonconformance rate (K_4) input will be zero for no non conformance report being issued and user to input the value as per the frequency of such reports being issued on site. Strategic quality management (K_5) is how actively the top management of the company is to achieve long term Client's quality requirements and is not relying completely on the quality team but is actively participating in auditing the quality systems, making operational plan and strategic goals, on its activeness on said issues input will be 1, a value between zero to 1 can be used as per the company situation. Equation 3.3 illustrates the incorporation of quality KPIs along with their respective weightings.

$$\omega_1[\alpha_1 K_1 + \alpha_2 K_2 + \alpha_3(0.34K_3 + 0.33K_4 + 0.33K_1) + \alpha_4 K_4 + \alpha_5 K_5] \qquad \textit{Equation 3.3}$$

Where ω_1 the collective group weightings assigned to the quality factors is, $\alpha_1, \alpha_2, \alpha_3, \alpha_4$ are the internal weight of each PI which are represented by K_1, K_2, K_3, K_4 and K_5.

3.5.2. Incorporation of safety performance indicators in equation

After finding the RII of the results obtained from the pilot survey, four PIs in the safety group had RII > 0.50 so they were considered significant to be incorporated in the equation. If adequate number of standard certified safety personnel (K_6) are present on site input 1 and 0 for no safety personnel, a value can be the input as per the percent of availability of such persons on site, the user input value will have 50% weight while the other 50% will be the value of K_7 . Accident frequency ratio (K_7) on site, 0 for no accidents and similarly user will input a value between 0 to 1 as per the accident frequency at site. If all the required personnel protective equipment (K_8) is being used on site and it checked and maintained on regular basis input will be 1 and 0 if no equipment is used, a value can be put between 0 to 1 as per percent of the availability of PPEs on site. Hands on safety trainings (K_9) to all site staff on regular basis the input will be 1 and 0 for no such input. Equation 3.4 illustrates the incorporation of safety KPIs along with their respective weightings.

$$\omega_2[\beta_1(0.5K_6 + 0.5K_7) + \beta_2 K_7 + \beta_3 K_8 + \beta_4 K_9] \qquad \textit{Equation 3.4}$$

Where ω_2 is the collective group weightage assigned to the safety factors, $\beta_1, \beta_2, \beta_3, \beta_4$ are the internal weightage of each KPIs which are represented by K_6, K_7, K_8, K_9 and K_{10}.

3.5.3. Incorporation of stakeholder satisfaction performance indicators

After finding the RII of the results obtained from the pilot survey, three PIs in the stakeholder satisfaction group had RII > 0.50 so they were considered significant to be incorporated in the equation. Number of change orders (K_{10}) in project, 1 for no change orders and a value between 0 to 1 as per the quantum of change orders. Conflicts/ disputes / claims (K_{11}) on the project 1 for zero such issue and a value between 0 to 1 as per the quantum of such issues. For stakeholder satisfaction (K_{12}) if the stake holders are highly satisfied 1, for high 0.85, for medium 0.5 and for low 0.15. The input value will have 34% weight while 33% weight will be given to the input value of K_{11} and the rest of 33% to K_{10}. Equation 3.5 illustrates the incorporation of stakeholder satisfaction KPIs along with their respective weightings.

$$\omega_3[\ \gamma_1 K_{10} + \gamma_2 K_{11} + \gamma_3(0.34K_{12} + 0.33K_{10} + 0.33K_{11})] \qquad \textit{Equation 3.5}$$

Where $\omega_3$the collective group weightings assigned to the safety factors is, $\gamma_1, \gamma_2, \gamma_3, \gamma_4$ are the internal weightage of each KPI which are represented by $K_{10}, K_{11}, K_{12}, K_{13}$ and K_{14}.

3.5.4. Incorporation of other performance indicators in equation

After finding the RII of the results obtained from the pilot survey, four PIs in the others group had RII > 0.50 so they were considered significant to be incorporated in the equation. If wastage (K_{13}) on the project is very high input 0.15, for high 0.3, for medium 0.5, for low 0.7 and for very low 0.9. The input value of the wastage will have 30% weight while 20% will be of K_1, 20% will be the input value of K_5 and 10% of K_3. If there any land acquisition (K_{14}) related problems faced on the project 1 for no problem and a value between 0 to 1 as per the percentage of such land being not handed over. Project management practices (K_{15}) being carried out on site to monitor and control progress and cost of the project, 1 for well implemented and 0 for no such activity. Problems faced during the execution phase because of the design process or the construction drawings or not well prepared estimates (K_{16}), input a value between 0 and 1 for such issues where 1 is for no issue. The input of the value will have 60% weight while the rest of the 40% is of the value input in variable K_{10}. Equation 3.6 illustrates the incorporation of other KPIs along with their respective weightings.

$$\omega_4[\rho_1(0.3K_{13}+0.2K_1+0.2K_5+0.2K_3+0.1K_{13}) + \rho_2 K_{14} + \rho_3 K_{15} + \rho_4(0.6K_{16} + 0.4K_{10})]$$

Equation 3.6

Where ω_4 is the collective group weighting assigned to the safety factors, $\rho_1, \rho_2, \rho_3, \rho_4$ are the internal weightage of each KPIs which are represented by $K_{13}, K_{14}, K_{15}, K_{16}$ and K_{17}.

3.5.5. Combined RPI Equation

Equation 3.7 shows the combined RPI equation which was generated by adding Equation 3.3, Equation 3.4, Equation 3.5 and Equation 3.6.

$$RPI = \omega_1[\alpha_1 K_1 + \alpha_2 K_2 + \alpha_3(0.34K_3 + 0.33K_4 + 0.33K_1) + \alpha_4 K_4 + \alpha_5 K_5] + \omega_2[\beta_1(0.5K_6 + 0.5K7) + \beta 2K7 + \beta 3K8 + \beta 4K9 + \omega 3\ \gamma 1K10 + \gamma 2K11 + \gamma 30.34K12 + 0.33K10 + 0.33K11 + \omega 4\rho 1(0.3K13 + 0.2K1 + 0.2K5 + 0.2K3 + 0.1K13) + \rho 2K14 + \rho 3K15 + \rho 4(0.6K16 + 0.4K10) \quad (0 \leq RPI \leq 1) \quad \text{Equation 3.7}$$

3.6. DEVELOPMENT OF EQUATION FOR ESTIMATING COST AT COMPLETION

As per Narbaev and De Marco (2011) EAC can be calculated using the Equation 3.8.

$$EAC = AC + (BAC - BCWP)/(W1CPI + W2SPI) \quad \text{Equation 3.8}$$

Where AC is the actual cost incurred up till the data date. BAC is the budgeted cost at completion i.e. the planned value for completing the whole project, BCWP is the budgeted cost work performed i.e. the planned value for carrying out the activities till data date. W1 and W2 are the complementary weights assigned to CPI and SPI and the sum of these weights is usually 1.

To incorporate the influence of RPI defined earlier in Equation 3.7 in Equation 3.8. Complementary weightings shall be assigned to CPI, SPI and RPI whose sum will be equal to 1. Equation 3.9 demonstrates the new formed equation of EAC incorporating the influence of RPI.

$$EAC = AC + (BAC - BCWP)/(W1CPI + W2SPI + W3RPI) \quad \text{Equation 3.9}$$

Where W1, W2 and W3 are the complementary weightings assigned to each index.

3.7. COMPLEMENTARY WEIGHTAGES SURVEY

As complimentary weightings to be assigned to each index in Equation 3.9 were required, a survey was conducted to asses these weightings. Adopting the methodology from Riedel and Chance (1989) who used index based formula and estimated EAC at four stages of project completion. Respondents were asked to give weightings in terms of percentage from 0 to 100% to CPI, SPI and RPI at four stages of the project which are 0 to 25%, 26 to 50%, 51 to 75% and 76 to 100%.

The survey from was prepared using Google forms and was distributed using emails, social and professional websites. To get a broader input the audience of the survey was kept global.

Statistical analysis tests including Anderson Darling normality test, Cronbach's Alpha test for reliability of data were applied on the data obtained from the survey. The results obtained for each index for 0 to 25% were normalized to 1, as the sum of the complementary weightings assigned to each index should be equal to one. Similarly results were normalized for the next three phases of the project i.e. 26 to 50%, 51 to 75% and 76 to 100%.

4. RESULTS AND ANALYSIS

4.1. INTRODUCTION

This chapter consists of the analysis on the collected data. Results are drawn and discussion is done over various findings in revelavant sections.

4.2. LITERATURE REVIEW

Literature review was used for the identification of PIs. A total of 55 PIs were identified and their frequency was calculated. RII of the identified factors was calculated and ranked accordigly as given in Table 4.1.

Table 4.1: Top 10 PIs ranked via literature review

Sr. No.	Performance Indicators	Frequency	Relative Importance Index
Stake Holder Satisfaction			
1	Stake Holder Satisfaction	26	0.4561
2	Conflicts / Disputes/ Claims	9	0.1579
3	Change Orders	8	0.1404
Quality			
4	Rework / Defects	20	0.3509
5	Quality systems	5	0.0877
6	Materials quality	4	0.0702
Safety			
7	Accident frequency ratio	16	0.2807
8	Safety training	7	0.1228
9	Jobsite toolbox meetings	4	0.0702
Others			
10	Wastage	3	0.0526

4.3. PILOT SURVEY

For ranking and finding respective weightings of the identified PIs pilot survey was conducted. Each indicator was ranked on a rating scale of 0 to +3 (opportunity) and 0 to -3 (threat). A sample questionnaire is attached as ANNEXURE-I. The audience of the questionnaire was kept global so international responses were collected. Email medium was primarily used and more than 300 researchers and field personals were contacted from which thirty nine (39) responses were collected giving a response rate of 13%. To check the reliability of the data of pilot survey Cronbach's Alpha Test was applied and Cronbach's Alpha value came out to be 0.9652 making it highly reliable. Geographic segmentation of respondents is given in Table 4.2. Similarly career segmentation and the experience of respondents is given in Table 4.3 and Table 4.4 respectively.

Table 4.2: Geographic Segmentation of Respondents

Country	Responses
Pakistan	24
United States of America	3
Finland	2
Saudi Arabia	2
Qatar	1
United Arab Emirates	1
Barbados	1
India	1
Portugal	1
Australia	1
United Kingdom	1
Turkey	1

Table 4.3: Career Segmentation of Respondents

Career	Count
Industry	31
Academia	8

Table 4.4: Experience of Respondents

Experience	Count
Entry Level	6
Intermediate Level	21
Manager Level	12

Scores from the pilot survey were used to find their RII and sixteen factors having RII greater than 0.5 were used further for our study as shown in Table 4.5.

Table 4.5: Ranking of PIs from their pilot survey having RII greater than 0.5

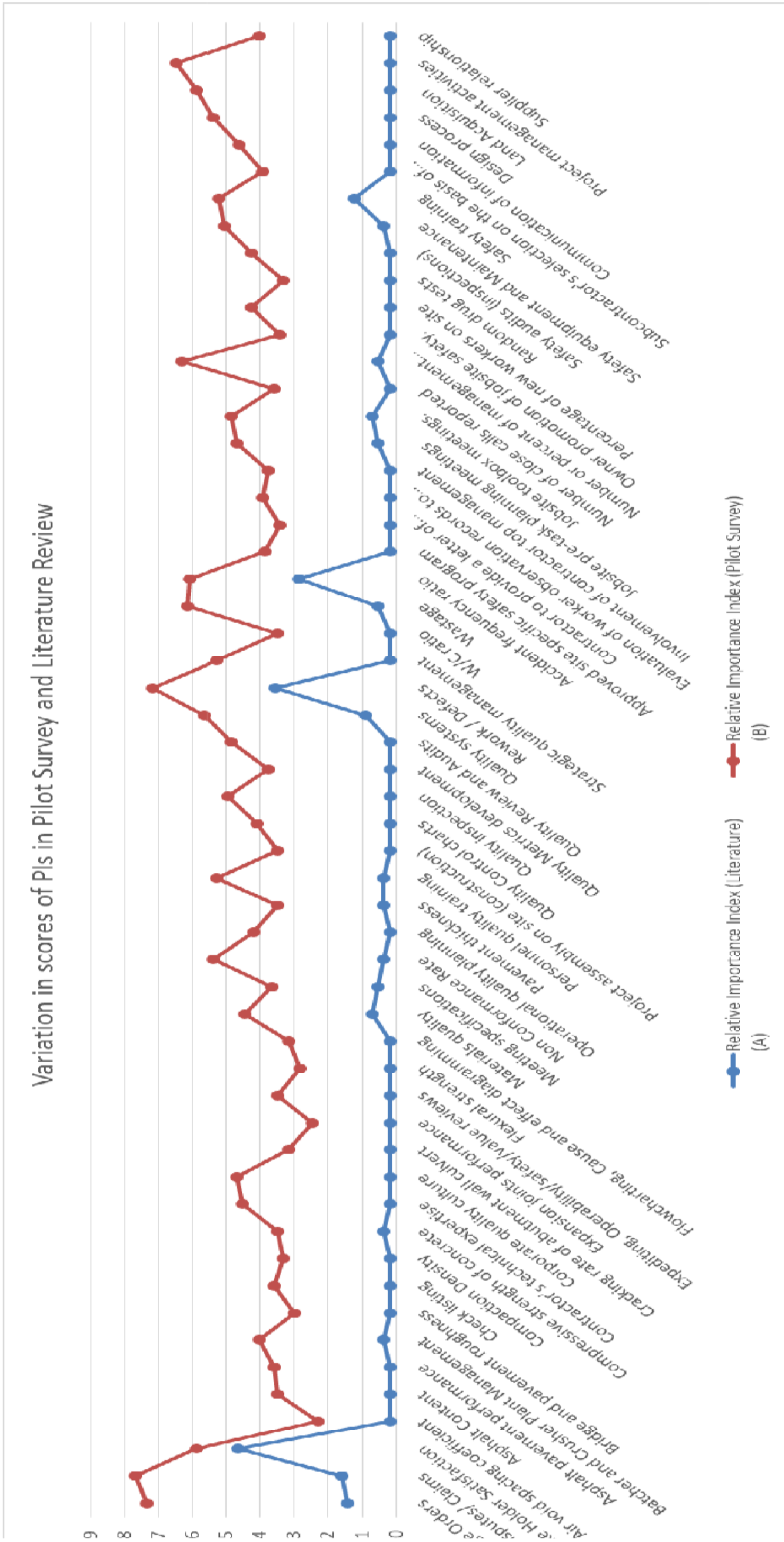
Factor	Relative importance Index
Quality	
Rework / Defects	0.717948718
Wastage	0.615384615
Quality systems	0.564102564
Nonconformance rate	0.538461538
Strategic quality management	0.52991453
Personnel quality training	0.52991453
Safety	
Management personnel with standard certification	0.632478632
Accident frequency ratio	0.606837607
Safety training	0.521367521
Safety equipment and maintenance	0.504273504
Stake Holder Satisfaction	
Conflicts / Disputes/ Claims	0.769230769
Change Orders	0.735042735
Stakeholder satisfaction	0.58974359
Others	
Project management activities	0.64957265
Land Acquisition	0.58974359
Design process	0.538461538

To find the correlation between the RII of PIs in the literature and the RII of the PIs on the pilot survey scores Spearman rank order correlation test was conducted and correlation was identified between the two results as Spearman rank order correlation coefficient ‘rs’ came out to be .5832 depicting correlation in the weightings of the literature and that of the pilot survey.

4.4. COMPARISON OF PI SCORES

To illustrate the association and variation in ranking of PIs as identified in the literature and in the pilot survey a line graph was generated as shown in Fig 4.1. The graph illustrates that the PIs having higher rank in the literature also got higher ranking in the pilot survey. Stakeholder satisfaction which has the highest weight in literature got comparatively higher RII in pilot survey as well. Similarly change orders, conflicts/ disputes / claims, reworks and quality systems had higher frequency in literature and scores from pilot survey also showed that these factors play important role as performance indicators. On the other side nonconformance rate, personnel quality training, strategic quality management, the design process and project management activities had lower ranking in the literature score but the pilot studies showed otherwise indicating that field employees consider these factors relatively more important than others as PIs. Similarly there were some PIs having ranking on the higher side like safety trainings and jobsite toolbox meetings which had relatively higher ranking in the identified safety PIs from the literature but got relatively lower ranking in the pilot survey indicating that the industry has reluctances towards adopting safety and other new trends that are being introduced in the market.

Figure 4.1: Variation chart of KPIs



4.5. EQUATION FOR RISK PERFORMANCE INDEX

After finding the RII of the scores given to each PI in pilot survey, factors having RII > 0.5 were further used in our equation as inputs. These RII scores within a group were generalized to 1 i.e. the cumulative weight within a group will be equal to 1. Internal weight of the PIs which were divided in four groups were found out. Then external weight of each group was also calculated and normalized and the complete details are shown in Tab 4.7.

Table 4.6: Normalized weigh of PIs.

Normalized Group Rep	Normalized Group Weight	Variable Rep	PIs	Normalized Weightings Rep.	RII	Normalized Internal Weight
Quality						
ω_1	0.29902	K_1	Nonconformance rate	α_1	0.53846	0.187
		K_2	Personnel quality training	α_2	0.52991	0.184
		K_3	Quality systems	α_3	0.5641	0.196
		K_4	Rework / Defects	α_4	0.71795	0.249
		K_5	Strategic quality management	α_5	0.52991	0.184
Safety						
ω_2	0.23513	K_6	Accident frequency ratio	β_1	0.60684	0.268
		K_7	Management personnel with OSHA certification	β_2	0.63248	0.279
		K_8	Safety equipment and maintenance	β_3	0.50427	0.223
		K_9	Safety training	β_4	0.52137	0.230
Stake Holder Satisfaction						
ω_3	0.21739	K_{10}	Change Orders	γ_1	0.73504	0.351
		K_{11}	Conflicts / Disputes/ Claims	γ_2	0.76923	0.367
		K_{12}	Stakeholder satisfaction	γ_3	0.58974	0.282
Others						
ω_4	0.24844	K_{13}	Design process	ρ_1	0.53846	0.225
		K_{14}	Land Acquisition	ρ_2	0.58974	0.246
		K_{15}	Project management activities	ρ_3	0.64957	0.271
		K_{16}	Wastage	ρ_4	0.61538	0.257

After incorporating all the weightings for RPI in Equation 3.7 we get our final equation for RPI shown in Equation 4.1.

$RPI = 0.29902[0.187K_1 + 0.184K_2 + 0.196(0.34K_3 + 0.33K_4 + 0.33K_1) + 0.249K_4 +$

$0.184K5 + 0.235130.268(0.5K6 + 0.5K7) + 0.279K7 + 0.223K8 + 0.230K9 + 0.217390.351K10 +$

$0.367K11 + 0.2820.34K12 + 0.33K10 + 0.33K11 +$

$0.24844[0.225(0.3K_{13} + 0.2K_1 + 0.2K_5 + 0.2K_3 + 0.1K_{13}) + 0.246K_{14} + 0.271K_{15} + 0.257(0.6K_{16} +$

$0.4K10) \quad (0 \leq RPI \leq 1)$ *Equation 4.1*

4.6. COMPLEMENTARY WEIGHTAGES SURVEY

To find the respective complementary weight of the indices a survey was conducted. Respondents were asked to give weightings to each CPI, SPI and RPI on a rating scale of 0 to 100 for four phases of the project completion i.e. from 0 to 25%, 26 to 50%, 51 to 75% and 75 to 100%. A sample questionnaire is attached as ANNEXURE-II. The audience of the questionnaire was kept global so international responses were collected. Email medium was primarily used and more than 1000 researchers and field personals were contacted from which one hundred and one (101) responses were collected giving a response rate of 10.1%. To check the reliability of the data of survey Cronbach's Alpha Test was applied and Cronbach's Alpha value came out to be 0.8278 making it highly reliable. Geographic segmentation of respondents is given in Table 4.7. Similarly career segmentation, organization type and experience of respondents are given in Table 4.8, Table 4.9, Table 4.10 respectively.

Table 4.7: Geographic Segmentation of Respondents

Country	Count
Pakistan	57
Saudi Arabia	10
Qatar	7
United Arab Emirates	6
United States of America	5
Australia	4
Kuwait	3

United Kingdom	2
India	2
Finland	2
Italy	1
Venezuela	1
Malaysia	1

Table 4.8: Career Segmentation of Respondents

Career	Count
Industry	81
Academia	20

Table 4.9: Organization Type of Respondents

Organization type	Count
Private	66
Semi-government	20
Government	15

Table 4.10: Experience of Respondents

Experience	Count
Entry Level	18
Intermediate Level	54
Managerial Level	29

Scores from the survey were normalized to 1 for each phase of the project and are shown in Table 4.11.

Table 4.11: Complementary weightings of each index

Index	Complementary Weight
0 to 25% project completion	
Cost Performance Index	0.4209
Schedule Performance Index	0.3011
Risk Performance Index	0.2780
26 to 50% project completion	
Cost Performance Index	0.4200

Schedule Performance Index	0.3209
Risk Performance Index	0.2591
51 to 75% project completion	
Cost Performance Index	0.4355
Schedule Performance Index	0.3174
Risk Performance Index	0.2471
76 to 100% project completion	
Cost Performance Index	0.4365
Schedule Performance Index	0.3027
Risk Performance Index	0.2607

4.7. EQUATION FOR ESTIMATING COST AT COMPLETION

To calculate the EAC, results obtained from the survey were incorporated in Equation 3.9.

Four equations were generated for different phases of the project completion. For 0 to 25% project completion the final equation to estimate EAC is given by Equation 4.2

$$EAC = AC + (BAC - BCWP)/(0.4209CPI + 0.3011SPI + 0.278RPI) \quad \textit{Equation 4.2}$$

For 26 to 50% project completion the final equation to estimate EAC is given by Equation 4.3

$$EAC = AC + (BAC - BCWP)/(0.42CPI + 0.3209SPI + 0.2591RPI) \quad \textit{Equation 4.3}$$

For 51 to 75% project completion the final equation to estimate EAC is given by Equation 4.4

$$EAC = AC + (BAC - BCWP)/(0.4355CPI + 0.3174SPI + 0.2471RPI) \quad \textit{Equation 4.4}$$

For 76 to 100% project completion the final equation to estimate EAC is given by Equation 4.5

$$EAC = AC + (BAC - BCWP)/(0.4365CPI + 0.3027SPI + 0.2607RPI) \quad \textit{Equation 4.5}$$

4.8. MATHEMATICAL MODEL

Using MS Excel developed equarions were modelled to generate results. The model was created in which inputs related to costs, quality, safety, stakeholder satisfaction and other PIs are given according to the specific project condition till the data date and EAC is obtained as a result. The model is given in Figure 4.2Figure **4.2**

Figure 4.2: MS Excel mathameitcal model illustration

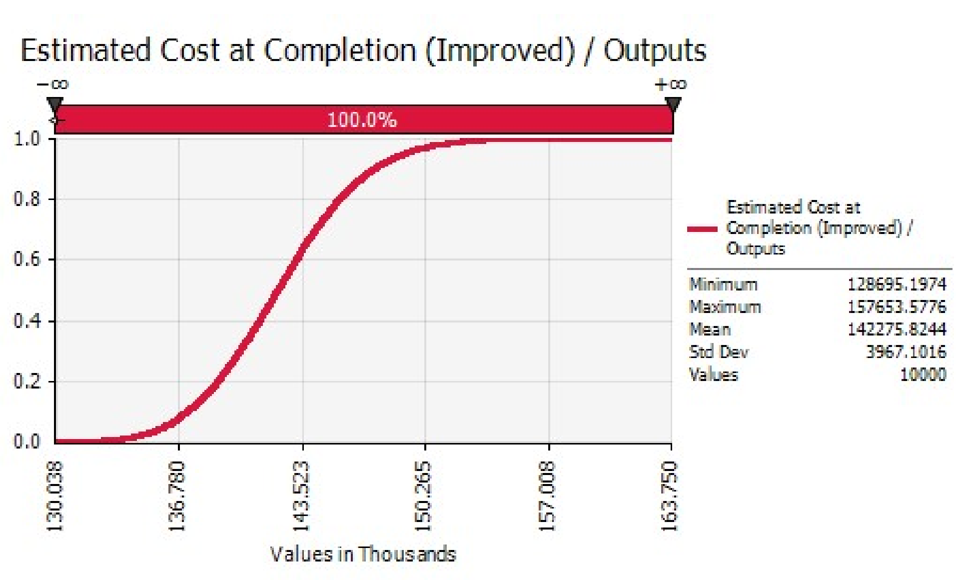
Estimated Cost at Completion Calculator	
Project Details	Inputs
Budgeted Cost at Completion	100000
Actual Cost	15000
Planned Cost	13000
Earned Value	11500
Percentage Complete (Physical Progress)	9
Quality	
Non conformance rate	0.8
Personnel quality training	0.9
Quality systems	0.8
Rework / Defects	0.9
Strategic quality management	0.7
Safety	
Accident frequency ratio	1
Management personnel with OSHA certification	0.7
Safety equipment and maintenance	0.9
Safety training	0.6
Stake Holder Satisfaction	
Change Orders	1
Conflicts / Disputes/ Claims	1
Stakeholder satisfaction	0.8
Others	
Design process	0.8
Land Acquisition	1
Project management activities	0.8
Wastage	0.9
Outputs	
Cost Performance Index	**0.77**
Schedule Performance Index	**0.88**
Quality Performance Index	**0.82**
Safety Performance Index	**0.80**
Stakeholder Satifaction Performance Index	**0.94**
Risk Performance Index	**0.86**
EAC (PMBOK) Formula 1	**145,491.49**
EAC (PMBOK) Formula 2	**130,434.78**
EAC (PMBOK) Formula 3	**103,500.00**
Estimated Cost at Completion (Improved)	**125,076.59**

Sensitivity analysis was done over MS Excel and @Risk® 5.5 software to check for the impact of RPI input varoiables to the overall result.

4.8.1. <u>Sensitivity analysis</u>

A random project environment was created as shown in Figure 4.3, data related to the costs were entered and the inputs related to the PIs were given to the model by defining their input ranges between 0 and 1 via @Risk 5.5. Along with the CPI and SPI a major weighting of the developed EAC depends upon RPI which gets its input value from the PIs relating to past quality, safety, stake holder satisfaction and other performances. Ten thousand iterations were performed using the software which means that the software entered 10,000 different input values to our variables between generating random RPI values as an input for calculating EAC for our model. The overall Cumulative Density Function (CDF) is shown in the Figure 4.3.

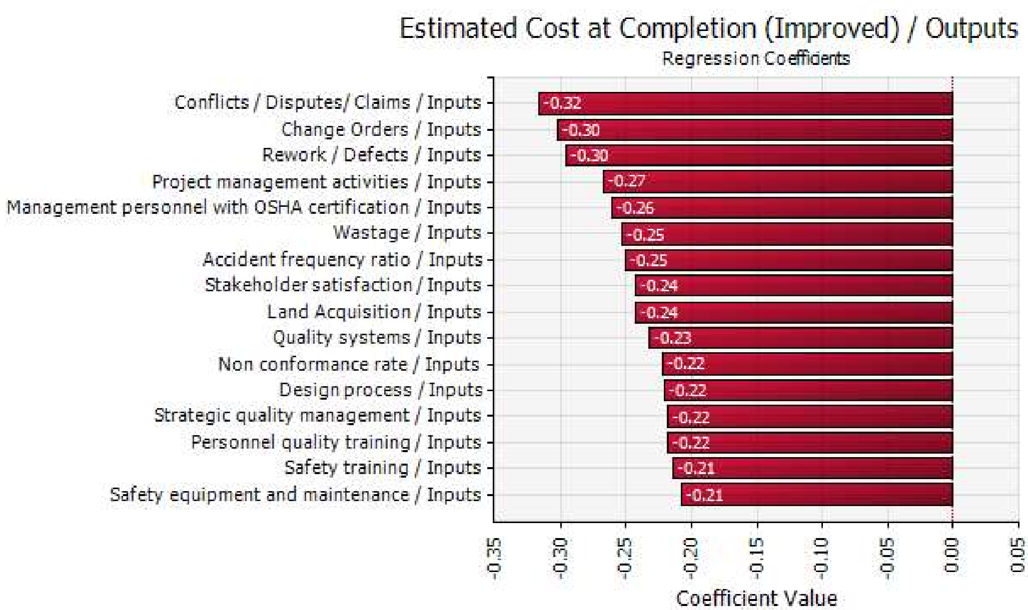
Figure 4.3: CDF



The CDF shown in Figure 4.3 shows that a project having cost statistics as shown in Figure 4.4 will have a minimum EAC of 128,695.1974 and maximum EAC of

157,653.5776. These figures show the impact of risk on EAC of the project i.e. if the project faces minimum risks related to quality, safety and customer satisfaction it will have minimum cost of 128,695.1974 but if the project faces such problems and the value of RPI drops down towards 0 then the EAC will be higher and as the CDF shows that it can reach a maximum of 157,653.5776 by the end of project closure. The CDF also shows the probability of completing the project at a certain cost for example there is only 25% probability that the project having 100,000 BAC will complete at 139500 in a random environment. Similarly the probability of the project to complete under 144,190 is 40% and the probability of the project to complete under 144,240 is 70%. The probability of the project to complete under 147,460 is 90%.

Figure 4.4: Regression Coefficients



We also get regression coefficients as result of sensitivity analysis showing the effect of our variables on EAC results as shown in Figure 4.4. The regression coefficient show that conflicts / disputes/ claims is the major input which has the most impact on the EAC value we get through our model. Similarly rework and change orders having regression coefficients of 0.30 has the second most major impact on the output result i.e. EAC, which is followed by project management activities and safety personals having standard certifications on site.

4.9. Case Studies

To validate the proposed model, the developed equation was applied to the data obtained from completed construction projects from two different countries. The project managers of the respective projects were asked various questions regarding the input variables (PIs) of the modeled equation. As stated previously in the methodology different weightings were assigned to CPI, SPI and RPI for four quarters of the project so the data of the project was obtained at four data points between 0 to 25%, 26 to 50%, 51 to 75% and 76 to 100% project completion. As the data is of completed projects and their actual cost at completion was known which was then compared with the result obtained from the developed equation in this research as well as the with the PMI's standard equations. The case studies allowed checking the behavior of the equation when applied on a real construction project. Due to the confidential nature of the data, the project description and details are not disclosed.

4.9.1. Case Study 1

The project was an administrative building constructed by a renowned construction firm. The contract amount of the project was 22.487 Million Pakistani Rupees (PKR) and the budgeted planned cost of the project was 21.251 Million PKR and the duration of the project was 10 months. The project got completed in time and under the planned budget. Table 4.13 shows the financial details of the project at various percentage completions.

Table 4.12: Financial Details of Case Study 1

Case Study No.1					
Completion Percentage	**20%**	**40%**	**70%**	**90%**	**100%**
Planned Value (PV)	4,537,335	8,006,568	14,776,095	18,826,870	21,251,421
Actual Cost (AC)	4,477,577	8,159,922	14,118,842	19,157,603	21,165,376
Earned Value (EV)	4,571,420	8,253,807	14,587,782	19,877,591	21,493,835

The inputs regarding the PIs were also taken at these data points as per the project and project manager's perspective. Table 4.14 shows the PI values as entered in the developed model between the range of 0 and 1.

Table 4.13: PI Values of Case Study 1

Case Study 1				
Percent Complete	20%	40%	70%	90%
Quality				
Non conformance rate	0.9	0.8	0.75	0.7
Personnel quality training	1	1	1	1
Quality systems	0.9	0.9	0.9	0.9
Rework / Defects	0.95	0.9	0.9	0.75
Strategic quality management	0.9	0.9	0.9	0.8
Safety				
Accident frequency ratio	1	0.95	0.85	0.8
Management personnel with standard certification	1	1	1	1
Safety equipment and maintenance	0.8	0.8	0.8	0.7
Safety training	1	1	1	1
Stake Holder Satisfaction				
Change Orders	1	1	1	0.8
Conflicts / Disputes/ Claims	1	1	1	1
Stakeholder satisfaction	1	1	0.85	0.85
Others				
Design process	0.95	0.95	0.85	0.75
Land Acquisition	1	1	1	1
Project management activities	1	1	1	1
Wastage	0.9	0.9	0.7	0.5

After using the inputs regarding the PIs and the financial data; CPI, SPI and RPI for the respective data points were calculated using the modeled equation and are shown in Table 4.15. The trend of CPI and SPI of the project somehow remained same throughout the project and was above 1.0 except for once when the SPI dropped to 0.98 at 70% completion, showing that the cost and schedule of the project somehow remained near the planned value but after the assessment of the actual cost at completion, the variance was only about 86 thousand Pakistani rupees from the planned project cost i.e. the project got completed 86,045 PKR lesser than the planned amount.

Table 4.14: Indices Values of Case Study 1

Case Study 1				
Percent Complete	20%	40%	70%	90%
Cost Performance Index	1.02096	1.01151	1.03321	1.03758
Schedule Performance Index	1.00751	1.03088	0.98726	1.05581
Quality Performance Index	0.92175	0.88149	0.86911	0.79183
Safety Performance Index	0.95547	0.93632	0.89802	0.8566
Stake Holder Satisfaction Performance Index	1	1	0.98564	0.89684
Risk Performance Index	0.95992	0.94274	0.91844	0.85017

The project may have been executed as per the plan but when we take into account the CPI and SPI of the project at various project completion percentages, the formulas defined by PMI show results that the project could have been completed in lesser amount than the actual amount spent to complete the project. If we take into account the project stats at 20% project completion the CPI of the project is at 1.02 and SPI is at 1.00 and as per the standard PMI formulas the EAC would be 20.693, 20.815 and 21.157 Million PKR respectively, which when compared with the actual cost at completion which is higher than the forecasted EAC amount shows on average a variance of 0.209 Million PKR. This cost difference can be explained by the methodology proposed in this research that a project having no schedule issues and being executed under planned budget may be exposed to some risks related to quality, safety and stakeholder satisfaction.

Similarly in this scenario where the project was being executed as plan in terms of cost and schedule but a RPI of 0.95 at 20% completion and it keeps dropping throughout the project execution which explains the fact that probability of the project facing some quality, safety or other issues is increasing as the project is getting closer to completion. In this case study the project faced such issues in the last quarter of the project completion and if we look at the RPI of this case study it dropped from 0.9 at 70% project completion to 0.85 at 90% completion. This sudden drop of RPI described the increase in probability of risk exposure of the project which this project actually faced in the last 20% of project completion during the finishes incurring additional cost which was not in the baseline plan.

S-curve of the project at completion is shown in Figure 4.5 describes the trend of planned, actual and earned value throughout the project execution.

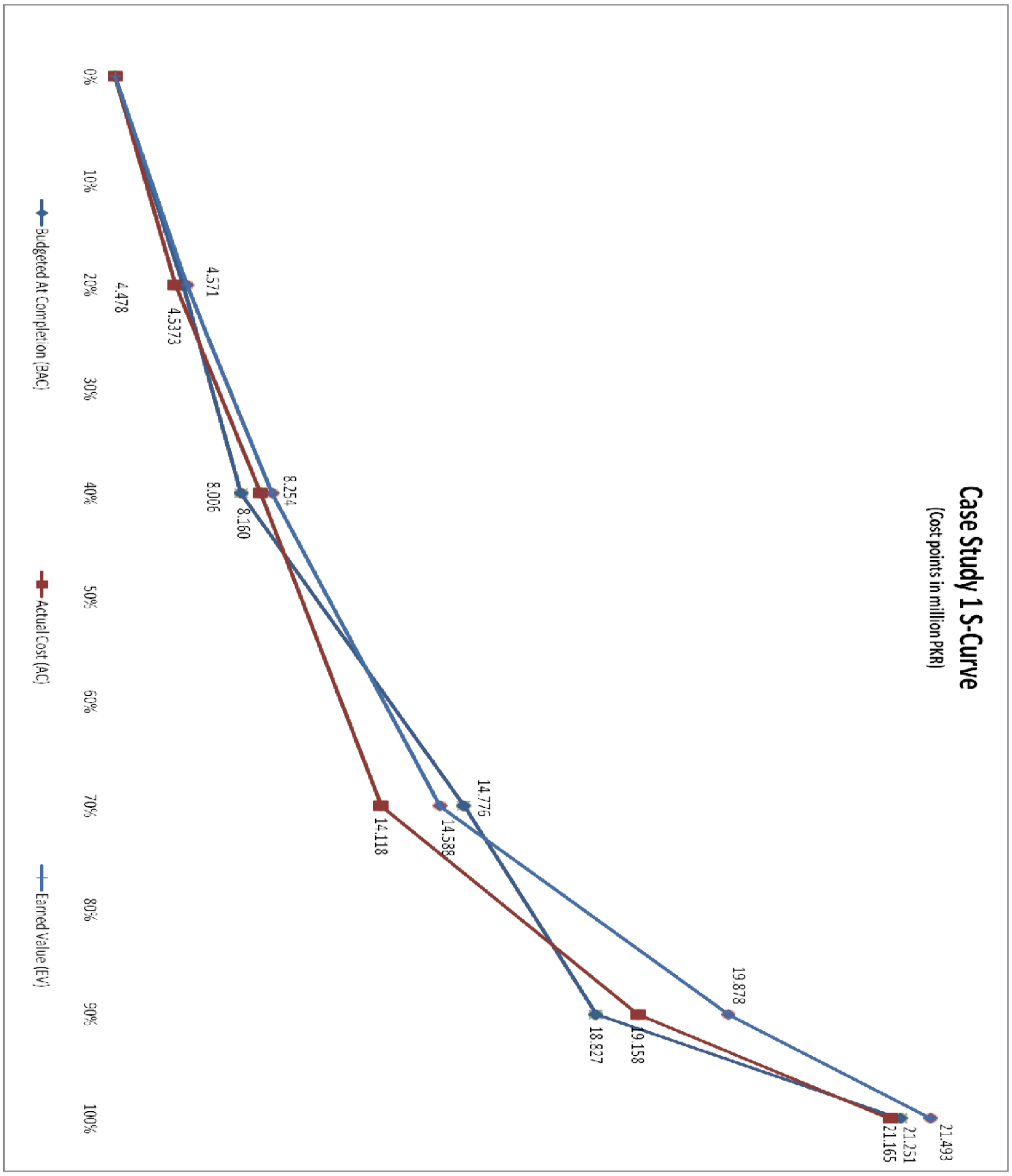


Figure 4.5 S-Curve of the Project

As the CPI and SPI of the project somehow remained near 1.0 up till 90% project completion so the PMI's EAC formulas forecast the project completion cost between 20.411 to 21.157 Million PKR throughout the project but when EAC was calculated using the modeled equation incorporation the RPI, the forecasted amount was more realistic and closer to the actual cost the project incurred to complete. The forecasted EAC using the proposed model ranged between 20.539 and 21.158 Million PKR during the project construction phase. Table 4.16 shows the comparison of EAC values by PMI's formula and the model proposed in this research.

Table 4.15: EAC values of Case Study 1

Case Study 1				
Percent Complete	20%	40%	70%	90%
EAC (PMBOK) Formula 1	20,693,345	20,624,781	20,651,527	20,411,682
EAC (PMBOK) Formula 2	20,815,162	21,009,690	20,568,272	20,481,671
EAC (PMBOK) Formula 3	21,157,577	21,157,536	20,782,481	20,531,433
Estimated Cost at Completion (Improved)	21,158,617	21,158,723	20,847,991	20,539,397

4.9.2. Case Study 2

The project was a school building. The contract amount of the project was 26.150 Million PKR and budgeted planned cost of the project was 24.352 Million Pakistani Rupees and the duration of the project was 12 months. The project got completed one month late on schedule and suffered some loss in terms of profit. Table 4.17 shows the financial details of the project at various percentage completions.

Table 4.16: Financial Details of Case Study 2

Case Study No.2					
Completion Percentage	**20%**	**40%**	**70%**	**90%**	**100%**
Planned Value (PV)	4,730,618	10,110,312	17,046,253	23,790,210	24,351,790
Actual Cost (AC)	5,155,460	11,230,050	17,939,110	23,091,835	25,751,048
Earned Value (EV)	5,001,432	10,742,017	16,331,189	22,438,437	24,600,494

The inputs regarding the PIs were also taken at these data points as per the project and project manager's perspective. Table 4.18 shows the PI values as entered in the developed model between the range of 0 and 1.

Table 4.17: PI values of Case Study 2

Case Study 2				
Percent Complete	20%	40%	70%	90%
Quality				
Non conformance rate	0.9	0.85	0.75	0.7
Personnel quality training	1	1	1	1
Quality systems	0.7	0.7	0.7	0.7
Rework / Defects	0.95	0.9	0.8	0.8
Strategic quality management	0.7	0.7	0.7	0.7
Safety				
Accident frequency ratio	0.97	0.9	0.85	0.8
Management personnel with standard certification	1	1	1	1
Safety equipment and maintenance	0.7	0.7	0.7	0.7
Safety training	1	1	1	1
Stake Holder Satisfaction				
Change Orders	1	1	0.9	0.8
Conflicts / Disputes/ Claims	1	0.9	0.6	0.6
Stakeholder satisfaction	0.85	0.85	0.5	0.5
Others				
Design process	0.6	0.6	0.6	0.6
Land Acquisition	0.6	0.7	0.7	0.9
Project management activities	0.7	0.7	0.7	0.7
Wastage	0.8	0.7	0.7	0.7

After using the inputs regarding the PIs and the financial data; CPI, SPI and RPI for the respective data points were calculated using the modeled equation and are shown in Table 4.19. The CPI of the project was 0.94 at 20% project completion and up till 90% project completion it climbed up till 0.97 that means that the start of the project was not well but later on cost consumption was controlled. The project was on schedule up till 40% project completion and was having a SPI of 1.04 but at 90% it had already dropped to 0.94. This change of SPI in the last 30% project duration indicates that the progress of the project somehow couldn't meet the planned value. The project exceeded the planned cost by 1.4 Million PKR reducing the contractor's profit. When asked about the reasons for loss in the project, the project manager highlighted few aspects that included a major rework of slab reinforcement, an accidental death at site, some land handing over issues which was Client's responsibility and caused schedule delay as well as extra man hours and overheads on site. The delay due to land handing over was later claimed by the contractor arising some dispute between parties.

Table 4.18: Indices values of Case Study 2

Case Study 2				
Percent Complete	20%	40%	70%	90%
Cost Performance Index	0.944	0.957	0.965	0.972
Schedule Performance Index	1.029	1.042	1.015	0.943
Quality Performance Index	0.846	0.818	0.762	0.737
Safety Performance Index	0.922	0.895	0.876	0.857
Stake Holder Satisfaction Performance Index	0.986	0.940	0.724	0.679
Risk Performance Index	0.861	0.840	0.768	0.756

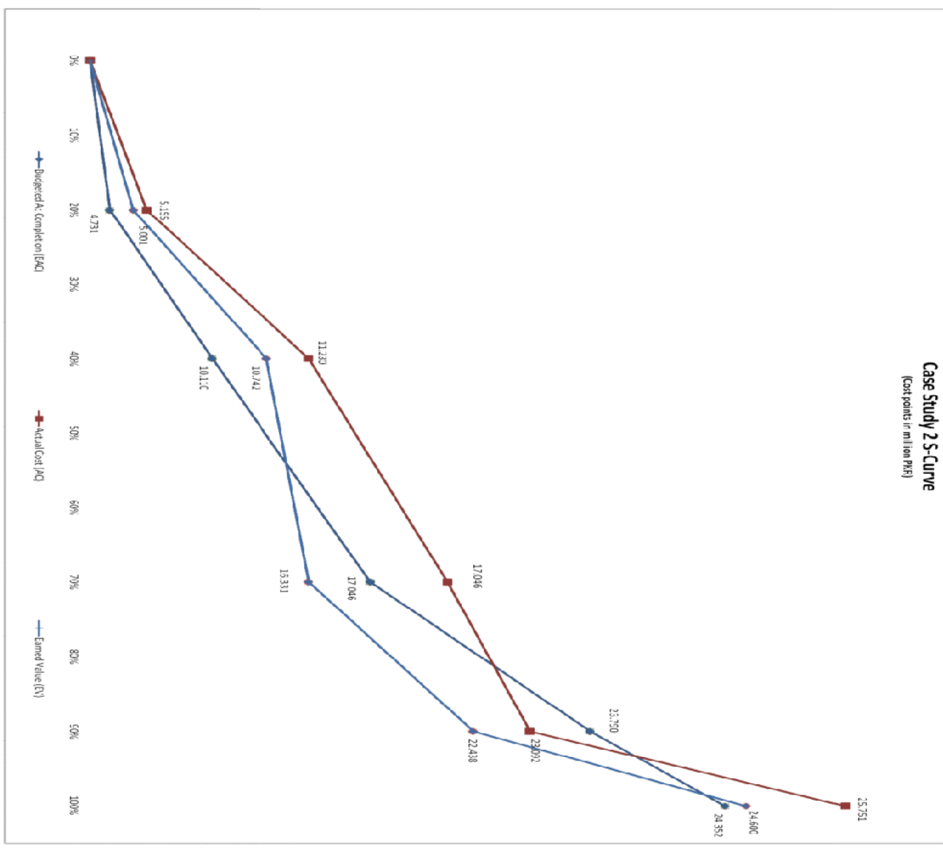
PMI's formulas when used to forecast the EAC at 20% project completion where the CPI of the project was at 0.94 and SPI at 1.02 anticipated an EAC of 25.195, 25.782 and 24.638 Million PKR respectively. This forecasted amount is lower than the actual cost at completion by an average of 0.54 Million PKR where as the modeled equation calculated an EAC cost of 25.733 Million which was lower by .018 Million from the actual cost. If we consider at 70% project completion where the CPI has improved to 0.965 and SPI is at 1.01 the anticipated EAC cost is 25.119, 25.229 and 24.971 by PMBOK's standard formulas whereas the modeled equation showed a value of 25.491 Million PKR because even though the CPI and SPI were not that alarming but the RPI of the project had dropped down to 0.76 which is fairly low and indicated that the project may face risks. As the modeled equation incorporates this risk perception while calculating EAC so it shows a relatively higher amount then the standard PMI's formulas. Table 4.20 shows the comparison of EAC values by PMI's formula and the model proposed in this research.

Table 4.19: EAC values of Case Study 2

Case Study 2				
Percent Complete	20%	40%	70%	90%
EAC (PMBOK) Formula 1	25,195,543	24,886,339	25,118,922	25,179,528
EAC (PMBOK) Formula 2	25,782,975	25,458,144	25,229,593	25,060,904
EAC (PMBOK) Formula 3	24,637,964	24,839,823	24,971,116	25,005,188
Estimated Cost at Completion (Improved)	25,733,886	25,501,287	25,491,656	25,201,486

S-curve of the project at 90% completion is shown in Figure 4.6 which describes the trend of planned, actual and earned value throughout the project execution. The figure also shows various forecasted EAC amounts at 90% project completion.

Figure 4.6: S-curve of Case Study 2



4.9.3. Case Study 3

The project was a oil and gas project in Qatar, the base line cost of the project was 610.913 Million Qatar Riyal (QTR), the planned duration was 27 months and the project had delays and completed in 33 months. The project also completed way above the planned value and the contractor had major loss in completing the project which he later on claimed. The financial details of the project at 85% and 100% completion are given in Table 4.21

Table 4.20: Financial Details of Case Study 3

Case Study No.3		
Completion Percentag	**85%**	**100%**
Planned Value (PV)	560,913,197.00	610,913,197
Actual Cost (AC)	601,510,329.52	738,736,881
Earned Value (EV)	502,941,518.52	700,784,634

The inputs regarding the PIs were also taken at 85% project completion as per the project manager's perspective. Table 4.22 shows the PI values as entered in the developed model between the range of 0 and 1.

Table 4.21: PI values of Case Study 3

Case Study 3	
Percent Complete	85%
Quality	
Non conformance rate	0.6
Personnel quality training	1
Quality systems	0.9
Rework / Defects	0.79
Strategic quality management	0.8
Safety	
Accident frequency ratio	0.94
Management personnel with standard certification	1
Safety equipment and maintenance	0.8
Safety training	1
Stake Holder Satisfaction	
Change Orders	0.65
Conflicts / Disputes/ Claims	0.5
Stakeholder satisfaction	0.5
Others	
Design process	0.5
Land Acquisition	1
Project management activities	0.8
Wastage	0.5

After using the inputs regarding the PIs and the financial data; CPI, SPI and RPI for the data point was calculated using the modeled equation and is shown in Table 4.23. The CPI of the project was 0.836 at 85% project completion that means that the project was going well above the planned budget. The project was also facing schedule issues and the SPI value at 85% project completion was 0.89. RPI when calculated at this data point after entering the variable values came out to be 0.765 explaining the fact that the project was facing quality, safety and other such issues. The project exceeded the planned cost by 127.823 Million QR.

Table 4.22: Indices Values of Case Study 3

Case Study 3	
Percent Complete	85%
Cost Performance Index	0.836
Schedule Performance Index	0.897
Quality Performance Index	0.779
Safety Performance Index	0.932
Stake Holder Satisfaction Performance Index	0.567
Risk Performance Index	0.765

PMI's formulas when used to forecast the EAC at the data point anticipated an EAC of 745.527, 730.642 and 709.482 Million QR respectively. This forecasted amount by one of the formulas is closer to the EAC but the other two formulas forecasted lower EAC. When the modeled equation developed in this research was used it forecasted an EAC cost of 730.693 which is also lower than the actual EAC which can be explained by the fact that the project may have suffered much more than its current status in terms of quality, safety and other risks. Table 4.24 shows the EAC costs forecasted by standard PMBOK's formulas and the developed equation.

Table 4.23: EAC values of Case Study 3

Case Study 3	
Percent Complete	85%
EAC (PMBOK) Formula 1	745,527,284
EAC (PMBOK) Formula 2	730,642,798
EAC (PMBOK) Formula 3	709,482,008
Estimated Cost at Completion (Improved)	730,693,411

Chapter 5

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. INTRODUCTION

This chapter concludes the research by stating the findings, conclusions, limitations and recommendations.

5.2. CONCLUSIONS

In the literature review 55 PIs were identified in groups namely quality, safety, stakeholder satisfaction and others. After conducting pilot survey 16 factors were further selected to be incorporated in the developed model. Some of these 16 factors had relatively high ranking in literature as well suggesting the consensus between the researchers and field professionals. A methodology was established for incorporation of these PIs in the developed equation. The scores from PI showed us the performance of each group individually i.e. status of quality, safety and stakeholder satisfaction. Risk Performance Index was developed which in itself has no value of its own but was a collective Index representing quality, safety, stakeholder satisfaction and other PIs as a group. Survey was conducted to find the complimentary weights to be assigned to CPI, SPI and RPI in developed EAC equation for 0-25%, 26-50%, 51-75%, 76-100% project completion. The developed equation was then applied on some case studies. One of the major limitations of traditional EVM index based formulas as identified by Narbaev and De Marco (2013) is unreliable forecasting in early stages of the project where as the results from the case studies revealed that the developed equation forecasted quite accurately with very little variance at the early stages of the project up to 40% project completion. The results of the case studies also revealed that the developed equation showed a variance of 0 to 3% from the actual CAC. This variance can explained by the fact that the data being input in the PIs (variables) were as per the perspective of the project manager and errors are also expected in quantification of the subjective data. Another important finding from the case studies was the comparison of the results of the traditional PMI's formulas. In case study 3 the PMI's formula AC + (BAC-EV)/SPIxCPI gives better forecasted value then the equation developed in this research but when we look at the results of this formula on the other two case studies it has the worst forecasting figures as compared with the other formulas. In case study 2 BAC/CPI forecasts better amount than the other two PMI formulas and similarly in case study 1 AC + (BAC-EV) forecasts more accurate results than the other PMI formulas. If the results of all case studies are studied it is visible that the established equation for forecasting EAC gives better results for all type of projects and during all stages of the project.

As the modeled equation uses the weightings obtained through survey, weightings of CPI, SPI and RPI can be manually adjusted by the project manager as per the project scenario and relative importance of schedule and risk of that project.

The introduction of the new performance Indices the project manager will have a quantitative measure of the issues pertaining to quality, safety and stake holder satisfaction. The indices can be helpful in evaluating the project performance and then controlling it for better project performance. Project managers when knowing a better forecasted figure of the amount at which the project is most likely to finish can take better and in time decisions to help the project get back on the plan.

The research has some limitations regarding the methodology of inputting the values of the PIs.

5.3. RECOMMENDATIONS

. The model used 16 PIs for measuring quality, safety, stakeholder satisfaction and other performance measurements. Other PIs and CSFs should be incorporated in the model to cater for more complexity and diversity in the nature of construction projects. The model should be developed as a standalone feature in project monitoring software to make it user friendly.

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ANNEXURE-I

Influencing Performance Indicators For Construction Quality, Safety, Stakeholder Satisfaction and Others.
Construction industry is facing several overrun issues especially those of cost and time. Earned value management technique has been in use traditionally to monitor and report these issues. Though it is a well known and well implemented technique, the fact that it considers only schedule and costs creates a gap of other success criteria for projects like quality, scope, safety, risk, etc. In the absence of these considerations, stakeholders usually fail to estimate an accurate cost at completion. Hence there is a need of involving and incorporating other key performance indices in this monitoring tool as well as the success criteria so that clearer and broader aspects of the project along with cost and schedule performance indices could be obtained. Your feedback will help in incorporating the impact of quality, safety, stakeholder satisfaction and related risks which in turn will provide information for better project monitoring and control. In case you have any questions, please feel free to contact me. Regards, Suqrat Babar Sbabar.cem5nit@nust.edu.pk +923325931002

SECTION 1: Personal Information	
Name:	
Country:	
Experience:	
Career:	
Organization:	

SECTION 2: Survey Response		
On a scale of -3 to +3, rate the factors where -3= Maximum Negative Effect (increasing the cost of the project) and +3= Maximum Positive Effect (not increasing the cost of the project) and 0= Does not Effect.		
Survey Question: Influence of the respective Performance Indicator (PI) on decision making in CM?		
Sr. No.	**Performance Indicators**	**Score**
Stake Holder Satisfaction		
1	Stake Holder Satisfaction	
2	Conflicts / Disputes/ Claims	
3	Change Orders	
Quality		
4	Rework / Defects	
5	Quality systems	
6	Materials quality	
7	Meeting specifications	
8	Wastage	
9	Non Conformance Rate	
10	Personnel quality training	
11	Batcher and Crusher Plant Management	
12	Pavement thickness	
13	Compressive strength of concrete	
14	Operational quality planning	
15	Contractor's technical expertise	
16	Quality inspection	
17	Check listing	
18	Quality Control charts	
19	Strategic quality management	
20	Corporate quality culture	
21	Project assembly on site (Steel Strutures)	
22	Flexural strength	

23	Water cement ratio	
24	Asphalt Content	
25	Compaction Density	
26	Air void spacing coefficient	
27	Asphalt pavement performance	
28	Bridge and pavement roughness	
29	Cracking rate of abutment wall culvert	
30	Expansion joints performance	
31	Expediting, Operability/safety/value reviews	
32	Quality Review and Audits	
33	Flowcharting, Cause and effect diagramming	
34	Quality Metrics development	
	Safety	
35	Accident frequency ratio	
36	Safety training	
37	Jobsite toolbox meetings.	
38	Jobsite pre-task planning meetings	
39	Number or percent of management personnel with 10-h (or 30-h) OSHA certification cards.	
40	Safety equipment and Maintenance	
41	Percentage of new workers on site	
42	Involvement of contractor top management	
43	Number or percent of subcontractors selected, in part, on the basis of satisfying specific safety criterion prior to being awarded the subcontract.	
44	Requirement that each subcontractor submit a site-specific safety program that must be approved prior to the performance of any work by that subcontractor	

45	Requirement that the CEO of each subcontractor provide a letter indicating the subcontractor's commitment to construction worker safety	
46	Percent of negative test results on random drug tests.	
47	Number of close calls reported	
48	Safety audits (inspections)	
49	Owner promotion of jobsite safety.	
50	Worker observation records are evaluated to determine the need for jobsite changes in the job safety program.	
Others		
51	Land Acquisition	
52	Supplier relationship	
53	Communication of information	
54	Project management activities	
55	The design process	

ANNEXURE-II

ESTIMATE AT COMPLETION

Construction industry is facing several overrun issues especially those of cost and time. Earned value management technique has been in use traditionally to monitor and report these issues. Though it is a well known and well implemented technique, the fact that it considers only schedule and costs and other project success criteria like quality, scope, safety, risk, etc. are indirectly considered. Such abstract considerations result into the stakeholders failing to estimate an accurate cost at completion. Hence there is a need of directly involving and incorporating other key performance indices in this monitoring tool as well as the success criteria so that clearer and broader aspects of the project along with cost and schedule performance indices could be obtained.

Your feedback will help in incorporating the impact of cost performance index, schedule performance index and risk performance index which in turn will provide information for estimating better cost at completion.

In case you have any questions, please feel free to contact me.

Regards,

Suqrat Babar

Sbabar.cem5nit@nust.edu.pk

+923325931002

Personal Information

Name:

Experience:

Career:

Organization Type:

Country:

Survey Questions

CPI= Cost Performance Index

SPI= Schedule Performance Index

RPI= Risk Performance Index, where RPI constitutes of factors related to construction Quality, Safety, Stakeholder Satisfaction , Others (wastage, land acquisitions, design process, etc)

Note: Enter a value between 0 to 100% for each question.

1. During 0 to 25% completion of the project, how much does the cost at completion depend upon CPI?
2. During 0 to 25% completion of the project, how much does the cost at completion depend upon SPI?
3. During 0 to 25% completion of the project, how much does the cost at completion depend upon RPI?
4. During 26 to 50% completion of the project, how much does the cost at completion depend upon CPI?
5. During 26 to 50% completion of the project, how much does the cost at completion depend upon SPI?

6. During 26 to 50% completion of the project, how much does the cost at completion depend upon RPI?
7. During 51 to 75% completion of the project, how much does the cost at completion depend upon CPI?
8. During 51 to 75% completion of the project, how much does the cost at completion depend upon SPI?
9. During 51 to 75% completion of the project, how much does the cost at completion depend upon RPI?
10. During 76 to 100% completion of the project, how much does the cost at completion depend upon CPI?
11. During 76 to 100% completion of the project, how much does the cost at completion depend upon SPI?
12. During 76 to 100% completion of the project, how much does the cost at completion depend upon RPI?